ACHIEVING AN 80% REDUCTION IN ONTARIO RESIDENTIAL HEATING ENERGY CONSUMPTION BY 2030:

A TIERED FRAMEWORK AND PRELIMINARY IMPLEMENTATION STRATEGY

By

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Bachelor of Arts, University of Calgary, 2006

A thesis

Presented to Ryerson University

In partial fulfilment of the

Requirements for the degree of

Master of Applied Science

In the Program of

Building Science

Toronto, Ontario, Canada, 2013

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Abstract

The increasing prevalence of climate change impacts and rising energy prices has highlighted the need to achieve deep energy savings now. To accomplish this, stricter prescriptive performance requirements for residential buildings are needed. The intent of this work is to develop a framework and policy implementation strategy to achieve an 80% reduction in Ontario residential heating energy consumption by 2030. A tiered framework of consumption targets was developed using OBC 2012 SB-12 requirements as a baseline and sample compliance packages created for each tier. Construction costs for the baseline and each tier compliance package were estimated and simple payback periods determined. Impacts of fuel escalation rates on payback periods were also considered. Significant cost premiums were found between the baseline consumption and overall 80% heating energy reduction target. Lack of experience and perceived risk were found to be the greatest barriers to achieving the overall energy reduction target. A preliminary strategy and supporting policy tools was developed, taking into consideration the observed barriers to adoption.

Acknowledgments

There any many thank-you’s deserved as a result of the completion of this thesis. First, I would like to extend my sincere gratitude to my supervisor Dr. Russell Richman for his support and encouragement throughout the process. I would also like to thank Dr. Miljana Horvat and Dr. Mark Gorgolewski for their support throughout the program.

Special thanks to the GTA-based builder who provided the cost data for the building envelope options as well as feedback on the designs.

I would also like to thank:

- Hayes Zirnhelt for allowing me to use the CCHT EnergyPlus model;
- Zola Windows and Pella Windows for their assistance with glazing cost; and
- Other local suppliers for HRV and furnace costs.

Finally, I would like to thank my family and friends for their love and support - particularly those friends who made the mistake of offering their editing skills.

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List of Abbreviations

ACH_{50}	Air changes per hour at 50 Pascal
AFUE	Annual fuel utilization efficiency
ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineers
BRE	British Research Establishment
CCBFC	Canadian Commission on Building and Fire Codes
CCHT	Canadian Construction and Housing Technologies
CMHC	Canada Housing and Mortgage Corporation
EPBD	Energy Performance Buildings Directive
EPS	Expanded polystyrene
ER	Energy Rating
EU	European Union
GTA	Greater Toronto area
GUI	Graphical user interface
HDD	Heating Degree Day
HRV	Heat recovery ventilator
HVAC	Heating, ventilation, and air conditioning
IDF	EnergyPlus input file
IEA	International Energy Agency
LEED	Leadership in Energy and Environmental Design
MMAH	Ministry of Municipal Affairs and Housing, Ontario
MW	Megawatts
NRCan	Natural Resources Canada
NBC	National Building Code
NFRC	National Fenestration Rating Council
OBC	Ontario Building Code
OBOA	Ontario Building Officials Association
OEE	Office of Energy Efficiency (Canada)
PHPP	Passive House Planning Program
PSI	Linear conductivity

RSI	Thermal resistance (Metric)
SB-12	OBC Supplementary Standard SB-12: Energy Efficiency for Housing
SBG	Sustainable Buildings Group at Ryerson University
SHGC	Solar heat gain coefficient
TI	Temperature index
TWh	Terra-watt hours
UK	United Kingdom
USA	United States of America
U-value	Heat transfer coefficient
XPS	Extruded polystyrene

1. Introduction

Growing environmental consciousness and rising energy prices have highlighted the urgent need to achieve deep energy savings in the residential building sector. Residential energy use accounts for 18% of Canadian secondary energy consumption; 62% of residential consumption is used to meet heating demands [1]. Although per capita energy demand is expected to decrease, the province predicts total demand will continue to grow approximately 15% through 2030 due to growing population and increased numbers of households [2].

Building codes first addressed energy and environmental issues after the 1970's energy crisis, however only recently (2009 in Ontario and 2012 nationally) have specific energy efficiency requirements been implemented into codes. The Ontario Building Code (OBC) currently includes energy efficiency requirements under Supplementary Standard SB-12, targeting the building envelope and heating, ventilation and air conditioning (HVAC) systems. The OBC recently published a requirement for a 15% increase in energy efficiency by 2017 [3]. Complete building code updates typically occur every five-year and energy efficiency targets beyond this date are unclear. In contrast, jurisdictions such as the European Union (EU) and the state of Massachusetts have identified performance goals for near net-zero energy consumption within the next 20 years, and have developed and begun implementation of supporting policies for these goals [4-6]. Identification of long-term goals and developing policies needed to achieve them is essential to drastically reducing heating energy consumption. Voluntary performance standards such as the Passive House Standard can be used to establish a benchmark for heating energy consumption and aid in the development of required prescriptive performance levels.

Achieving ultra-energy efficient buildings should be considered a vital component of energy and climate change policy. Establishing appropriate performance targets in combination with increased prescriptive requirements is key to reducing both energy consumption and the environmental impact of the residential building sector. While continued investment in the growth of the renewable energy is necessary, additional funding and regulatory support is needed to further increase energy conservation efforts in the residential building sector. Increased stringency in energy efficiency requirements now offsets future growth in energy demand as population increases. Economic, environmental, and social benefits of energy efficiency measures implemented into building code now will also continue beyond their payback period and throughout the life of the building.

1.1. Problem Statement

There is consensus that residential heating energy consumption must be drastically reduced. However, there is uncertainty as to what levels of heating energy consumption can be achieved and what the associated costs are. The purpose of this work is to develop a framework and implementation strategy to achieve an 80% reduction in Ontario residential heating energy consumption by 2030. The framework will outline smaller incremental heating energy performance targets and propose possible compliance packages to achieve the 80% reduction goal by the target date. The implementation strategy identifies existing policy structures and recommends supporting policy tools to assist with achieving the reduction goal by the target date. Existing performance metrics and compliance options, along with cost premiums associated with building to the proposed performance levels and the impact of increasing energy prices will inform the development of the framework and implementation strategy.

1.2. Thesis Objectives and Research Questions

The primary objectives of this work are to:

(i) Identify performance metrics and levels associated with heating energy consumption in current building codes and estimate Ontario single-family dwelling heating energy intensity;

(ii) Make analysed recommendations to reduce heating energy intensity based on the outcome of objective (i) and establish tiered performance targets for heating energy consumption and develop a framework to be implemented in the Ontario Building Code to achieve the target;

(iii) Develop a framework for objective (ii) to be implemented in the Ontario Building Code to achieve the targets;

(iv) Establish typical envelope assemblies and associated cost analyses to support the recommend framework in objectives (ii) and (iii); and

(v) Contribute towards the development of a policy implementation strategy in support of objectives (ii) and (iii) by recommending specific policy tools based on the outcome of objective (iv).

From these objectives, the following research questions arise:

1. **How is residential energy efficiency addressed in current Canadian building codes, specifically Part 9 of the National Building Code and Ontario Building Code?**
   1.1. What performance metrics are used in Canadian building codes to assess energy performance and what levels are they set at?
   1.2. How does the energy performance of a home built to National Building Code and Ontario Building Code requirements compare to that of an aggressive performance standard such as Passive House?
   1.3. Which building envelope components should be targeted to reduce residential secondary energy consumption, when taking into account cost?
   1.4. In the Canadian context, what is optimal energy performance and at what levels should metrics be set to achieve optimal energy performance?
2. **How can Ontario reduce heating energy consumption by 80% by the year 2030?**
   2.1. What performance levels should be set along the way?
   2.2. What is a typical sample compliance package to achieve a tiered energy performance based system?
3. **How does cost impact present and future building practices relating to residential energy performance?**
   3.1. What is the difference in cost between residential constructions built to current building code regulations and those built to achieve the recommended energy performance?
   3.2. How does cost impact policies regarding sustainable building practices, specifically those relating to energy performance?
4. **How can increased prescriptive levels be implemented within Canadian building codes, specifically the Ontario Building Code?**
   4.1. What is the current policy structure?
   4.2. What strategies have been successful in other countries?
   4.3. What impact have voluntary rating and certification systems had on the policy agenda?

4.4. What strategies and steps can be used to implement the increased prescriptive levels within Canadian building codes, specifically the Ontario Building Code?

1.3. Organization

This thesis is organized in the following manner:

Chapter 2, "Methodology", identifies the scope of the research and discusses the methods used to satisfy the thesis objectives and research questions.

Chapter 3, "Literature Review", provides background information relevant to the objectives of the research. The National and Ontario Building Codes were examined to identify their approach to residential energy efficiency. Literature related to life cycle costing and the impact of innovation was also reviewed. Finally, international precedents in energy efficiency policy and building codes were analysed, along with research focused on the development of energy efficiency policy instruments.

Chapter 4, "Performance Metrics and Levels in Canadian Building Codes", identifies the performance metrics and levels used in the National and Ontario Building Codes and are then compared to the levels anticipated to meet the Passive House Standard. Performance metrics and levels are identified for the following target areas: opaque surfaces, glazed components, air tightness, and HVAC efficiencies.

Chapter 5, "Quantification of Ontario Residential Heating Energy Intensity", explains the energy simulation approach used to quantify Ontario residential energy intensity. Justification is provided for the simulation software and reference house used. Simulation variables and iterations are also identified.

Chapter 6, "Development of Tiered Framework of Performance Targets", defines optimal energy performance, develops recommendations for prescriptive performance levels, and a tiered framework to implement the 80% heating energy reduction target by 2030. Sample compliance packages to meet each of the tier performance targets are also introduced.

Chapter 7, “Economic Analysis”, shows the construction costs and results of the economic analysis of the baseline and tiered framework. Results of sensitivity analyses of various fuel escalation rates are also presented.

Chapter 8, “Discussion”, provides comments of the research carried out and identifies issues to be addressed by the preliminary implementation strategy and supporting policy tools.

Chapter 9, “Preliminary Implementation Strategy”, presents the implementation strategy and supporting policy tools developed.

Chapter 10, “Future Research”, gives an overview of areas requiring additional research.

Chapter 11, “Conclusions”, summarizes the research carried out and issues encountered.

2. Methodology

2.1. Overview

The primary contributions of this work are the following:

1. Heating energy intensity of residential single-family dwellings built to current National Building Code (NBC), Ontario Building Code (OBC), and an ultra-energy-efficient level (identified as single-family dwellings designed to Passive House Standard levels) were estimated. Results informed proposed increases to prescriptive performance metrics and levels with the objective to reduce secondary heating and cooling energy consumption to an ultra-energy-efficient level considered to be net-zero grid capable[1].
2. Typical building envelope assemblies to support the recommended levels were developed in collaboration with a local Toronto developer for Ontario climate zone 1 and 2.
3. An economic analysis of current conventional construction methods and proposed building envelope assemblies to prescriptive performance levels was performed for climate zone 1 and cost effectiveness determined on a dollar per square metre and total construction basis.
4. Economic analyses using current costs and considering several fuel escalation rates were performed. The results of the economic analyses supported the development of an implementation strategy and supporting policy recommendations for the proposed increased performance levels into the OBC.

2.2. Performance Metrics and Levels in Canadian Building Codes

Performance metrics in the NBC, OBC, and Passive House Standard were identified for four target areas – (i) opaque surfaces, (ii) transparent surfaces, (iii) HVAC efficiency, and (iv) air leakage. Both the types of metrics used and the levels at which requirements were set were

[1] Within the context of this research, net-zero grid capable is defined as energy use equivalent to the proportion of renewable energy in the current energy mix [9, 11]. For example, if the current energy mix consists of 20% renewable energy, current energy consumption should be reduced by 80%.

compared, and discrepancies between the two building codes and Passive House levels were identified.

2.3. Estimation of Residential Energy Intensity

Energy intensity of a reference case single-family home was estimated through energy modelling using EnergyPlus and the metrics and levels stated in the NBD and OBC for the identified targets areas. To identify the progression of space heating and cooling energy intensity and establish a baseline, a total of 30 simulations were performed (Figure 2-1).

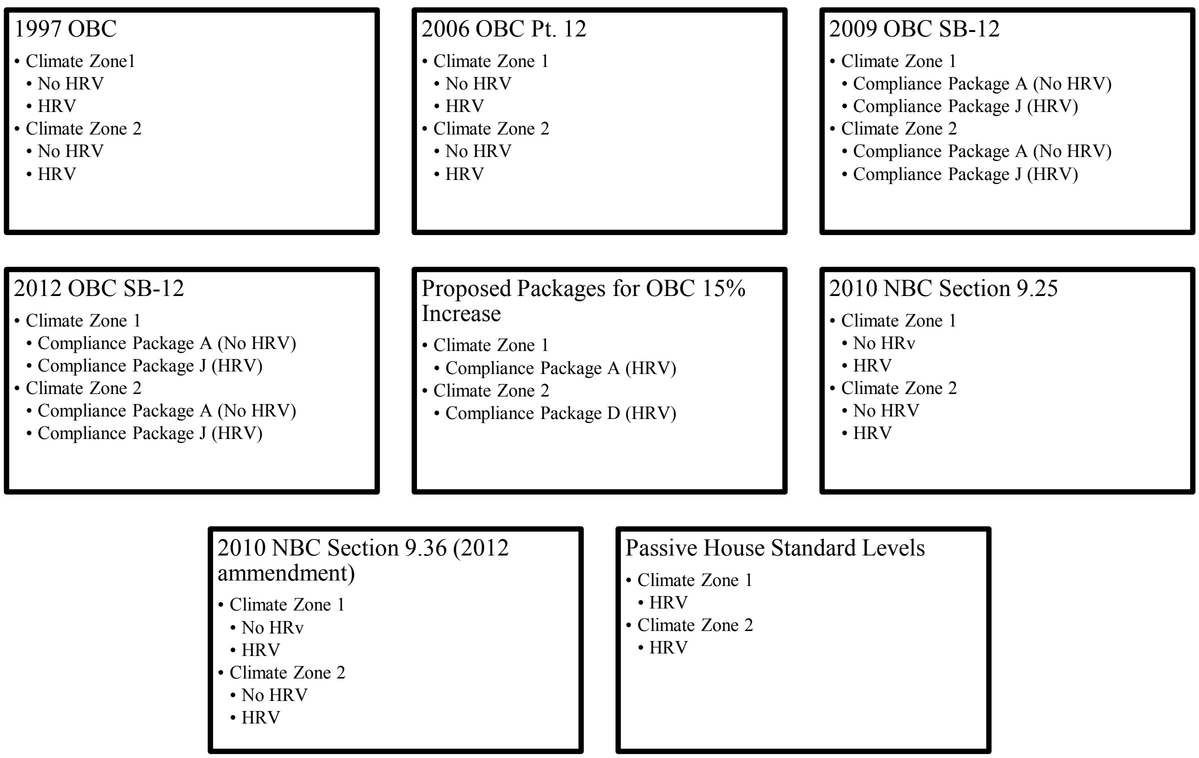


Figure 2-1 - EnergyPlus Simulations

The Canadian Construction and Housing Technologies (CCHT) test house was used as the reference case for modelling, using the EnergyPlus CCHT model developed by the Sustainable Buildings Group (SBG) at Ryerson University [7]. Geometry and site of the building remained unchanged for each simulation. The following inputs were modified to meet the requirements of each of the buildings codes simulated (Figure 2-2).

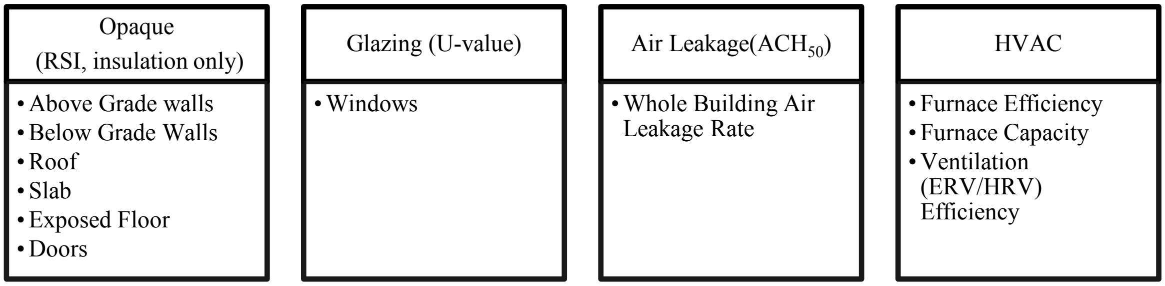


Figure 2-2 – Modified Modeling Inputs

For opaque surfaces, framing percentages for the reference case house were calculated to account for the impact of framing on the thermal resistance of the building envelope. These values were then used to calculate composite thermal resistance (RSI) values used for the insulation material inputs in the model.

Results of the initial energy modelling established a current Canadian baseline of energy intensity on which recommendations were developed. Target areas were identified for proposed increases to performance metric levels based on performance metrics in existing building code and Passive House Standard certification requirements. An ultra-energy-efficient performance level, identified as Passive House Standard levels[2], was determined as the overall target for energy intensity. A tiered framework was developed to implement increased prescriptive levels in stages to achieve the energy intensity target by the goal date of 2030. A proposed compliance package was developed for each tier that would meet the subject energy performance target. Each compliance package outlines prescriptive performance metrics and levels for each of the four target areas. These were then modelled using EnergyPlus to determine if the prescriptive requirements met the proposed energy consumption target outlined in representative tier of the framework.

2.4. Economic analysis of 'Conventional' Construction Versus Proposed Prescriptive Performance Levels

To support the recommendations for the proposed prescriptive performance levels and the implementation of the tiered framework, an economic analysis was performed. The economic

[2] These levels are an estimate as to the general levels required to support a Passive House design in Toronto's climate (OBC climate zone 1, < 5000 HDD). A certified Passive House design was not completed as part of this research.

analysis identified the difference in cost per major building envelope component and target areas of current conventional, code compliant constructions and those in the proposed compliance packages. Costs were determined based on the example compliance packages as input in the energy model. A greater Toronto area (GTA) based large-scale residential developer provided estimates for materials and labour costs, which were calculated on a dollar per square metre basis. Two additional factors were also considered in the economic analysis, (i) a period of market uptake for the new construction practices, and (ii) potential energy cost savings incurred based on several estimated fuel escalation rates over the proposed implementation period. Results assisted with further development of the policy implementation strategy.

2.5. Preliminary Implementation Strategy

Upon completion of the economic analysis, recommendations for the prescriptive performance levels, compliance packages, and tiered implementation framework were finalized. Current policy structures at the federal and provincial level, as well as international precedents in energy efficiency and sustainable building policy were researched. Voluntary rating and certification systems and their impact of the policy agenda were also considered. Findings were used to identify policy instruments, procedures to implement the proposed compliance packages, increased prescriptive performance levels, and tiered framework into Canadian building codes, specifically the OBC.

3. Literature Review

3.1. Ontario Energy Mix and Long Term Energy Outlook

Canada has a varied energy mix determined by regional availability, price, and end-use demand [8]. Nearly 83% of primary energy production comes from fossil fuels, and only 8% of primary energy production is from low carbon sources such as hydro, solar, and wind (Figure 3-1) [9]. Although energy supplies from renewable sources are increasing, it is still a small portion of Canada's energy [10].

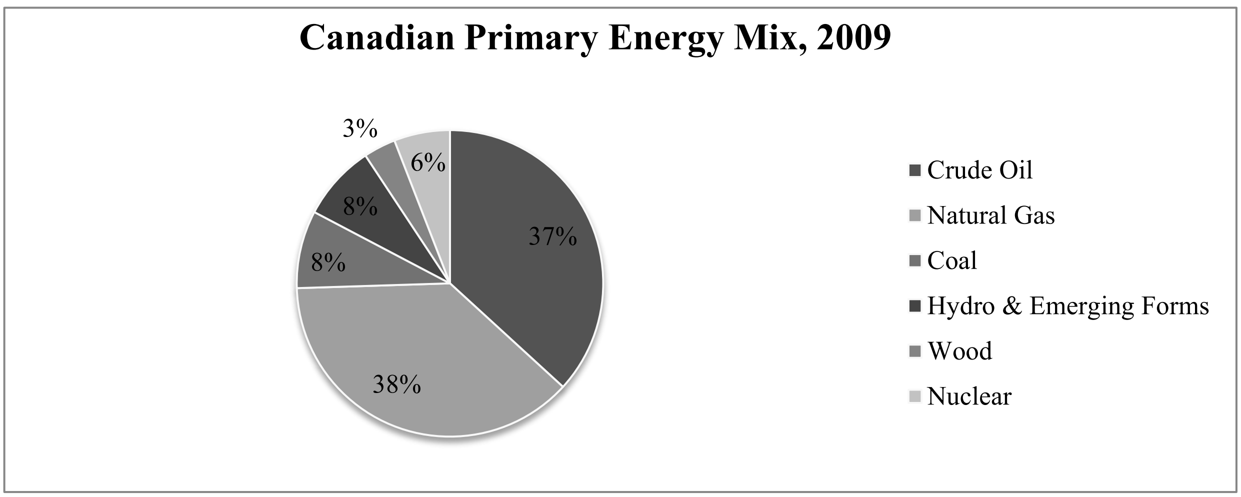


Figure 3-1 – Primary Energy Production, 2009 [9]

Ontario's current energy supply mix is dominated by nuclear energy (56%), followed by hydroelectricity (Figure 3-2). Coal is in the process of being phased out of the provinces energy supply by 2014, and shares of natural gas and renewable supplies are expected to increase to replace its supply share.

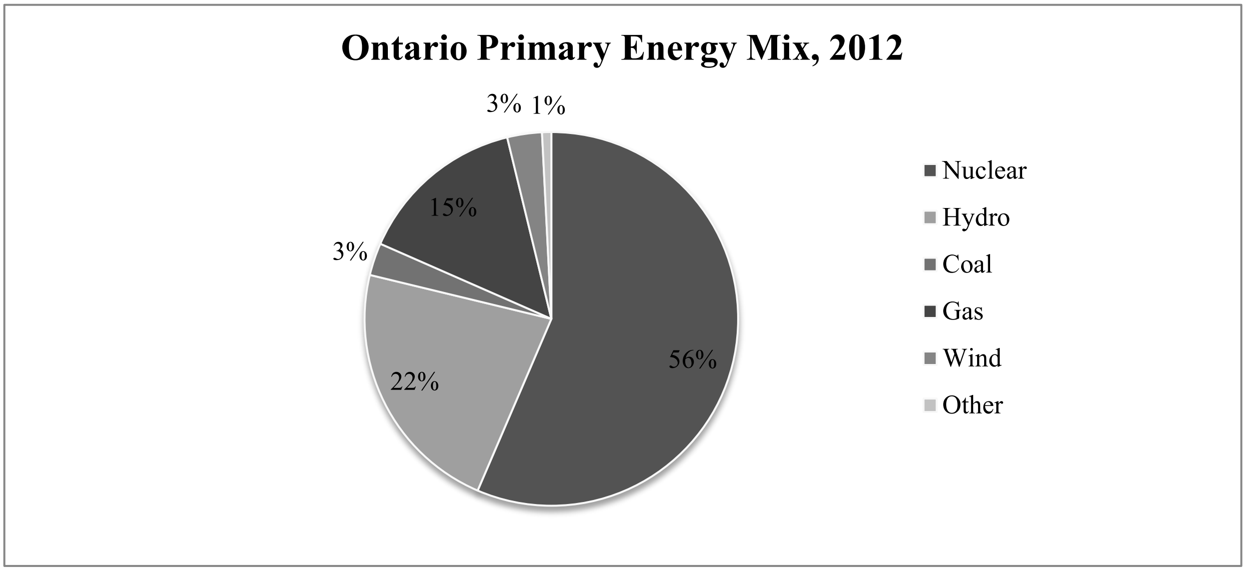


Figure 3-2 - Ontario Primary Energy Mix [11]

Residential energy use accounts for 18% of Canadian secondary energy consumption; 62% of residential consumption is used to meet heating demands [1]. Three quarters of Ontario households use forced-air furnaces to heat their homes [12] and most homes use natural gas as their main heating energy source (67%) (Figure 3-3).

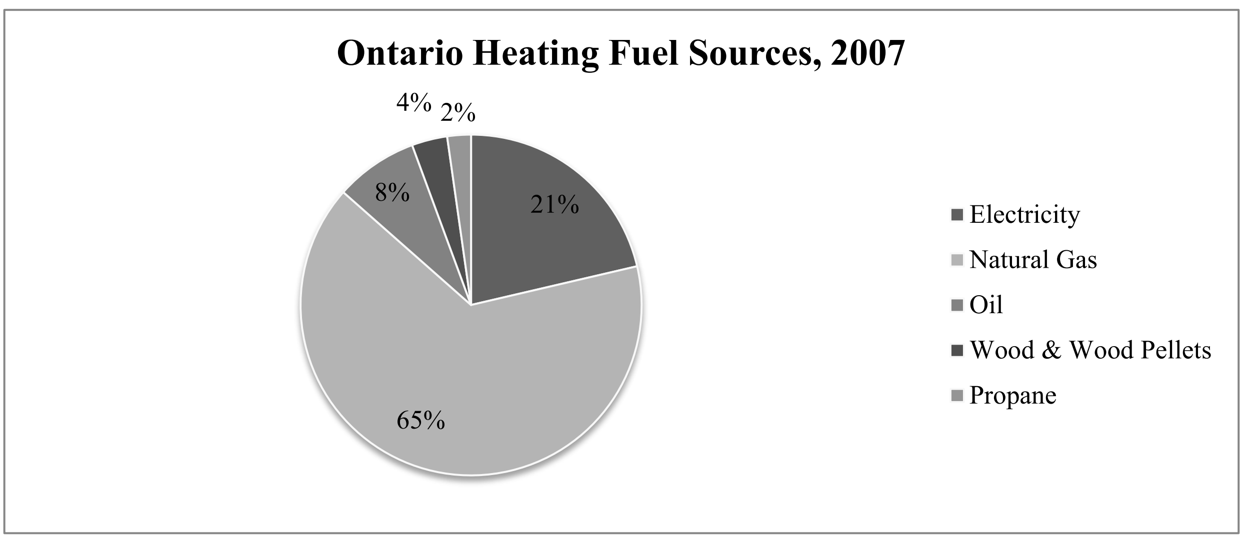


Figure 3-3 -Ontario Type of Main Heating Fuel Used [13]

Ontario has predicted energy demand with increase 15% over present levels through 2030 [2]. Although per capita energy demand is expected to decrease, total demand will increase because of increasing population. Ontario predicts an increase of 1.1 million households by 2030 [2]. The province has identified conservation as a cornerstone in the long-term energy plan, achieving net savings two to three times over the life of the conservation investment. Ontario's electricity conservation targets include achieving a capacity of 7100 MW and generation of 28 TWh – the equivalent of taking 2.3 million homes off the grid [2]. However, conservation targets for natural gas, the primary energy source for heating in Ontario (Figure 3-3), were not specified despite identifying the residential building sector as contributing up to 30% on the provinces reduction target [2]. Although conservation is proposed as a cornerstone of the provinces long-term energy plan, focus is on the province's electric grid infrastructure and expansion. The conservation efforts and goals needed to meet the province's energy reduction targets are not clearly defined. Due to the large share of natural gas used for heating, reducing heating energy use would make substantial contributions to the province's energy conservation targets.

3.2. Canadian Building Codes

3.2.1. National Building Code

The NBC was established as a model code and becomes law once adopted by provincial and territorial governments. The NBC is typically published every five years [14]. It provides technical provisions establishing minimum acceptable measures for design and construction and outlines applicable criteria and technical standards for materials, products, and assemblies [14]. The Canadian Commission on Building and Fire Codes (CCBFC) develops the NBC with voluntary input from both public and private sector experts across the country [15]. The provinces and territories provide policy input through their own committee, the Provincial/Territorial Policy Advisory Committee on Codes [15]. Requests for new objectives/requirements involves a multistep process with various stages of review – it can take nearly two years before changes are implemented into [15]. Though this process provides transparency in the development of the objectives of the code, it is slow. Urgent issues, such as energy efficiency, cannot be promptly addressed by the building code.

The provisions outlined in the code focus primarily on new construction. The NBC centres on the following objectives and scope (Figure 3-4):

Objectives	Scope
•Safety •Health •Accessibility •Fire & structural protection •Environment	•Fire protection •Occupant safety & accessibility •Structural design •Environmental Separation •Heating, cooling, and ventilation •Plumbing Services •Housing and Small Buildings

Figure 3-4 - NBC Objectives and Scope [16]

In 2005, a replacement of the term ‘requirement’ with ‘acceptable solutions’ accompanied format changes from a prescriptive to objective-based format. These changes intended to make compliance easier to achieve, particularly when ‘unconventional’ construction techniques are used. The changed also reflected the principle that building codes establish acceptable levels of risk, but also cannot describe or cover all possible valid design and construction solutions [17]. The intent of the objective based formant is to provoke greater ingenuity in design and construction; however, incentives for designers and contractors to pursue solutions that deviate from standard practices, such as overall performance targets, are not included in the NBC. The focus remains on minimum prescribed requirements.

The most recent NBC was first published in 2010. Significant technical changes to this edition included [18]:

- Increased requirements for glazing: minimum surface condensation, and maximum U-values, minimum Temperature Index Values, and thermal break requirements for metal frames;
- Requirement that building envelope must have thermal insulation, an air barrier, and a vapour barrier; and
- The properties and position of all materials must meet requirements for heat transmission and vapour permeability.

Revisions to Part 9, Houses and Small Buildings, were released in early 2012, and published in late 2012. All buildings falling under Part 9 must now comply with Section 9.36 Energy Efficiency (specifically, sections 9.36.2. to 9.36.4.). Changes include [19-21]:

- Addition of ‘Environment” as an objective of the code and ‘Excessive Use of Energy’ as a sub-objective;
- The addition of dedicated energy efficiency requirements (Section 9.36.), including:
    - Methods for measuring and calculating building envelope areas and thermal resistances (including effective thermal resistance of assemblies),
    - Construction detailing methods,
    - Minimum effective thermal resistance characteristics for envelope assemblies and maximum heat transfer coefficients for glazing systems,
    - Methods to address air leakage, and
    - Minimum efficiency values HVAC and water heating equipment;
- Three compliance paths: prescriptive or trade-off requirements, performance (energy modelling), and the National Energy Code for Buildings (NECB);
- Detailing requirements for continuous air barrier planes and systems.

3.2.2. Ontario Building Code

Provinces and territories have the authority to regulate the design and construction of buildings adopting the NBC as is, or developing their own code based on the NBC [22]. The 2006 Ontario Building Code (OBC) aims to promote public safety and outlines minimum technical requirements for the construction, change of use, renovation, and demolition of buildings. The 2006 OBC contains significant and unique variations in content and scope compared to the NBC. In addition to the four main NBC objectives, the 2006 OBC also includes [23]:

- Fire,
- Structural,
- Water and sewage protection of buildings,
- Resource conservation (energy and water),
- Environmental integrity, and
- Conservation of buildings.

The OBC is also the only provincial building code that has dedicated parts of the code specifically to change of use, renovation, and resource conservation.

Performance requirements for residential buildings were originally covered under Part 9 (Homes and Small Buildings). Under Part 12, Resource Conservation, energy efficiency requirements came into effect for permits applied for before December 31, 2011. Energy efficiency requirements for Homes and Small Buildings are covered, including requirements for thermal insulation, thermal design, and water efficiency. Supplementary Standard SB-12 Energy Efficiency for Housing was first released in 2009, offering alternative compliance options for subsections 12.3.2 and 12.3.3 (which outlined minimum thermal insulation and thermal design requirements). The most recent update of SB-12 was released January 1, 2012, at which point subsections 12.3.2 and 12.3.3 were no longer applicable. The intent of SB-12 is to provide [24],

> …Prescriptive requirements to achieve an acceptable air leakage rate and efficiency level as an alternative to achieving a rating of 80 when evaluated in accordance with… NRCan's 'EnerGuide for New Houses: Administrative and Technical Procedures'…the energy efficiency levels achieved in this [standard] are intended to meet or exceed… the level that would be met by model analogues evaluated against the EnerGuide Rating System. (p. 12)

The SB-12 offers three compliance options (Figure 3-5):

Prescriptive Compliance Packages

- Based on Ontario climate zones (zone 1 - <5000 HDD, zone 3 - >5000 HDD), space heating equipment efficiency and fuel type;
- Prescriptive performance levels for opaque surfaces, glazing, furnaces, HRV's (if applicable to the package), and domestic hot water equipment.

Performance Compliance

- Two annual energy use simulations are required comparing the simulated annual energy use of the proposed design against that of an applicable compliance package.
- The simulated energy use of the proposed design must be less than that of the compliance package

Other Acceptable Compliance Methods

- Buildings demonstrating compliance with technical requirements for 'Energy Star for New Homes: Technical Specifications – Ontario'.

Figure 3-5 -Supplementary Standard SB-12 Energy Efficiency Compliance Options

The compliance packages were developed for SB-12 requirements based on an archetype house. The archetype house was developed according to relevant house characteristics derived from a sample of 100 Ontario houses representing the most popular modals of tract homes built by the provinces largest builders, including a proportion semi-detached and attached buildings [25]. Housing characteristics used to develop the archetype included [25]:

- Foundation wall area,
- Ceiling area,
- Exterior main wall area,
- Floor area,
- Exposed floor area,
- Slab perimeter,
- Slab area,
- Window area,
- Air change rate, and
- House volume.

An arithmetic mean of all data gathered for each characteristic was then used to derive the attributes of the archetype. Compliance packages were developed based on combinations of mechanical equipment and envelope upgrades achieving an EnerGuide 80 rating for the archetype house. Measures selected based on whether they reduced energy use in the building and represented a well-understood practice or easily accessible technology [26]. The intent of the compliance packages developed was not to [26],

> …Introduce new construction approaches to the housing industry… [but were] mindful to guard against forcing home builders to adopt poorly understood methods to avoid an upsurge in building defects that could result as the industry struggles to master the uncommon approaches to construction. (p. 9)

Packages were developed through a combination of energy savings measures reflective of features in certified Energy Star and R-2000 homes and analysed for cost impact and energy savings, as well as associated environmental impacts and barriers to adoption [26]. Designs following compliance packages requirements are assumed to also achieve EnerGuide 80 performance levels [24]. Although there is a performance-based option for compliance, verification of EnerGuide 80 ratings for designs following the SB-12 compliance packages is not required. Emphasis is placed on meeting minimum prescriptive requirements to achieve code compliance rather than predicted energy use performance.

The newest OBC (2012) states energy efficiency requirements under Part 12 will increase 15% over 2012 levels as of January 1, 2017 [3]. Release of an updated SB-12 is expected ahead of this date. Changes to the building code were evaluated based on a number of considerations including [27]:

- Effectiveness in meeting stated goals,
- Consistency with code objectives,
- Stakeholder impacts (such as cost relating to design choices),
- Capacity of building sector to implement changes in a safe and effective manner,
- Workload and liability implications for municipalities,
- Enforceability, and
- Transition period.

The proposed increases to energy efficiency requirements supports Ontario's priorities relating to consumption reduction goals identified in the Long Term Energy Plan, as well as reduction of greenhouse gas emissions and the province's climate change strategy [28].

3.3. Voluntary Energy Efficiency Standards in Canada

Natural Resources Canada (NRCAN) and the Office of Energy Efficiency (OEE) have developed voluntary energy efficient initiatives aimed at housing. R-2000 was first released in the early 1980's and is a voluntary national performance standard aimed at cost effective energy efficient building [29]. It is a performance based standard, with certification achieved on the basis of a home's predicted energy performance in relation to the Hot2000-defined target [29]. Construction must be by a R-2000 licensed builder [29]. The only specific performance standard required for certification is an air leakage level of 1.5 air changes per hour at 50 Pascal (ACH_{50}) [29]. Performance levels for the building envelope must be above building code. Certified buildings must meet an energy performance target as calculated by Hot2000. R-2000 certified homes typically consume 30% less energy than conventionally built homes [30].

The EnerGuide rating system was developed to aid in evaluating the energy efficiency of both new construction and retrofitted homes [31, 32]. A rating on a scale of 1 to 100 is given based on the energy performance of the building envelope, HVAC, and domestic water heaters, and energy consumption of standard lighting and appliances [32]. A rating of 0 indicates a very energy inefficient home, with a rating of 100 indicates little to no purchased energy [32]. Most new construction rates in the range of 70 to 100, with 80 being the targeted rating of the OBC [33]. The final energy rating is performed by an independent energy advisor and requires a blower door test [32]. The data is then stored in a database and a label and report prepared for the homeowner. Although EnerGuide rating are being proposed as a mandatory energy performance requirements, owners may also not understand the difference in the rating scale, and that a difference between an 80 and 85 rating can indicate a substantial difference in energy consumption than the difference in ratings indicates [34].

Energy Star for New Homes provides energy efficiency guidelines and performance metrics that exceed those specified by minimum building code requirements. As with both EnerGuide and R-2000, third party verification is required and construction by a licensed builder [35]. Two compliance options are available: prescriptive or performance (energy modelling). In comparison to R-2000 and EnerGuide, province specific sets of builder option packages are presented [35]. For Ontario, sets of packages are outlined for three different climate zones (northern, mid/eastern, and southern). Similar to the OBC, performance trade-offs between different building elements occur among the builder option packages. Requirements for maximum air leakage rates are dependent on climate zone and detached or attached dwelling, ranging from 2.0 ACH_{50} to 3.0 ACH_{50} [35]. Unlike the OBC, building envelope RSI values are stated as effective values and a table outlining average framing percentage based on typical framing techniques are outlined for use in effective RSI calculations.

The Passive House Standard is a voluntary building performance standard originating from Germany. Popularity of this performance standard has been growing in North America since the early 2000's. Building envelopes of certified Passive Houses are highly insulated and required to have high performance glazing. Certified Passive House buildings are required to be extremely air tight (0.6 ACH_{50}) with low heating loads (less than 15 $kWh/m^2/year$) and annual primary energy consumption (less than 120 kWh/m^2/year) [36, 37]. The primary energy demand is "the amount of non-renewable primary energy… necessary for providing the energy carrier… considering the energy content of raw materials as well as the losses from distribution conversation and delivery to the end-user" [37]. The PHPP software (version 1.1) uses various primary energy factors, depending on the energy source of the location [37]. Using these factors, total secondary energy demand on Ontario would be approximately 53 kWh/m^2/year, with less than 15 kWh/m^2/year dedicated to heating demand.

3.4. International Precedents

3.4.1. State of Massachusetts

Massachusetts was one of the first states in the United States of America (USA) to develop comprehensive policies surrounding energy efficiency. In addition to the goal of zero-net energy buildings by 2030, the State hopes to require that all new buildings meet the Passive House standard by 2020 [5, 6]. Other policy initiatives underway include changes to the state's building code, workforce development initiatives, building labelling analysis, and design development of state-owned zero net energy demonstration projects [38].

3.4.2. European Union

The European Union (EU) implemented mandatory collective energy efficiency targets for all member countries under the Energy Performance of Buildings Directive (EPBD) [4]. These targets include (i) establishing targets for the overall reduction of greenhouse gas emissions (20% of 1990 levels by 2020), (ii) increasing the market share of renewable energy sources (20% of market share by 2020), (iii) new publically owned and occupied building must be nearly net zero energy by 2018, (iv) all new buildings must be nearly net-zero energy by 2020, and (v) all buildings being constructed, rented or sold must have energy performance certificates [4].

Although the targets are mandatory, each member state is required to devise their own methodologies to measure building energy performance. Therefore, the directive does not state specific performance metrics. The methodology should account for aspects within and outside of the building envelope, such as [4]:

- Thermal characteristics of the building,
- Thermal bridges,

- Heating and hot water supply systems,
- Ventilation (including air leakage),
- Lighting,
- Passive solar systems,
- Indoor climate and comfort conditions,
- The design and orientation of the building
- Local solar exposure,
- Active solar systems,
- Co-generation district or block heating, and
- Natural lighting.

Germany has also passed an Energy Savings Ordinance and Renewable Energies Heat Act, in addition to the EPBD. The Energy Savings Ordinance plans to introduce standards for nearly zero energy buildings. Under the Renewable Energies Heat Act, all new buildings must be heated using renewable energy sources [39]. Energy Performance Certificates are compulsory for new buildings and major refurbishments, and are gradually being introduced for existing buildings for sale, rent, or public use [39]. Certificates are based on the energy demand for new buildings, calculated according to surface area to volume ratio [39]. Also included are minimum requirements for energy efficiency of the envelope and maximum heat transfer coefficients, which act as a threshold for primary energy demand [39].

The United Kingdom (UK), in partnership with Building Research Establishment (BRE) Global, has a developed and implemented the Code for Sustainable Homes, an environmental assessment method for newly constructed homes [40]. The Code covers a variety of categories but compliance is only mandatory for those where the building code also applies [40]. Homes must achieve outline performance targets for the following categories to achieve compliance: building envelope performance levels, dwelling emission rates, indoor water use, energy efficiency, and durability [40]. Remaining categories (environmental impact of materials, management of surface water run-off from developments, and storage of non-recyclable waste and recyclable household waste) are awarded points based on an assessment against predetermined performance targets [40]. Buildings are assessed at two stages, design and post-construction. A certificate is then issued illustrating the rating of the home is given, on a scale of 1 to 6 stars (1 being the lowest) [40].

3.4.3. Summary

R-2000, EnerGuide, and EnergyStar are all government developed and funded voluntary energy efficiency initiatives that range in performance requirements. The Passive House Standard is also a voluntary performance standard, however it was developed independent of government. In contrast to the EU who has established mandatory collective targets for all member countries, energy efficiency measures beyond those stated in the building code are voluntary. As well, the end goals of the voluntary standards vary, as well as in the specificity of their requirements and the levels in which they deviate from building code. R-2000 is a certification based on performance, while Energy star is a high performance prescriptive based certification. EnerGuide rates a homes energy performance based on a scale. Both R-2000 and Energy Star require maximum air leakage levels be met as a certification requirement, while EnerGuide requires only a blower door test be performed. Other than a specific air leakage requirement, R-2000 does not state specific performance metric levels for the building envelope or HVAC systems. The performance of the building envelope must simply be greater than the applicable building code. EnergyStar is similar in format to the OBC SB-12, except EnergyStar states effective RSI values and maximum ACH levels as requirements. The three Canadian standards require that a builder licensed for the subject performance standard build the homes as a means of quality assurance. In contrast, Passive House certification is achieved through meeting the specified performance targets and using Passive House certified building components such as windows and heat recovery ventilator's (HRV's).

Impacts of new construction on resource conservation are a combination of voluntary programs (20%) and regulations (80%) [41]. Although energy efficiency requirements are included in the OBC, those standards exceeding current requirements remain voluntary. If Ontario intends to achieve their long-term goals of significantly reducing energy consumption, particularly within the residential building sector, clear targets and requirements that are more stringent are needed.

4. Performance Metrics and Levels in Canadian Building Codes

4.1. Opaque Surfaces

4.1.1. National Building Code

Within Part 9, Houses and Small Buildings, in the NBC, thermal requirements are stated as a minimum ratio of outboard to inboard thermal resistance based on the plane of low air and vapour permeance. The total insulation exterior to the plane of low air and vapour permeance is divided by the total RSI interior of the plane to determine if the assembly meet the ratio required for the climate zone (Table 4-1). Exterior and interior air films must be included in the calculation of the ratio [16]. Values are based on the heating degree-days (HDD) of the building location [16]. In addition to the ratio, minimum outboard RSI values based on framing size are also stated according to HDD, and minimum sheathing thermal resistance (RSI/mm) are also stated according to minimum sheathing thickness (mm) (Table 4-1). Though this shapes the design of the envelope construction, the ratio defines the position of low permeance materials within the building assemblies, accounting for all materials in the assembly and does not specifically define thermal insulation values [16].

Table 4-1 – NBC Sheathing Minimum Thermal Resistance Values [16]

Heating Degree Days of Building Location				**< 4.999**	**5,000 – 5,999**	**6,000 – 6,999**	**7,000 – 7,999**	**8,000 – 8,999**	**9,000 – 9,999**	**10,000 – 10,999**	**11,000 – 11,999**	**> 12,000**
Example of City in Heating Degree Days Range				**Vancouver, BC; Toronto, ON Montreal, QC**	**Calgary, AB; Winnipeg, MB**	**Athabasca, AB; Flin Flon, MB**	**Attawapiskat, ON; Big Rout Lake, ON**	**Yellowknife, YT**	**Inuvik, NT**	**Holman/Ulukhaqtuuq, NT**	**Arctic Bay NU**	**Mould Bay, NT; Isachon, NU**
Min. RSI Ratio				**0.2**	**0.3**	**0.35**	**0.4**	**0.5**	**0.55**	**0.6**	**0.65**	**0.75**
Min. Outboard Thermal Resistance, RSI				**0.46**	**0.69**	**0.81**	**0.92**	**1.16**	**1.27**	**1.39**	**1.50**	**1.73**
38 x 89 Framing	**Min. Sheathing Thickness**	**Sheathing Thermal Resistance, RSI/mm**	**0.0300**	10	18	22	26	34	37	41	45	53
			0.0325	10	17	20	24	31	34	38	42	49
			0.0350	9	16	19	22	29	32	35	39	45
			0.0400	8	14	16	19	25	28	31	34	40
38 x 140 Framing	**Min. Sheathing Thickness**	**Sheathing Thermal Resistance, RSI/mm**	**0.0300**	19	31	37	43	55	61	67	73	85
			0.0325	17	28	34	39	50	56	61	67	78
			0.0350	16	26	32	37	47	52	57	62	72
			0.0400	14	23	28	32	41	45	50	54	63

Changes to Part 9 of the NBC were released in late 2012. Within Section 9.36. Energy Efficiency, thermal resistance requirements are stated as RSI values for each building envelope component depending on climate zone and if an HRV is installed. Values stated are for effective insulation values. Minimum RSI requirements, specifically for above grade and below grade walls, for designs not including an HRV tend to be slightly higher than for designs including installation of an HRV. The thermal resistance requirements for the NBC 2012 amendment are included in Table 4-2.

Table 4-2 - NBC 2012 Amendment – Effective Thermal Resistance Requirements for Climate Zones 6 and 7a [19]

Components		**Climate Zone**	
		Zone 6 (4000-4999 HDD)	**Zone 7a (5000-5999)**
Ceiling Below Attics	**w/o HRV**	8.67	10.43
	w/ HRV	8.67	8.67
Cathedral Ceilings and Flat Roofs	**w/o HRV**	4.67	5.02
	w/ HRV	4.67	5.02
Walls (Above Grade)	**w/o HRV**	3.08	3.08
	w/ HRV	2.98	2.98
Floors Over Unheated Spaces	**w/o HRV**	4.67	5.02
	w/ HRV	4.67	5.02
Foundation Walls	**w/o HRV**	2.98	3.46
	w/ HRV	2.98	2.98
Unheated floors	**w/o HRV**	uninsulated	uninsulated
Below frost line	**w/ HRV**	uninsulated	uninsulated
Above frost line	**w/o HRV**	1.96	1.96
	w/ HRV	1.96	1.96
Heated floors	**w/o HRV**	2.32	2.84
	w/ HRV	2.32	2.84
Slab On Grade with an integral footing	**w/o HRV**	1.96	3.72
	w/ HRV	1.96	2.84

Nominal thermal resistance values, depending on framing type and stud spacing are given to aid in determining if the wall design meets compliance. For ceilings below attics under sloped roofs, effective thermal resistance can only be reduced to the extent necessary to accommodate the slope of the roof [19].

4.1.2. Ontario Building Code

Under Prescriptive Compliance Packages, SB-12 introduced a number of compliance packages a builder could choose which would satisfy building requirements. Compliance packages are selected based on Ontario climate zone, then according to space heating equipment type (furnace or electric space heating) and efficiency. Each compliance package lists performance metric requirements for the following building envelope components and equipment:

- Ceiling (with or without attic space),
- Exposed floor,
- Walls above grade,
- Basement walls,
- Below grade slab,
- Edge of below grade slab less than 600mm,
- Heated slab or slabs less than 600mm below grade,
- Windows and sliding glass doors,
- Skylights,
- Space heating equipment,
- HRV, and
- Domestic hot water heater

The sets of compliance packages are defined first by climate zone (Zone 1 or 2), then by the efficiency of the space heating equipment ($\geq$ 90%, between $\leq$ 78 %and $\leq$ 90%, and electric space heating). The compliance packages for each climate zone and space heating equipment efficiency range are then distinguished by a number of trade-offs. Required RSI values of building components and maximum thermal resistances values for glazing vary between packages according to the minimum annual fuel utilization efficiency (AFUE) of the space heating equipment, the domestic hot water heater minimum efficiency, and the presence of an HRV and its efficiency. For example, for space heating equipment with AFUE's $\leq$ 90%, typically if higher efficiency space heating equipment and an HRV is installed, a trade-of is made for lower RSI values in the above grade and basement walls and higher U-values for glazing (Packages H to J). In other cases if space-heating equipment with a higher efficiency is installed with a higher efficiency domestic water heater, higher U-value windows can be installed (Packages C and D). For space heating with AFUE's between $\leq$ 78 %and $\leq$ 90%, an

HRV must be installed, with slight changes in the RSI values for building components with the efficiencies ranging depending on the space heating equipment AFUE. For electric space heating, RSI values depend on the efficiency of the HRV, which must be installed.

The OBC will introduce requirements for a 15% increase in energy efficient over 2012 SB-12 requirements on January 1, 2017 [42]. Proposed changes to requirements include compliance packages with requirements stated as overall U-values (heat transfer coefficients) for entire building envelope assemblies, as well as compliance packages following the 2012 SB-12 format [43]

4.1.3. Passive House Standard

The Passive House standard does not have a specific requirement for thermal resistance of the building envelope to achieve certification. A maximum overall heat loss coefficient (U-value) of 0.15 $W/m^2 \cdot K$ (RSI 6.67 $m^2 \cdot K/W$) is recommended but is dependent on the local climate and levels needed to meet the specific heat demand target and primary energy consumption target [36, 37]. Envelope constructions vary in the materials used and overall RSI values between individuals designs based on the specific climate of a building. Envelopes are designed as such that they enable the building to meet the energy performance requirements for certification. Thermal insulation levels for Passive House certified homes are typically higher than those specified in both the NBC and OBC.

4.2. Transparent Surfaces

4.2.1. National Building Code

The NBC prescribes two thermal performance metrics for glazing systems (Section 9.7.4), U-value ($W/m^2 \cdot K$) and Temperature Index (TI), either of which can be used to satisfy the requirement.

Values for each metric are stated for three temperature ranges (warmer than -15°C, between -15°C and -30°C, and colder than -30°C), based on the 2.5% January Design Temperature of the location (Canadian Commission on Building and Fire Codes, 2010). The TI (also referred to as

Condensation Potential) of windows is a number that represents a number of factors, including [44, 45]:

- The potential of temperature gradients occurring over the glass, sash and frame surfaces,
- It relates the interior surface temperature to the exterior temperature, and convection occurring within the air space and on surfaces that are highly sensitive to environmental conditions, and
- It also accounts for the surrounding construction of the window and frame materials, wind, window coverings, and the orientation of the building.

TI can also inform a suitable interior relative humidity that will not cause condensation [45]. In essence, TI states that the closer the interior surface temperature of the window is to the indoor temperature, the greater the condensation resistance of the system [45]. It also links the condensation resistance of a glazing unit to its thermal performance and design, and informing the optimal level of interior relative humidity [45].

The equation for TI is as follows:

$$TI = (T_x - T_e) / (T_i - T_e) \qquad \text{(Equation 1) [44, 45]}$$

Where,

T_x – surface temperature

T_e – exterior air temperature

T_i – interior temperature

The 2012 amendment to the NBC now states the required thermal characteristics of glazing as maximum U-values or minimum energy ratings, based on the HDD of the building location. Either metric can be used to satisfy code requirements.

4.2.2. Ontario Building Code

In addition to U-value requirements, the OBC also prescribes requirements for the Energy Rating (ER) of glazing systems. The ER metric measures a fenestration system's overall energy performance, taking into account such factors as systems [46]:

- Solar heat gain,
- Heat loss via conduction, convection, and radiation, and

- Heat loss due to air leakage.

The comprehensiveness of the ER metric allows for more thorough comparisons between glazing systems. Lower U-factors and air leakage rates along with higher solar heat gain coefficient (SHGC) results in a higher ER, which can be anywhere from 0 to 100, with higher ER values are most desirable in terms of increasing energy performance. However, the ER metric does not predict in-situ performance or specific energy savings, especially since the actual performance of a system is heavily dependent on installation and detailing [46].

The simplified ER equation is:

Simplified Energy Rating Equation

$$ER = (57.76 \times SHGC_w)-21.90 \times U_w)-(1.97 \times L_{75}) + 40) \qquad \text{(Equation 2) [46]}$$

Where,

$SHGC_w$ is the fenestration solar heat gain coefficient for the reference size system in Table 1 of CSA A440.2-09;

U_w is the fenestration U-factor ($W/m^2 \cdot K$) the reference size system in Table 1 of CSA A440.2-09; and

L_{75} is the fenestration air leakage at 75 Pa ($L/s\text{-}m^2$) established in accordance to Clause & in CSA A440.2-09.

4.2.3. Passive House Standard

Although not a requirement for Passive House certification, windows are recommended to have a U-Value of equal to or less than 0.8 $W/m^2 \cdot K$ and have a solar transmittance value (g-value) of at least 50 % [37]. The g-value is similar to that of the SHGC, which measures "the fraction of incident solar radiation on the fenestration system that appears as solar heat gain in the building" (CSA A440.2-09)[46].

4.3. Air Leakage

4.3.1. National Building Code

The NBC specifies separate metric levels for air leakage characteristics for components and assemblies as well as sheet and panel-type materials used in the construction of assemblies. Components or assemblies separating conditioned spaces from unconditioned spaces are required to control air leakage, and materials intended to act as the air barrier must have an air leakage characteristic of equal to or less than 0.02 L/(s·m^2) at 75 Pa (Part 5 Environmental Separation, Section 5.4 Air Leakage) [16, 21]. Materials separating conditioned spaces from unconditioned, exterior spaces or the ground must have an air leakage characteristic of less than 0.1 L/(s·m^2) at 75 Pa (Part 9, Houses and Small Buildings, the Code) [16]. No requirement for whole building air leakage values or characteristics is stated in this edition of the NBC.

The 2012 changes to the NBC include additional requirements for detailing to increase the air tightness of residential homes, though no specific air leakage rate is stated as a requirement nor is verification required for compliance. Detailing requirements include [21]:

- A continuous air barrier system;
- Sealing of joints in cases where an air barrier system includes rigid panel-type material;
- For flexible sheet material, joints must be lapped not less than 50 mm, sealed and structurally supported;
- Electrical wiring, outlets switches, and light fixtures penetrating plane of air tightness must be sealed; and
- All joints and junctions must be sealed.

4.3.2. Ontario Building Code

Air leakage requirements for the OBC are dependent on the compliance path chosen to meet requirement 12.2.1.2.(3)(a), in Part 12 Energy Efficiency in the OBC 2006. For those projects seeking the EnerGuide 80 rating, a blower door test must be performed upon construction completion for certification. No specific air leakage level is stated as a requirement, but an assumption can be made that lower air leakage rates are generally correlated with higher EnerGuide ratings. Projects using the SB-12 requirements for compliance have three compliance options for air leakage requirements. For projects using Section 2.1.1. 'Prescriptive Compliance Packages', there is no specific air leakage target that must be met for compliance. Projects following Section 2.1.2 'Performance Compliance' for projects going the performance package route, the air leakage rate of a detached home is assumed to be 2.5 air change per hour at 50 Pascal (ACH_{50}) for energy modelling of the proposed building [24]. Any values less than this require verification by approved air leakage test methods. Under Section 2.1.3. 'Other

Acceptable Compliance Methods', specifically those projects pursuing compliance with NRCan's "Energy Star for New Homes", detached houses in southern and mid/eastern Ontario must achieve an air leakage rate of at least 2.5 ACH_{50}, and 2.0 ACH_{50} for detached houses in Northern Ontario [35].

The 2009 version of SB-12 also included a section on "Measures to Control Air Infiltration" (Chapter 3). These requirements were omitted from the 2012 SB-12. Key requirements include [47]:

- Air leakage rate for exterior windows of less than 1.65 m^3/h per metre of crack length (in accordance with CAN/CSA-A440.1);
- Assemblies separating conditioned from unconditioned spaces must include a continuous air barrier from the interior of the building into the wall, floor, attic or roof spaces as well as extend throughout the basement;
- Air barrier must have an air leakage characteristic of less than 0.02 $L/(s \cdot m^2)$ at 75 Pa; and
- All joints must be sealed with compatible materials to ensure continuity.

Additional requirements were included outlining procedures for various detailing specifics, such as, where an interior wall meets an exterior wall or where an exterior air barrier is penetrated by fenestration. Methods and materials to minimize air leakage are outlined. These requirements were likely included to aid in achieving the stricter air leakage rates implemented within the 2009 SB-12.

4.3.3. Passive House Standard

Passive House also requires a whole building air leakage rate be achieved for certification. Passive House certified homes are required to have an overall air leakage rate of no more than 0.6 ACH_{50}, verified by a blower door test performed to the Passive House defined standard required for certification [48].

4.4. HVAC Efficiencies

4.4.1. National Building Code

The amended 2010 NBC specifies a minimum AFUE of 90% for gas. Installation of an HRV was not required as part of the 2010 code, but a minimum sensible efficiency of 60% is required if one is installed.

4.4.2. Ontario Building Code

Furnaces efficiencies in SB-12 vary according between compliance packages, but requirements range from 90 to 94% AFUE. Not all compliance packages state a requirement for the installation of an HRV, but those that do range from 55 to 70% AFUE.

4.4.3. Passive House Standard

There is no minimum furnace efficiency specified to achieve passive House certification. Heating demand is certified Passive Houses is low enough that conventional furnaces are not typically used. Passive House certified buildings must achieve a minimum of 75% heat exchanged from exhaust air by a heat exchanger [36].

4.5. Thermal Bridging

Attention to detailing to prevent thermal bridging in enclosure constructions is important as it can significantly impact the thermal performance of the building envelope, and thus, the energy performance of a building. The OBC first included requirements for thermal bridging in the 2006 edition with the requirements remaining the same through to the 2012 SB-12. Wood framed buildings, using studs with an RSI of 0.9 or less, must be insulated by a material that is at least equal to 25% of the thermal resistance requirement for the insulation part of the building component (section 12.3.2.2) [23]. Some of the compliance packages proposed for the 15% increase in energy efficiency include external insulation, which would effectively minimize thermal bridging [42]. The 2012 amendment to the NBC do not include specific requirements to address thermal bridging, however the requirements for thermal resistance of building components have been framed to account for thermal bridging by stating effective RSI-values as requirements, rather than nominal which has typically be done in the past. Methods to calculate effective thermal resistances are outlined in A-9.36.2.4.(1), and include the isothermal-planes method and the parallel-path flow method described in ASHRAE Fundamentals [49]. Tables outlining typical framing and cavity percentages for typically wood and steel frame assemblies (Tables A-9.36.2.4. (1)A. and A-9.36.2.4. (1)C.). Minimal thermal bridging is defining characteristic of Passive House constructions and key to achieving certification. Passive House specifies that interfaces with a Psi-factor (linear conductivity) of ≤ 0.1 W/m·K are essentially thermal bridge free [36, 37, 50].

5. Quantification of Ontario Residential Energy Intensity

5.1. EnergyPlus

EnergyPlus is a whole building energy modelling program. Energy models developed using EnergyPlus are built using inputs defined by the user rather than the program or a graphical user interface (GUI). All inputs can be tailored to accurately represent the building, increasing the accuracy of the results. For this reason, EnergyPlus was used to perform the energy simulations used in this research.

5.2. Canadian Centre for Housing Technology Test House

The Canadian Centre for Housing Technology (CCHT) constructed two identical houses 1998 to test advanced technologies, using one house as a baseline (reference) house and the second as the test house [51]. The houses are typical in construction, appearance, and layout of tract built houses available in markets throughout Canada [51]. Based on their representation of typical Canadian single detached residential buildings, the geometry and construction of the CCHT houses were used to develop the energy model used in this research. Using the CCHT EnergyPlus model developed by Zirnhelt [7], building energy performance simulations were carried out using the EnergyPlus energy modelling software.

The orientation of the building was assumed to be the same as the original CCHT house location, with the rear of the house facing north, and the front facing south (Figure 5-1 to Figure 5-4).

Figure 5-1 – CCHT House Front Elevation [52]

Figure 5-2 – CCHT House Rear Elevation [52]

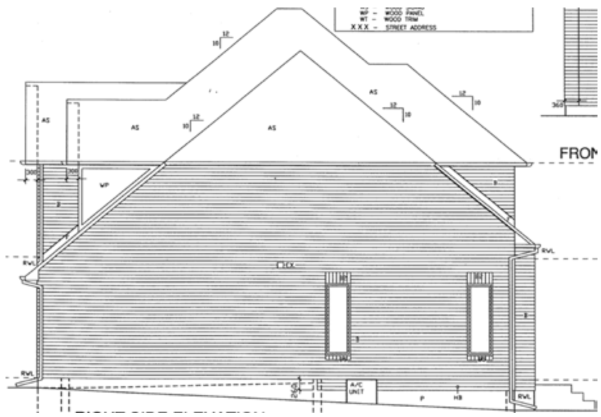


Figure 5-3 – CCHT House Right Side Elevation [52]

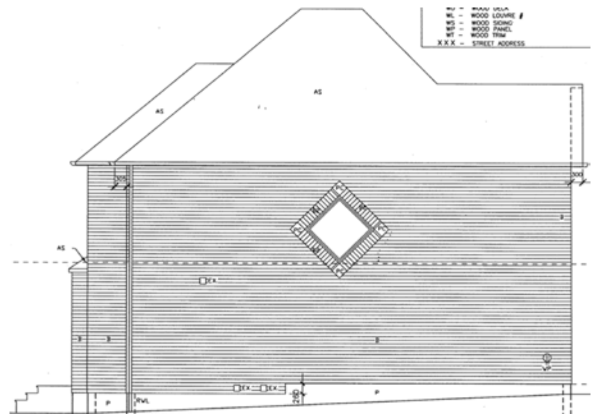


Figure 5-4 - CCHT House Left Side Elevation [52]

5.3. Simulation Variables

The following are the variables modified for all simulations performed to meet each building code/standard requirements:

- Wall assembly construction,
- Construction material characteristics (insulation),
- HRV efficiency and operating schedules,
- Glazing characteristics,
- Air leakage rates, and
- Furnace efficiency.

With the exception of OBC 2009 and 2012 SB-12 and the 2012 amendment to the NBC, simulations that had varying levels for thermal resistance requirements for no HRV and HRV, all construction material characteristics, glazing, and furnace efficiencies were kept the same for both no HRV and HRV simulations.

To simplify the modelling process and reduce the number of iterations, the following variables were kept constant for each simulation, as per the original CCHT idf file developed by Zirnhelt [7]:

- Building orientation,
- Building geometry,
- Occupancy activity schedules,
- Heating/furnace operating schedules,
- Lighting schedules,
- Electric equipment,
- Hot water equipment,
- Construction material characteristics (except of insulation),
- Zones (conditioned areas),
- Building surfaces (dimensions and type of walls, roofs, and floors),
- Fenestration surfaces (number, size, and location),
- Zone infiltration flow coefficient and rate, and
- Heating, cooling, and ventilation equipment set-up and flow rates.

An example of one of the EnergyPlus idf files is included in Appendix A.

5.4. Iterations

Five versions of the OBC, including part 9 of the 1997 version, part 12 of the 2006 version, and the first version (2009), most recent update (2012), and proposed 15% increase (2017) of the Supplementary Standard 12 Energy Efficiency for Housing, were modelled to show how changes to the building code have influenced residential energy consumption in Ontario. For Supplementary Standard SB-12, Compliance Package A was modelled to show a case with no HRV installed and Compliance Package J was modelled, after being identified as the package most commonly used by builders [53]. In addition to the most recent version (2010) of the NBC, and the proposed changes planned for publication in Fall 2012 were modelled to show where the

NBC is presently at, and the direction national requirements are moving to in their impact on residential energy consumption. For the Passive House levels, values for inputs were based on the envelope construction of the Passive House One, a house designed in Toronto to achieve Passive House Standard certification [54]. The simulations performed were outlined in Figure 2-1.

The parameters of the energy modelling were based on Ontario climate zones as defined by the OBC. The OBC bases its requirements on two climate zones, with Zone 1 as less than 5000 HDD (corresponding to Zones 1 in the NBC) and Zone 2 as greater than 5000 HDD (corresponding to Zone 2 in the NBC). Toronto was selected as the climate for Zone 1 modelling (3250 HDD) and Timmins was selected as the climate for modelling (6200 HDD). Timmins was chosen based on the number of HDD and availability of an EnergyPlus climate file.

For each code and climate zone, a simulation was run both with and without an HRV. This was done as some codes such as the OBC SB-12 2009 and 2012 have separate thermal requirements for assemblies and glazing if an HRV is installed. The NBC does not require the installation of an HRV, but have minimum efficiency ratings required if an HRV is installed. Installation of HRV's in Passive House certified homes is required to achieve the performance levels required for certification but installation is not a specific requirement for certification.

5.5. Target Areas

5.5.1. Opaque

5.5.1.1. Building Codes

Performance metric levels were identified in each of the OBC and NBC requirements for following opaque surfaces:

- Above grade walls,
- Below grade walls,
- Slab (if applicable),
- Roof,
- Exposed floor (if applicable).

The following are the assumptions that were made for the simulations:

- For all OBC and NBC simulation (except the 2012 amendment to the NBC), the thermal resistance values stated as requirements were assumed to be nominal values;
- OBC 1997 did not have a thermal resistance requirement for the slab, so the slab was modelled as per the original construction of the CCHT house (75 mm concrete);
- For exposed floors in the OBC 2006 simulation, the thermal resistance requirement for above grade walls was used as the code did not specify a thermal resistance requirement for exposed floors (the garage ceiling in the CCHT house);
- For doors, an assumption was made that there was no storm door, and for each iteration the door was modelled with an RSI of 0.7, as stated in the OBC and NBC codes.

Based on the original envelope assemblies of the CCHT house, modifications were made to meet each of the code's requirements. Changes made include changes to insulation types, levels of insulation and size of wall studs, and additional of exterior rigid insulation. Assemblies modelled are included in Appendix B**.** Table 5-1 outlines how each version of the building codes and Passive House approach requirements for opaque surfaces.

Table 5-1 - Opaque Surface Thermal Resistance Requirements

Code	**Requirements for Opaque Surfaces**
OBC 1997 – Part 9	Stated minimum nominal thermal resistance values are for insulation only.
OBC 2006 – Part 12	Stated minimum nominal thermal resistance values are for insulation only.
OBC 2009 – Supplementary Standard SB-12	Stated minimum nominal thermal resistance values are for insulation only.
OBC 2012 - Supplementary Standard SB-12	Stated minimum nominal thermal resistance values are for insulation only.
OBC 2017 Proposed 15% Increase in Energy Efficiency	Stated minimum nominal thermal resistance values are for insulation only.
NBC 2010 – Section 9.25	Ratio of outboard to inboard thermal resistance is calculated including all envelope materials from exterior to interior.
NBC 2010 amendment (2012) – Section 9.36 Energy Efficiency Requirements	Stated minimum effective thermal resistance values are for insulation only.
Passive House	A recommendation for a maximum heat transfer coefficient is given, but is not required for certification.

The conductivity values for the insulation selected for modelling were adjusted according to calculated framing percentages for the CCHT house (Appendix C). It is assumed that requirements for minimum thermal resistance are not effective values. Only the NBC 2012 proposed code changes state that the stated thermal resistance requirements are effective values.

Because the 2006 OBC Part 9 Houses and Small Buildings uses the same minimum ratio of outboard to inboard thermal resistance used in the 2010 NBC, the OBC Part 12 requirements were modelled, in an attempt to show the progression of the OBC requirements and their impact on the energy performance of residential buildings.

The OBC's supplementary standard SB-12 introduced a number of compliance packages a builder could choose which would satisfy building requirements under Section 2.1.1. Prescriptive Compliance Packages. For modelling, Compliance Packages A and J were selected, as builders identified Package J as the most commonly used and Package A was selected to compare results that did not include an HRV.

Thermal requirements for opaque surfaces in both the OBC and NBC are stated as minimum RSI-values. For Passive House levels, the recommendation for thermal requirements of the envelope is stated as a maximum U-value of 0.15 $W/m^2 \cdot K$, which was converted to RSI 6.67 $m^2 \cdot K/W$ for modelling (values are based on the Central European climate) [36].

Insulation types for the simulations were chosen based on their ability to meet the thermal resistance levels stated in the requirements of the subject building code. Framing size was increased from 38 by 89 mm to 38 by 140 mm to accommodate increased insulation thickness where required. For the energy modelling, conductivities of insulation materials were weighted to account for framing using the calculated framing percentages for the CCHT test house. Calculations for both the framing percentages and weighted conductivities can be found in Section 5.5.1.2 and Appendix C**.**

The following tables (Table 5-2 and Table 5-3) list the building component thermal resistance requirements for each building code modelled by climate zone.

Table 5-2 - Thermal Resistance Requirements per Building Code - Climate Zone 1

Building Code / Standard	Opaque Component				
	Roof	Exposed Floor	Above Grade Wall	Below Grade Wall	Slab
	Minimum Thermal Resistance (RSI, $(m^2 \cdot K)/W$)				
OBC 1997	5.4	4.4	3	1.41	1.41
OBC 2006 Pt. 12	7	4.4	3.4	2.11	1.41
OBC SB-12 2009 – Compliance Package A	8.81	5.46	4.23	3.52	0.88
OBC SB-12 2009 – Compliance Package J	8.81	5.46	3.87	2.11	-
OBC SB-12 2012 – Compliance Package A	8.81	5.46	4.23	3.52	0.88
OBC SB-12 2012 – Compliance Package J	8.81	5.46	3.87	2.11	-
OBC SB-12 Proposed 15%	10.56	5.46	4.66[1]	4.96[2]	-
NBC 2010 - Section 9.25	0.2	0.2	0.2	0.2	0.2
NBC 2010 - Section 9.36 – No HRV	8.67	4.67	3.08	2.98	1.96
NBC 2010 - Section 9.36 – HRV	8.67	4.67	2.97	2.98	1.96
Passive House Standard Levels[3]	6.67	6.67	6.67	6.67	6.67

[1] 3.34 + 1.32 continuous insulation
[2] 3.52 + 1.4 continuous insulation
[3] Passive House states that all opaque exterior components must be less than U-value 0.15 $W/(m^2 \cdot K)$, which is equal to an RSI value of 6.67 $(m^2 \cdot K)/W$ (based on the Central European Climate) [36].

Table 5-3 - Thermal Resistance Requirements Per Building Code – Climate Zone 2

Building Code / Standard	Opaque Component				
	Roof	Exposed Floor	Roof	Below Grade Wall	Roof
	Minimum Thermal Resistance (RSI, $(m^2 \cdot K)/W$)				
OBC 1997	6.7	4.4	3.87	1.41	1.41
OBC 2006 Pt. 12	7	4.4	4.22	2.11	1.41
OBC SB-12 2009 – Compliance Package A	8.81	5.46	5.11	3.52	0.88
OBC SB-12 2009 – Compliance Package J	8.81	5.46	4.23	2.11	-
OBC SB-12 2012 – Compliance Package A	8.81	5.46	5.11	3.52	0.88
OBC SB-12 2012 – Compliance Package J	8.81	5.46	4.23	2.11	-
OBC SB-12 Proposed 15%	10.56	5.46	4.22	5.63[1]	-
NBC 2010	0.3	0.3	0.3	0.3	0.3
NBC 2012 amendment – No HRV	10.43	5.02	3.08	3.46	1.98
NBC 2012 amendment – HRV	8.67	5.02	2.97	2.98	1.96
Passive House Standard Levels[2]	6.67	6.67	6.67	6.67	6.67

[1] 3.34 + 1.32 continuous insulation
[2] Passive House states that all opaque exterior components must be less than U-value 0.15 $W/(m^2 \cdot K)$, which is equal to an RSI value of 6.67 $(m^2 \cdot K)/W$ (based on the Central European climate [36].

5.5.1.2. Framing Percentages

Framing percentages were calculated for both above and below grade walls, accounting for double top plates. For modelling, each exterior wall was input as multiple building surfaces to account for differences in exterior façade (brick and siding) and installation of windows.

Framing percentages were calculated for sections of walls without windows, and those with windows. Table 5-4 outlines the framing percentages for walls.

Table 5-4 - Framing percentage per Building Component

Component	Framing Percentage (%)
Above Grade Wall	18.3
Below Grade Wall	14.2
Ceiling Bottom Cord	4.1
Window Wall (South Wall 1a)	20
Window Wall (South Wall 3a)	25
Window Wall (East Wall 1b)	19
Window Wall (North Wall 1)	26
Window Wall (North Basement Wall 1a)	12
Window Wall (West Wall 1a)	2

The calculated framing percentages were then used to adjust the RSI values of the insulation. Due to the format in which construction material properties are input into EnergyPlus, which requires the conductivity of the material, the composite RSI values were divided by the material thickness to determine the adjusted conductivity of the material (Appendix C).

Two separate framing percentages were calculated for roofs: one for the bottom cord and the second for the truss to account for changing insulation thicknesses per building code requirements. The bottom cord framing percentage was calculated using the same method as for walls without windows (Appendix C). The second framing percentage was calculated for the web bracing and top cord portions of each truss.

Top cord framing percentages were calculated for the Zone 1 baseline, Zone 2 Tier 2, and Tier 4 levels. Framing percentages for all other compliance packages were calculated using the linear interpolation method outlined in Appendix C**.** The framing percentages used for each simulation are outlined in Table 5-5. The calculated framing percentages were then used to adjust the RSI values of the roof insulation, using the same method employed for walls.

Table 5-5 - Roof Framing Percentages

Code	Insulation Height (m)	Framing Percentage (%)
OBC 1997 Zone 1	0.1216	1
OBC 1997 Zone 2	0.1723	1
OBC 2006 Zone 1 & 2	0.1840	1
OBC 2009 Zone 1 & 2 Compliance Package J	0.2546	1
OBC 2012 Zone 1 & 2 Compliance Package J	0.2546	1
OBC SB-12 Proposed 15% Increase –Zone 1 Compliance Package A, Zone 2 Compliance Package D	0.3328	1
NBC 2012 Zone 1 with & w/o HRV, Zone 2 with HRV	0.2487	1
NBC 2012 Zone 2 w/o HRV	0.3458	1
Passive House Levels	0.9000	3

5.5.2. Transparent Surfaces

Two input methods are available in EnergyPlus for glazing units. The ‘Complex Method’ divides the glazing unit into three classes – glazing, gas mixture, and frame and divider [55]. An input within each class requires a number of material properties and metric values be known. This method is useful for modelling existing glazing units. The second is the ‘Window:Material:SimpleGlazingSystem’, which requires only three metrics to be input, (i) U-value, (ii) SHGC, and (iii) Visible transmittance [55]. The latter method was used for because generic fenestration products representing overall performance were being used for modelling rather than specific products.

Generic fenestration products were selected from Table 9 in American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) Fundamentals, Ch.15 that meet U-value requirements for OBC and NBC. Average SHGC values were taken from Table 10 in ASHRAE Fundamentals, Ch. 15 [49], for glazing systems (including frames) matching the given U-values obtained from Table 4 [49]. Values and characteristics of the windows chosen from ASHRAE are listed in Table 5-6. For Passive House levels, the U-value and SHGC (g-factor) stated by the standard (referred to in Section 4.2.3) were used for the EnergyPlus inputs. The Visible Transmittance value used, 0.812, is the rated National Fenestration Rating Council (NFRC) value at normal incidence, as stated in the Input Output Reference [55].

Table 5-6 - Window Characteristics for EnergyPlus

Code	Window Type	U-Value Requirement ($Wm^2·K$)	U-Value ($W/m^2·K$)	SHGC
OBC 1997	operable fixed	3.3	3.31 3.18	0.62 0.67
OBC 2006	operable fixed	2	1.96 1.98	0.53 0.58
OBC 2009 SB 12 Pkg. A	operable fixed	1.6	1.55 1.5	0.5 0.55
OBC 2009 SB 12 Pkg. J	operable fixed	1.8	1.78 1.74	0.49 0.53
OBC 2012 SB 12 Pkg. A	operable fixed	1.6	1.55 1.5	0.5 0.55
OBC 2012 SB 12 Pkg. J	operable fixed	1.8	1.78 1.74	0.49 0.53
OBC SB-12 Proposed 15%	operable fixed	1.6	1.55 1.5	0.5 0.55
NBC 2010 – Section 9.25	operable fixed	2.5	2.44 2.24	0.53 0.58
NBC 2010 amendment (2012) – Section 9.36 Energy Efficiency Requirements	operable fixed	1.6	1.55 1.5	0.5 0.55
Passive House Levels	operable fixed	0.8 0.8	0.8 0.8	0.5 0.5

5.5.3. Air Leakage

Of the codes modelled, the 1997 OBC, 2006 NBC, and 2010 NBC did not state specific levels or requirements for whole building air leakage rate that buildings must meet or are assumed to meet if built to code. Few studies have been conducted on air leakage in Canadian residential buildings. For air leakage rates of homes built between 1991 and 1997, Harris (2009) cites results from two studies. An NRCan study from 1997, found the average air leakage rate of homes built between 1991 and 1997 to be 3.1ACH_{50} [56]. In contrast, data from the Green Communities Canada's EnerGuide for Houses database found homes built between 1991 to 1997 to have air leakage rates of 4.4 ACH_{50} and homes built between 1995 to 2000 to have rates of 3.7 ACH_{50} [57]. An average of these three values (4.05 ACH_{50}) was used in the simulation of the OBC 1997.

For the OBC 2006, air leakage rates were found to be 3.5 ACH_{50} for homes built between 2001 to 2005, and 2.8 ACH_{50} for homes built between 2006 and 2009 [57]. Industry experts identified an average air leakage rate of 3.42 ACH_{50} for homes built to 2006 OBC requirements [58]. In their study "Energy Efficiency Measures for Part 9 Housing in the Ontario Building Code", Lio & Associates (2006) analysed the 2006 OBC for its energy efficiency measures, performing energy simulations using a base case. In the base case, they used an air leakage rate of 3.5 ACH_{50}. Although the Harris (2009) report found air leakage rates to be 2.8 ACH_{50} it was assumed that that the lower air leakage rate was due to improving construction methods as builders became more familiar with the code requirements. As such an average of 3.46 ACH_{50} from the Harris study and Blaszak's findings was used for modelling of the OBC 2006.

The 2012 amendment to the NBC does not include a specific requirement for an overall air leakage rate for prescriptive compliance. However, to meet the Performance Compliance requirements, energy simulations must be carried out and air leakage values for energy model calculations are stated. A building constructed to comply with Section 9.25, Heat Transfer, Air Leakage and Condensation Control, is assumed to achieve an air leakage rate of 3.2 ACH_{50} [21]. This rate corresponds to that found in the Harris study, which identified homes with rooms over the garage also having an average air leakage rate of 3.2 ACH_{50} and used for the NBC 2010 simulations. A building showing that the air barrier system is constructed in compliance with Subsection 9.25.3 and articles 9.36.2.9 and 9.36.2.10., can be assumed to achieve an air leakage rate of 2.5 ACH_{50} [21].

Table 5-7 - Air Leakage Rates per Building Code

Code	Air Leakage Rate (ACH_{50})	Source
OBC 1997	4.05	Not a requirement. Estimated average based on Harris' study[57].
OBC 2006	3.46	Not a requirement. Estimated average based on Harris' and Lio and Associates studies [26, 57].
OBC SB-12 2009	3.1	Stated in Code - assumption for Performance Compliance energy simulation requirement [47]
OBC SB-12 2012	2.5	Stated in Code - assumption for Performance Compliance energy simulation requirement [24]
OBC SB-12 Proposed 15%	2.5	Assumed.
NBC 2010 – Section 9.25	3.2	[21].
NBC 2010 amendment (2012) – Section 9.36 Energy Efficiency Requirements	2.5	Stated in Code - assumption for Performance Compliance energy simulation requirement [19]
Passive House Levels	0.6	Stated as requirement.

It is important to note that the NBC 2012 amendment and OBC SB-12 2009 and 2012 do not prescribe specific air leakage rates as requirements for the prescriptive compliance paths. Rather, those codes stated an assumed air leakage value to be used for modelling to meet the performance compliance path. In other words, buildings designed to meet those code requirements are assumed to achieve those air leakage rates, however verification is not a requirement.

5.5.4. HVAC

5.5.4.1. Furnaces

Gas furnaces were used as the space heating equipment for all building code simulations consistency and to aid in establishing a baseline for energy consumption. The OBC SB-12 contains separate requirements and compliance packages for electric baseboard heating, however this type of space heating equipment is not commonly used in Ontario single-family detached dwellings [12]. As well, gas furnaces are not typically used in certified Passive House designs. The efficiencies of the furnaces for each of the simulation iterations are as follows (Table 5-8):

Table 5-8 - Furnace AFUE's per Building Code

Building Code / Standard	Zone 1		Zone 2		Source
	w/o HRV	w/ HRV	w/o HRV	w/ HRV	
OBC 1997	80	80	80	80	Assumption
OBC 2006 Pt. 12	90	90	90	90	[23]
OBC SB 12 - 2009	90	94	90	94	[47]
OBC SB 12 - 2012	90	94	90	94	[24]
OBC SB-12 Proposed 15%	n/a	90	n/a	94	[28]
NBC 2010 – Section 9.25	90	90	90	90	[16]
NBC 2010 amendment (2012) – Section 9.36 Energy Efficiency Requirements	92	92	92	92	[21]
Passive House Levels[1]	97	97	97	97	Assumption

[1] Certified Passive House do not typically have furnaces installed.

Both the 1997 OBC and 2010 NBC did not state specific requirements for furnace efficiency values, therefore an AFUE of 80% was assumed. Furnace efficiencies for OBC SB-12 vary depending on which compliance package is selected by the builder. As previously mentioned, compliance packages are separated into 3 groups: (i) space heating equipment with AFUE ≥ 90%, (ii) space heating equipment with AFUE ≥ 78% and ≤90%, and (iii) electric space heating [24]. Compliance packages modelled were selected from group (i), with efficiency's of 90% (Compliance Package A) and 94% (Compliance Package J) [53]. The 2012 amendment to the NBC state an efficiency of 92% is required for all gas fired warm air furnaces [19].

5.5.4.2. Heat Recovery Ventilators

Simulations were run both with and without HRVs as some (OBC 1997, OBC 2006 Pt. 12, NBC 2010, and NBC 2012 amendment) of the subject codes state separate thermal resistance requirements for designs including the installation of an HRV. Those that did not include separate building envelope requirements did include a minimum efficiency requirement should an HRV be installed (Table 5-9). Only the OBC SB-12 requirements call for the installation of HRV's, depending on the compliance package selected to meet the prescriptive path. To compare against a Compliance Package without a HRV requirement, package A was selected.

Table 5-9 - HRV Efficiency by Building Code Requirement

Code	HRV (Sensible) Efficiency (%)
OBC 1997	55
OBC 2006 Pt. 12	55
OBC SB 12 - 2009 (Compliance Package J)[1]	60
OBC SB 12 - 2012 (Compliance Package J)[1]	60
OBC SB-12 Proposed 15% Increase – Zone 1 Compliance Package A	55
OBC SB-12 Proposed 15% Increase – Zone 2 Compliance Package D	70
NBC 2010 – Section 9.25	55
NBC 2010 amendment (2012) – Section 9.36 Energy Efficiency Requirements	60
Passive House Levels[2]	85

[1] The HRV efficiency stated is for the selected compliance package only. Both the requirement for installation of an HRV system and its efficiency is dependent on the selected compliance package.
[2] Passive House does not specify a required efficiency level for HRV, but high sensible efficiency levels are typical of certified buildings [48].

To simplify modelling, and eliminate the need to modify the inputs for the mechanical systems for the idf file, for iterations without the HRV, the heat exchanger schedule was turned off, with the ventilation schedule left on. Inputs for 'Sensible Effectiveness at 100% Heating Air' and 'Sensible Effectiveness at 75% Heating Air' were set to zero to ensure no power was being used by the heat exchanger.

5.6. Occupancy Schedules

Occupancy schedules from Zirnhelt's original CCHT idf file were not modified for these simulations. This includes scheduling for appliance operation, hot water equipment, and lighting, based on 4-person occupancy. Occupancy schedules are run for each simulation, accounting for energy use during daily (24-hour) periods of occupancy. Simulation results account for the impact of occupancy on heating and cooling energy consumption.

5.7. Modelling Results

The results of the simulations are shown in Figure 5-5 in kWh/m^2/year. The area was determined by calculating the treated floor area of the house – the interior floor area measure from interior walls, excluding interior partition walls and stairwells, and including the basement at 60% (based on the Passive House Standard and Hot2000 method, Appendix D**)**. The Passive House Standard level simulations consumed significantly less energy in both climate zones compared to all versions of the OBC and NBC modelled. Of the Canadian codes, the OBC SB-12 2012 consumed the least amount of energy in Zone 1, while the NBC 2012 amendment consumed the least in Zone 2. Reasons for the differences in consumption will be examined in the following sections.

5.7.1. Opaque Surfaces

Comparing the opaque surface requirements between the building codes reveals shows several inconsistencies. Although the NBC is the model building code for the entire country, levels for opaque surface requirements were less stringent than the OBC. With the exception of the Zone 2 results for the 2012 amendment to the NBC, the OBC simulations had significantly lower levels of energy consumption than the NBC simulations. A significant difference between the two versions of the NBC (2010 and 2012 amendment) modelled is the use of the outboard to inboard thermal resistance ratio in the 2010 version, and the use of prescriptive thermal resistance requirements per building component in the 2012 amendment. Because the NBC 2010 requirements for thermal resistance are objective–based (meeting the 0.2 outboard to inboard thermal resistance ratio) rather than prescriptive, it is difficult to identify the actual level of improvement the NBC 2012 amendment provide but it can be assumed that it is substantial. Because the outboard to inboard thermal resistance ratio does not define specific RSI values for the building envelope, values for the roof and above grade walls in the 2010 NBC simulations were lower than those in the 2006 OBC simulation, as well as those in the 2009 and 2012 OBC SB-12 simulations.

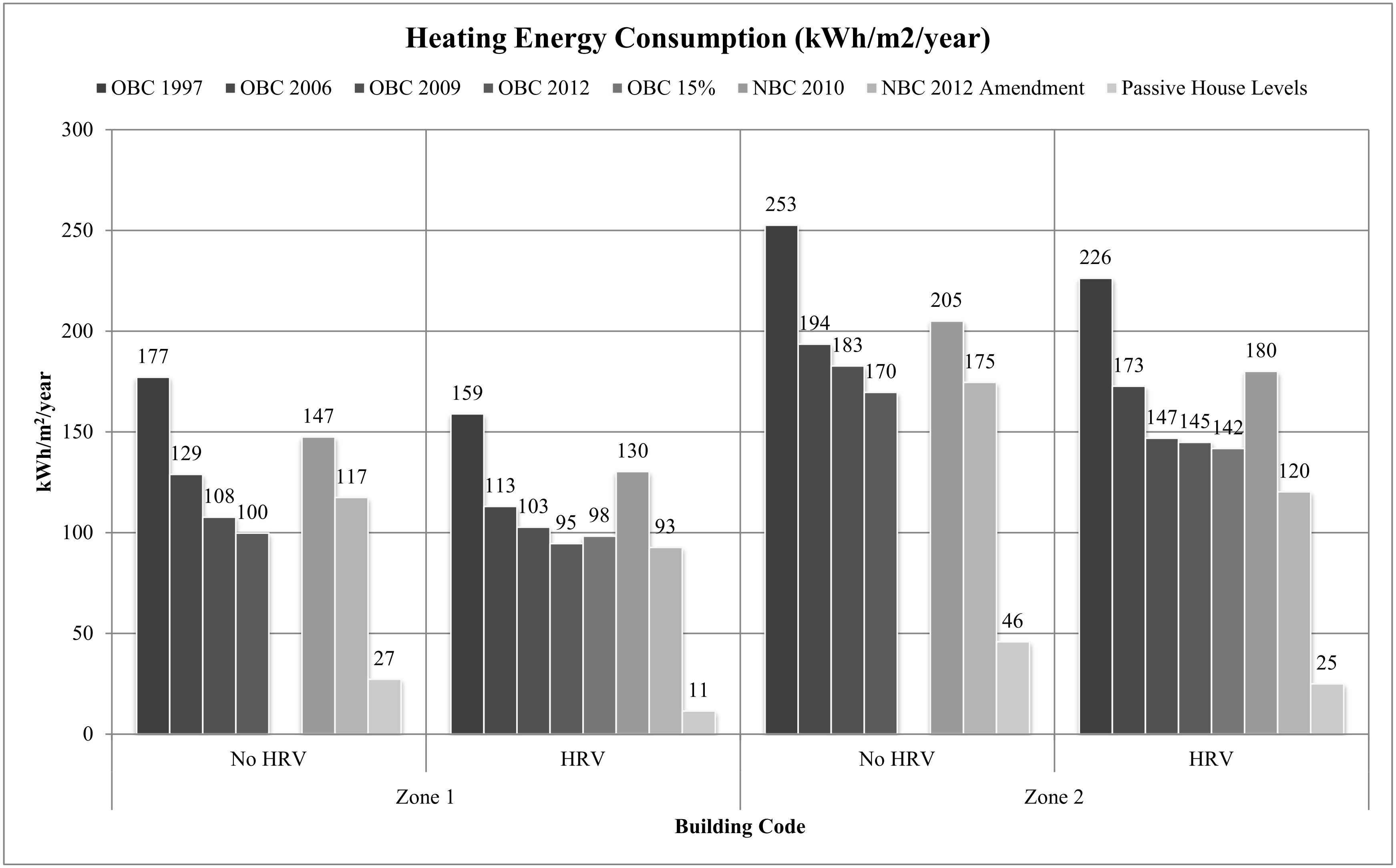


Figure 5-5 – Heating Energy Consumption (Electricity and Gas)

***All proposed compliance packages for the OBC 15% increase in energy efficiency included HRV requirements**

For the OBC, the decline in energy consumption over the last four versions can partly be attributed to increases in thermal resistance requirements for the building envelope. Prescriptive levels for building envelope thermal resistance have increased since the 1997 version of the code, but remained the same from 2009 to the 2012 SB-12.

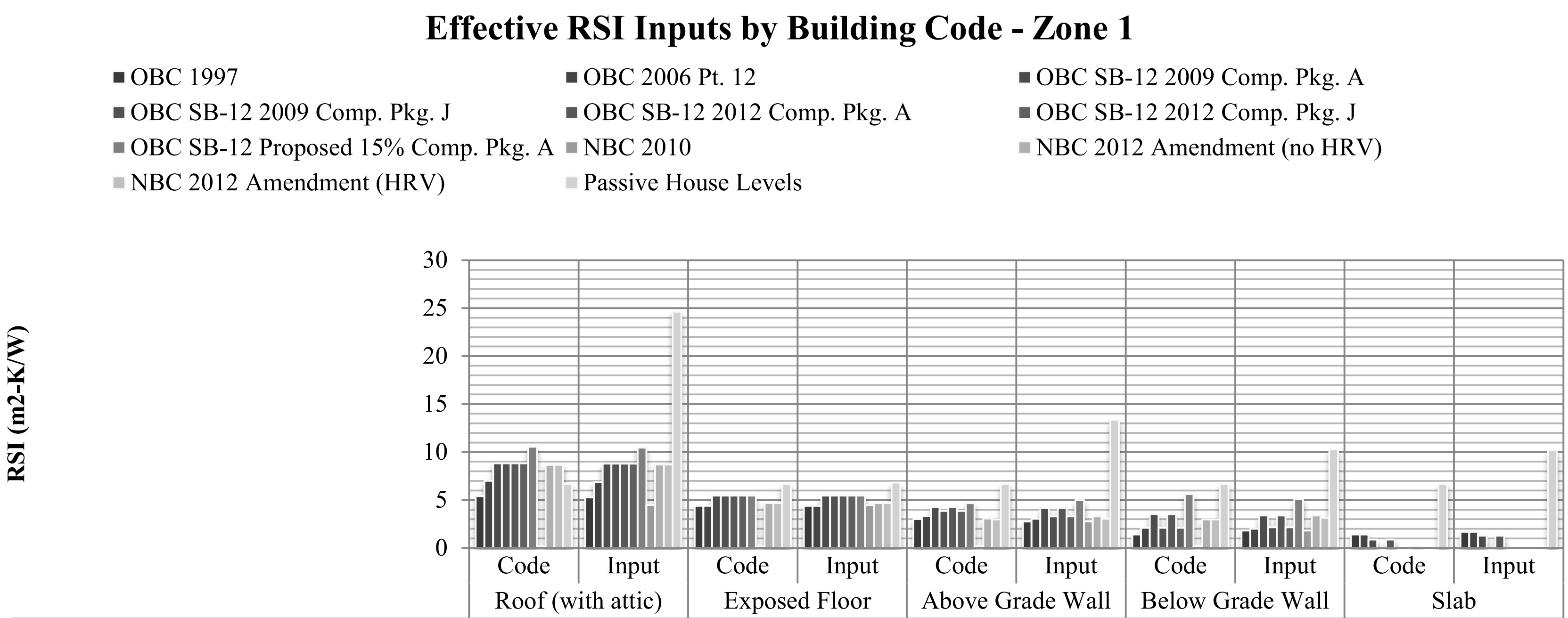
Comparing the results of the 2012 OBC and the NBC 2012 in both climate zone the OBC consumed less energy in Zone 1 (100 and 95 kWh/m^2/year in Zone 1 and 170 and 145 kWh/m^2/year Zone 2) than the NBC 2012 Zone 1 (147 and 130 kWh/m^2/year), and more energy than the NBC 2012 in Zone 2 (205 and 180 kWh/m^2/year). Of the Canadian codes, the OBC 2009 and 2012 SB-12 had the highest levels of thermal resistance in above and below grade walls and exposed floors, as well as the roof in Zone 1 (Figure 5-6**)** The NBC 2012 had higher insulation levels for the slab and the roof in Zone 2 (Figure 5-7). For the slab, the OBC requirements were 1.41 RSI in both the 1997 and 2006 versions, and 0.88 in both the 2009 and 2012 SB-12 with no HRV (Figure 5-6 and Figure 5-7). The OBC does not require slab insulation in the 2009 and 2012 SB-12 if an HRV is installed. In contrast the NBC 2012 requires an RSI of 1.96 for the slab. For the roof, the NBC 2012 had higher thermal resistance levels requirements for the roof in Zone 2 (Figure 5-7). The NBC 2012 also consumed the least amount of energy of the Canadian codes in the Zone 2 simulations (120 kWh/m^2/year). The NBC 2012 had an effective RSI requirement of 10.43, compared to a nominal requirement of 8.81 for the OBC (as input into EnergyPlus, 10.46 and 8.78 respectively). The lower energy consumption of the NBC 2012 in Zone 2 compared to the other versions of the Canadian building codes can be attributed, in part, to higher roof insulation levels (RSI 8.69).

Looking strictly at the thermal resistance of the building components (with the exception of the roof), the RSI values input for modelling were generally higher than the code requirements as a result of filling the stud space (Figure 5-6 and Figure 5-7). This difference was due to the framing sizes (89 by 38mm and 140 by 38mm) and the amount of insulation the cavity could accommodate. For the walls and exposed floor, it was assumed that the thickness of the insulation was equal to the framing cavity size. As well, due to the limited types of interior insulation available, there were minimal differences between some RSI values of the above and below grade wall assemblies (Figure 5-6 and Figure 5-7).

Though the Passive House Standard does not state specific requirements for thermal resistance levels of opaque surfaces, to reach the performance levels required to achieve certification, extremely high thermal resistance levels are needed. The levels needed for certification are significantly greater than those prescribed in Canadian building codes. Passive House levels for the exposed floor, above and below grade walls, and slab were on average double to nearly three times the levels of the Canadian requirements. The difference in consumption between the Passive House levels (27 and 11 kWh/m^2/year in Zone 1 and 46 and 25 kWh/m^2/year in Zone 2) and the Canadian codes levels support the position that a highly insulated building envelope, particularly a highly insulated roof, slab, and below grade walls, significantly reduces space heating and cooling energy consumption.

5.7.1.1. Nominal vs. effective RSI

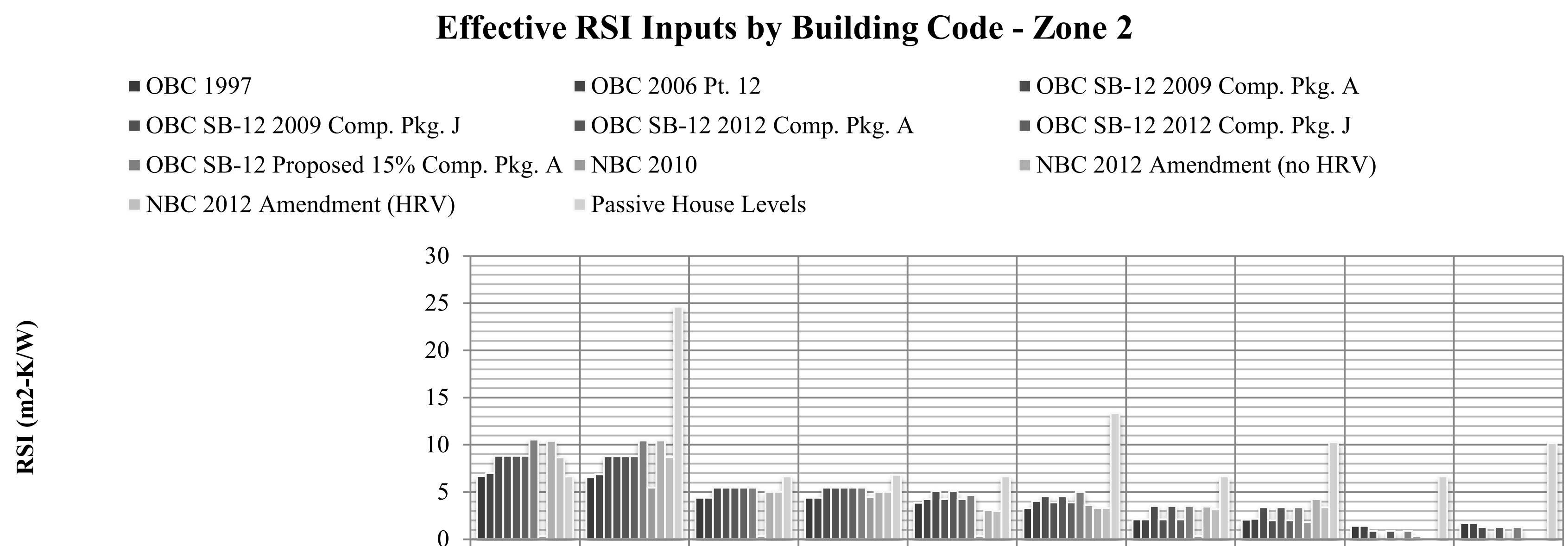
A key difference between the 2012 amendment to the NBC and both the NBC 2010 and OBC versions is that thermal resistance requirements for building components are stated as nominal RSI values rather than effective. The framing percentage calculations (Table 5-4) showed framing has a considerable impact on the RSI value of the building envelope. Figure 5-6 and Figure 5-7 show the inputs versus the code/standard requirements for opaque surfaces, where significant variations were observed. The framing percentage is largely impacted by the window-to-wall ratio, specifically the stud width and types of framing methods used (conventional versus advanced) and styles of trusses used and the amount of bracing required [19]. While the NBC 2012 amendment list average framing percentage per envelope component, actual framing percentages will vary according to the design of the building and construction methods used. Knowing the impact framing has on the thermal performance of a building will inform both the design and construction of the building envelope to achieve optimal energy performance. To ensure a high-performance building envelope, requirements should be stated as effective RSI values



	Roof (with attic)		Exposed Floor		Above Grade Wall		Below Grade Wall		Slab	
	Code	Input	Code	Input	Code	Input	Code	Input	Code	Input
OBC 1997	5.4	5.28	4.4	4.4	3	2.75	1.41	1.81	1.41	1.69
OBC 2006 Pt. 12	7	6.89	4.4	4.4	3.34	3.04	2.11	2	1.41	1.69
OBC SB-12 2009 Comp. Pkg. A	8.81	8.78	5.46	5.46	4.23	4.14	3.52	3.4	0.88	1.27
OBC SB-12 2009 Comp. Pkg. J	8.81	8.78	5.46	5.46	3.87	3.29	2.11	2.16	0	0
OBC SB-12 2012 Comp. Pkg. A	8.81	8.78	5.46	5.46	4.23	4.14	3.52	3.4	0.88	1.27
OBC SB-12 2012 Comp. Pkg. J	8.81	8.78	5.46	5.46	3.87	3.29	2.11	2.16	0	0
OBC SB-12 Proposed 15% Comp. Pkg. A	10.56	10.46	5.46	5.46	4.66	4.98	5.63	5.09	0	0
NBC 2010	0.2	4.48	0.2	4.44	0.2	2.75	0.2	1.81	0.2	0
NBC 2012 Amendment (no HRV)	8.67	8.69	4.67	4.67	3.08	3.29	2.98	3.4	0	0
NBC 2012 Amendment (HRV)	8.67	8.69	4.67	4.67	2.98	3.04	2.98	3.14	0	0
Passive House Levels	6.67	24.62	6.67	6.81	6.67	13.33	6.67	10.28	6.67	10.16

Requirement & Effective RSI Input

Figure 5-6 - Effective RSI Inputs By Building Code – Zone 1



	Roof (with attic) Code	Roof (with attic) Input	Exposed Floor Code	Exposed Floor Input	Above Grade Wall Code	Above Grade Wall Input	Below Grade Wall Code	Below Grade Wall Input	Slab Code	Slab Input
OBC 1997	6.7	6.56	4.4	4.4	3.87	3.29	2.11	2.07	1.41	1.69
OBC 2006 Pt. 12	7	6.89	4.4	4.4	4.22	4.04	2.11	2.16	1.41	1.69
OBC SB-12 2009 Comp. Pkg. A	8.81	8.78	5.46	5.46	5.11	4.56	3.52	3.4	0.88	1.27
OBC SB-12 2009 Comp. Pkg. J	8.81	8.78	5.46	5.46	4.23	3.89	2.11	2	0	0
OBC SB-12 2012 Comp. Pkg. A	8.81	8.78	5.46	5.46	5.11	4.56	3.52	3.4	0.88	1.27
OBC SB-12 2012 Comp. Pkg. J	8.81	8.78	5.46	5.46	4.23	3.89	2.11	2	0	0
OBC SB-12 Proposed 15% Comp. Pkg. A	10.56	10.46	5.46	5.46	4.66	4.98	3.52	3.4	0.88	1.27
NBC 2010	0.3	5.47	0.3	4.44	0.3	3.6	0.3	1.81	0.3	0
NBC 2012 Amendment (no HRV)	10.43	10.46	5.02	5.02	3.08	3.29	3.46	4.25	0	0
NBC 2012 Amendment (HRV)	8.67	8.69	5.02	5.02	2.98	3.29	3.17	3.4	0	0
Passive House Levels	6.67	24.62	6.67	6.81	6.67	13.33	6.67	10.28	6.67	10.16

Requirement & Effective RSI Input

Figure 5-7 - Effective RSI Inputs By Building Code – Zone 2

5.7.1.2. Summary

The simulations showed that the more recent versions of the OBC (2009 and 2012) had lower heating energy demand the NBC, with the exception of the NBC 2012 simulations for Zone 2 with an HRV. NBC simulations. Both OBC and NBC thermal resistance levels are low compared to those required to obtain Passive House certification in the Ontario climate zones. Overall, the Passive House levels of thermal insulation are significantly higher than all building code versions modelled. As previously mentioned, Passive House does not state specific requirements for envelope RSI values, but high values are inherently needed if the building is to meet heating demand requirements for certification.

5.7.2. Transparent Surfaces

There was a significant difference in the performance requirements for glazing among the codes (Figure 5-8). Glazing performance requirements in the OBC have not changed significantly over the last three versions of the code. The NBC 2010 requirements are the second highest of the codes modelled, with only the OBC 1997 having lower requirements. The Passive House Standard requires significantly higher performance windows than all other codes modelled, with a heat transfer coefficient more than half of the lowest OBC and NBC requirement. Since windows are the weakest point of thermal resistance in the building envelope, increasing performance requirements for glazing is key in reducing heat loss and energy consumption.

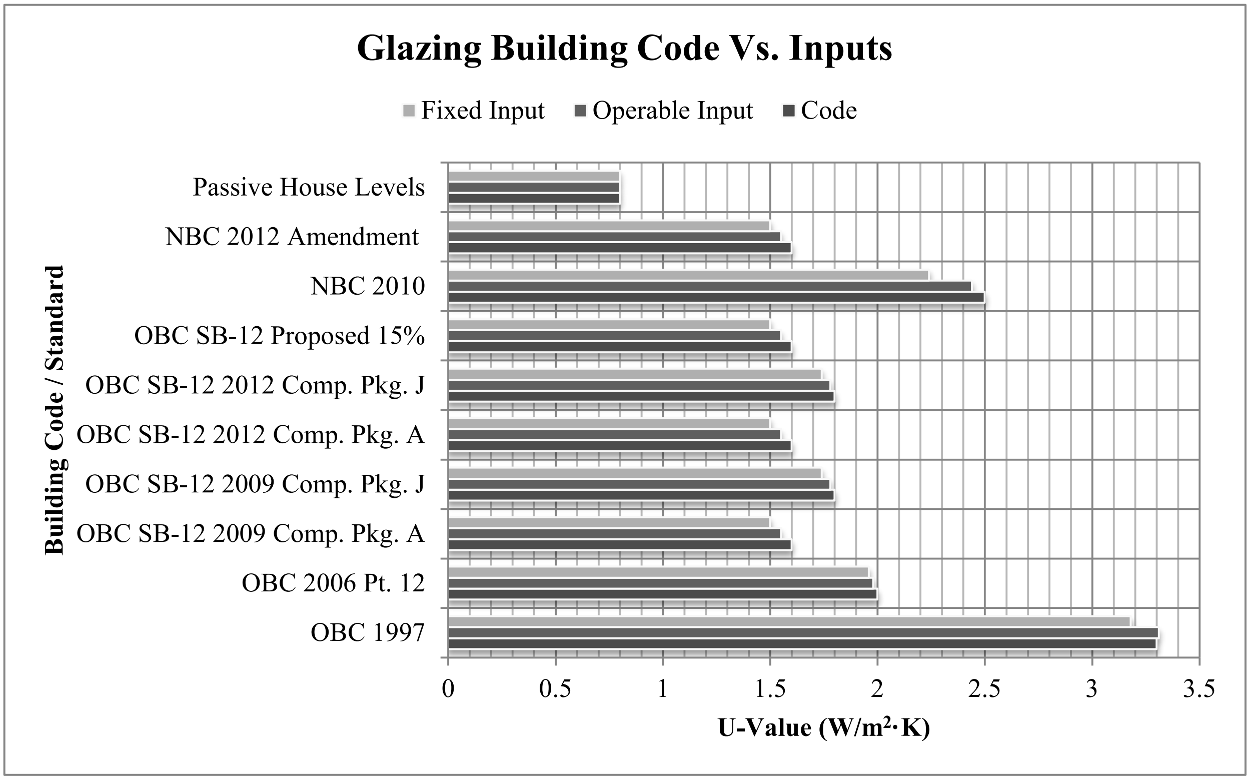


Figure 5-8 - Glazing Building Code Vs. Inputs

5.7.3. Air Leakage

Air leakage levels vary widely across the building codes and Passive House levels (Figure 5-9). The difference in space heating energy consumption between the OBC 2009 and 2012 SB-12 simulations support the position that increasing the air tightness of a building decreases space heating energy consumption, as only the assumed air leakage rate was different (from 3.1 to 2.5 ACH_{50}) between the two versions of the code. However, both the OBC SB-12 2012 and NBC 2012 amendment have assumed air leakage rates four times that of Passive House Standard levels.

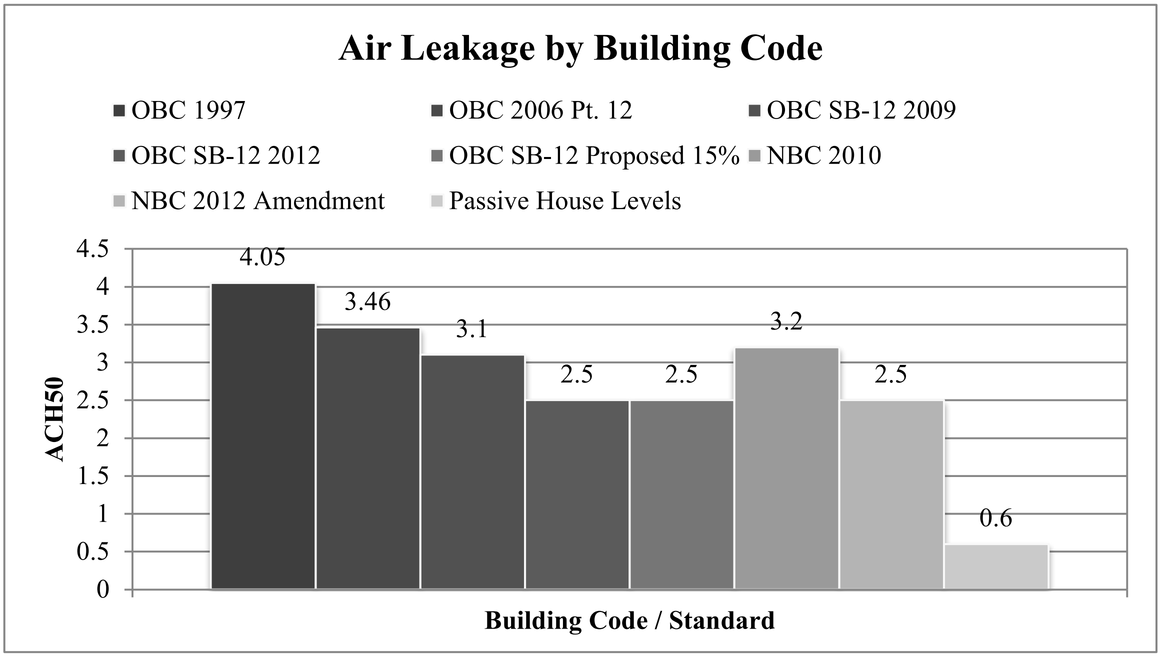


Figure 5-9 - Air Tightness Building Code Inputs

It is important to note that only the Passive House Standard requires third party verification of air leakage rates for certification. The air leakage rates stated in both the OBC SB-12 requirements and NBC 2012 amendment are levels assumed to be achieved is a building is constructed to the performance requirements outlined in the code are met, specifically requirements pertaining to air barriers and air tightness, and to be used when modelling a building to determine its EnerGuide rating. Presently, neither the OBC nor NBC require verification of air leakage levels for prescriptive or performance paths for compliance. Verification is only required if an EnerGuide rating is pursued. Along with having the greatest potential for improvement, air tightness is arguably the most important area in achieving consumption levels close to Passive House Standard levels, as even a highly insulated building will have a high heating and cooling demand if not adequately detailed to prevent air infiltration and exfiltration.

5.7.4. HVAC

Furnace efficiencies among the building codes modelled are relatively high (Figure 5-10). With the exception of the OBC 1997, there was only a 5% difference in efficiency between the codes modelled, and only a 1% difference between both OBC Compliance Package J and the Passive House Standard levels. Due to the small differences in furnace efficiencies it can be assumed that this has a smaller impact on energy consumption compared to the performance of the building envelope. With a highly insulated and properly detailed building envelope, heating demand will already be reduced, resulting in lower heating and cooling energy consumption.

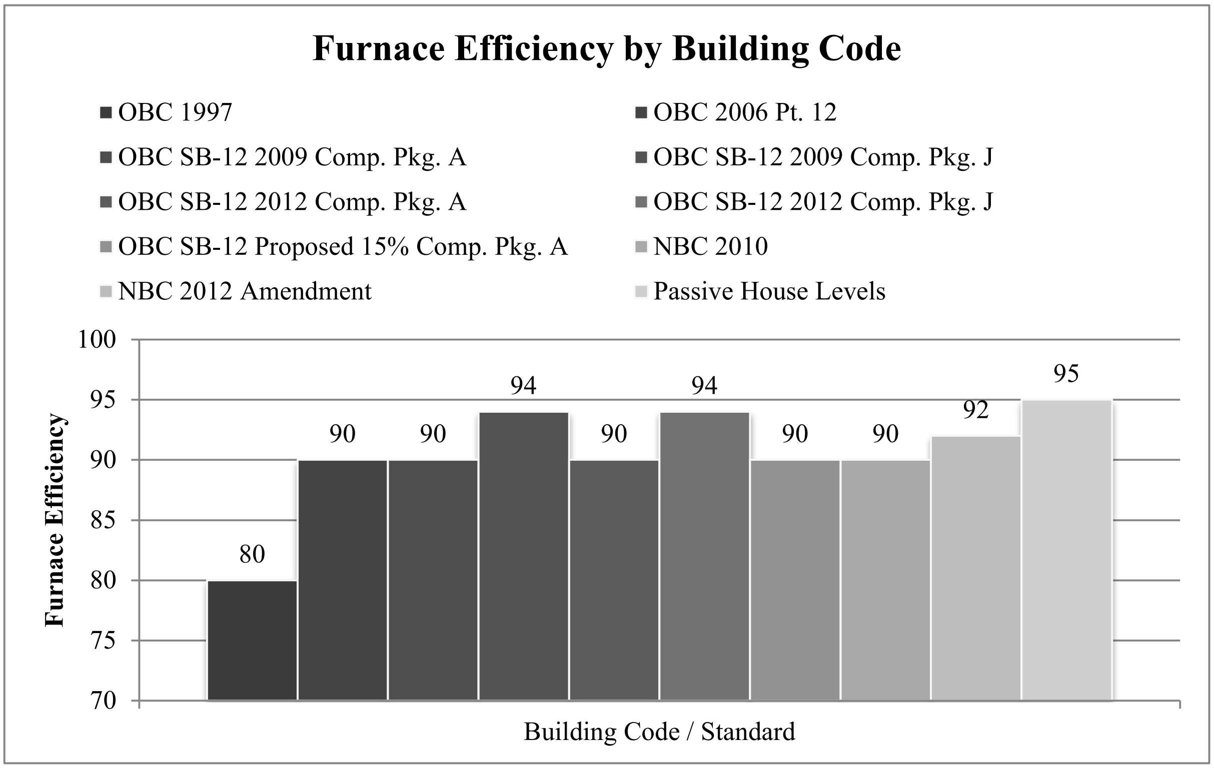


Figure 5-10 - Furnace Efficiency By Building Code

Requirements for HRV installation also varied. Older versions of the OBC, along with the NBC 2010, do not require an HRV be installed, but do have a minimum efficiency requirement if one is installed. Efficiency requirements were low in comparison to the Passive House levels. This is likely due to the absence of minimum air leakage requirements in the Canadian codes, as HRV are increasingly more effective in decreasing heating and cooling energy consumption with increased air tightness. As air tightness is increased, there is a greater need for mechanical ventilation.

Heating energy consumption was reduced in the simulations with an HRV compared to those without, with greater energy savings were observed in Zone 1 over Zone 2 (Figure 5-11). The OBC 2009 and 2012 simulations showed energy savings of 5% in Zone 1, and 20% and 15% in Zone 2, respectively. The NBC 2010 simulations showed a 12% increase in savings for both climate zones. The NBC 2012 amendment showed the greatest energy savings, with 21% in Zone 1 and 31% in Zone 2 (with 60% efficiency). As air tightness requirements are put in place, and air leakage levels decrease, the installation of an HRV will be necessary to maintain indoor comfort and air quality levels, and ensure proper ventilation levels are achieved.

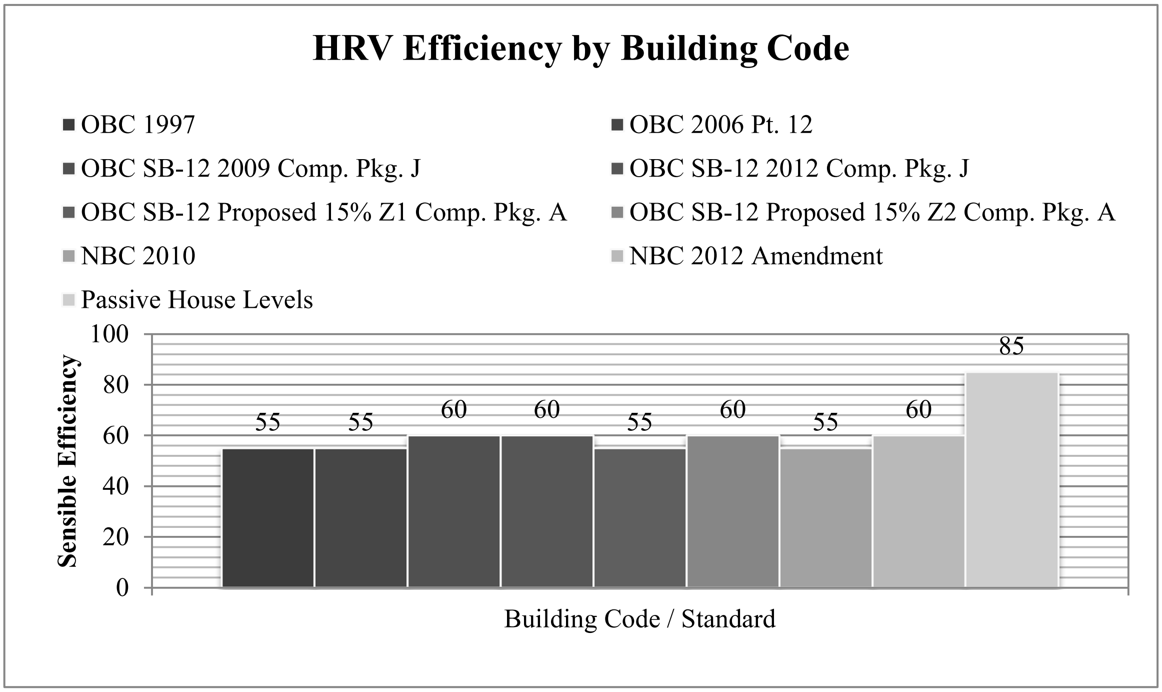


Figure 5-11 - HRV Efficiency By Building Code

5.7.5. Trade-offs

The OBC 2009 and 2012 SB-12 and NBC 2012 amendment include trade-offs for lower thermal resistance requirements for some building envelope components when an HRV is installed. The installation of an HRV in the OBC SB-12 2009 and 2012 results in a trade-off of lower thermal resistance values for above- and below-grade walls, as well as higher heat transfer coefficients for windows and higher furnace efficiencies. A small decrease in the thermal resistance of above grade walls is observed in the NBC 2012 when an HRV is installed in Zone 1; in Zone 2 installing an HRV lowers thermal resistance requirements for the roof, above grade walls, and slab. It is assumed that the trade-offs are meant to ensure a minimum energy performance level is met while taking into account the cost of installing the HRV. Emphasis should first be on a high-performance building envelope and second on high efficiency HVAC system for two primary reasons. The building envelope typically has the longest life cycle of all building elements and the least likely to be prioritized for retrofit by homeowners, as it is perceived having a low return on investment, with potential cost savings not easily identifiable. A highly insulated building envelope will also reduce the heating and cooling demand of the building, resulting in less use of heating and cooling systems. The cost savings from reduced use may be greater than the cost saving from installing higher efficiency equipment.

5.7.6. Summary

Overall, energy consumption varied between the versions of the Canadian building codes and Passive House Standard levels. Significant improvements in average space heating energy use are evident over the last four editions of OBC thermal requirements for residential buildings. Table 5-10**,** Table 5-11**,** Table 5-12**,** and Table 5-13 show the percent difference in annual heating energy consumption between each of the building codes.

Table 5-10 – Percent Increase in Heating Energy Consumption - Zone 1 No HRV

	Percent Increase Over Code						
	OBC 1997	**OBC 2006**	**OBC 2009**	**OBC 2012**	**NBC 2010**	**NBC 2012 Amendment**	**Passive House Levels**
OBC 1997	-	137%	164%	178%	120%	151%	652%
OBC 2006	73%	-	120%	129%	87%	110%	475%
OBC 2009 SB-12	61%	84%	-	108%	73%	92%	396%
OBC 2012 SB-12	56%	77%	93%	-	68%	85%	367%
NBC 2010	83%	114%	137%	148%	-	126%	543%
NBC 2012 Amendment	66%	91%	109%	118%	80%	-	432%
Passive House Levels	15%	21%	25%	27%	18%	23%	-

Table 5-11 - Percent Increase in Heating Energy Consumption - Zone 1 With HRV

	Percent Increase Over Code							
	OBC 1997	**OBC 2006**	**OBC 2009**	**OBC 2012**	**OBC Proposed 15%**	**NBC 2010**	**NBC 2012 Amendment**	**Passive House Levels**
OBC 1997	-	141%	155%	168%	162%	122%	172%	1393%
OBC 2006	71%	-	110%	119%	115%	87%	122%	990%
OBC 2009	65%	91%	-	109%	105%	79%	111%	900%
OBC 2012	60%	84%	92%	-	96%	73%	102%	829%
OBC Proposed 15%	62%	87%	96%	104%	-	75%	106%	861%
NBC 2010	82%	115%	127%	138%	133%	-	141%	1142%
NBC 2012 Amendment	58%	82%	90%	98%	94%	71%	-	812%
Passive House Levels	7%	10%	11%	12%	12%	9%	12%	-

Table 5-12 - Percent Increase in Heating Energy Consumption - Zone 2 No HRV

	Percent Increase Over Code						
	OBC 1997	**OBC 2006**	**OBC 2009**	**OBC 2012**	**NBC 2010**	**NBC 2012 Amendment**	**Passive House Levels**
OBC 1997	-	131%	138%	149%	123%	145%	552%
OBC 2006	77%	-	106%	114%	94%	111%	423%
OBC 2009 SB-12	72%	94%	-	108%	89%	105%	399%
OBC 2012 SB-12	67%	88%	93%	-	83%	97%	371%
NBC 2010	81%	106%	112%	121%	-	117%	448%
NBC 2012 Amendment	69%	90%	96%	103%	85%	-	381%
Passive House Levels	18%	24%	25%	27%	22%	26%	-

Table 5-13 - Percent Increase in Heating Energy Consumption - Zone 2 With HRV

	Percent Increase Over Code							
	OBC 1997	OBC 2006	OBC 2009	OBC 2012	OBC Proposed 15%	NBC 2010	NBC 2012 Amendment	Passive House Levels
OBC 1997	-	131%	154%	156%	160%	126%	188%	906%
OBC 2006	76%	-	118%	119%	122%	96%	144%	691%
OBC 2009	65%	85%	-	101%	104%	82%	122%	588%
OBC 2012	64%	84%	99%	-	102%	80%	120%	580%
OBC Proposed 15%	63%	82%	97%	98%	-	79%	118%	567%
NBC 2010	80%	104%	123%	124%	127%	-	150%	721%
NBC 2012 Amendment	53%	70%	82%	83%	85%	67%	-	481%
Passive House Levels	11%	14%	17%	17%	18%	14%	21%	-

For the OBC, the largest improvements occurred in climate zone 1 between the 1997 Part 9 requirements and 2006 Part 12 requirements. Zone 2 showed slightly smaller improvements. Slight improvements in heating energy consumption are also observed between the 2006 Part 12 requirements and the 2009 SB-12 requirements, for both climates zones. This can be attributed to increases in prescriptive thermal resistance values for the building envelope components, increased performance requirements for glazing, and improvements in air tightness.

The smallest improvements occur between the 2009 and 2012 SB-12 simulations, in both climate zones. This improvement can be attributed to the increase in assumed air leakage rate achieved (3.1 to 2.5 ACH_{50}). The proposed compliance packages for the OBC 15% increase did not achieve substantial savings, with Zone 1 actually consuming 4% more energy and Zone 2 consuming 2% less than the OBC 2012 SB-12.

Significant variations occur between the modelled space heating energy use of the OBC and NBC, particularly the two most recent editions of each code. The simulation results for the space heating energy use of the 2010 NBC are nearly equal to those of the OBC 2006 Part 12 results for both of the climate zones. The 2012 amendment to the NBC performed better than the 2012 OBC SB-12 in both climate zones with an HRV, however consumed more energy without an HRV in both climate zones

Passive House levels simulations reveal a significant gap in space heating energy use over the 2012 OBC SB-12, the OBC 15% increase, and the 2012 NBC amendment. The substantial reduction in energy use for space heating can be attributed to a combination of higher insulation values, better performing windows, and increased air tightness (Figure 5-6, Figure 5-7, Figure 5-8, and Figure 5-9).

The simulation results support the position for increased prescriptive levels for each of the target areas. Though the OBC 2012 SB-12 and NBC 2012 amendment are moving towards improving energy performance, a substantial gap remains between the energy performance of the single family homes in the current building stock and that of a home built to Passive House Standard levels. For opaque surfaces, particular attention should be focused on roof and below grade walls/slab, as well as stating requirements as effective values. Improving the performance of glazing will also be key, as glazing is the weakest point of thermal resistance in the building envelope. The most important area for reducing heating and cooling energy consumption will be requirements for maximum whole building air leakage rates and verification by blower door test.

6. Development of Tiered Framework of Performance Targets

6.1. Definition of optimal energy performance

In the context of this research, optimal energy performance is defined as a building whose annual heating energy consumption is at a level equal to the renewable share of the Ontario energy supply mix based on 2012 data (approximately 20%) [9, 11]. The energy performance of the proposed building will be measured the energy simulation results of the same building design modelled to the OBC 2012 SB-12 Compliance Package J requirements. A residential building reducing heating demand to a level of optimal energy performance would assist in bringing the overall energy demands of the building closer to achieving net-zero grid capacity as the amount of thermal energy consumed by the building would be within the current grids renewable supply capacity.

In comparison to Passive House, which implicitly states a numeric target that must be met to achieve certification (primary energy consumption of 120 kWh/m^2/year and a heating demand of 15kWh/m^2/year), this definition of optimal energy performance is not linked to a specific numeric target. This was done for two reasons:

1. Linking the definition to the 2012 renewable share of the energy supply mix rather than a specific numeric target ensures that definition does not allow for an increase in heating energy consumption as the share of renewables in the energy supply mix increases.
2. The absence of a specific numeric target accounts for variations in climate as well the impact of the building's design on thermal energy consumption (for example size, orientation, window-wall ratio, etc.).

6.2. Analysis of Existing Metrics and Levels

6.2.1. Opaque Surfaces

Thermal insulation requirements in the NBC do not include specific performance metrics although requirements state insulation is required in the building envelope [16] . The ratio of outboard to inboard thermal resistance does not emphasize the importance of insulation in the energy performance of a building. The ratio calculation is not straightforward nor does it promote higher RSI-values in residential buildings. However, the 2012 amendment to the NBC outlines thermal insulation requirements per component and the values stated are for effective RSI values, which acknowledges, to some extent, the impact of thermal bridging. Stating requirements as specific RSI-values based on component and climate will also promote greater consistency between the building codes.

The OBC thermal requirements for the building envelope are separated by component (ex. above grade or below grade wall, ceiling, etc.). Thermal resistance values for compliances packages in the OBC are for the thermal insulation component only, and are based on the location of the building (for HDD zone), efficiency of the space heating equipment, and heating energy source. The format of the OBC energy performance requirements are easy to understand and account for differences in capital cost. Based on the selected compliance package, trade-offs are permitted between higher efficiency HVAC equipment and reduced thermal insulation in the envelope. Although capital cost is a deciding factor in the design and construction of buildings, the requirements need to promote conservation and long-term life cycle cost savings. More emphasis on the promotion of the building envelope will reduce overall heating demand throughout the life of the building. Homeowners are also less likely to upgrade the building envelope than HVAC equipment, as envelope upgrades are more intrusive.

Stating building envelope requirements by component also recognizes the magnitude of loss varies across the building envelope. For example, heat loss vertically through a ceiling with an attic space is greater than through above grade walls, and thus warrants a higher thermal resistance requirement. The OBC also state requirements as nominal RSI values. Moving towards requirements for effective RSI values considers the impact thermal bridging, and recognizes the influence framing can have on the thermal performance of the building envelope. Stronger consideration is needed of thermal bridging in OBC requirements.

The Passive House Standard emphasizes overall building envelope performance, stating a recommended maximum thermal heat loss coefficient that applies to the entire building envelope and is generally thought to be specific to the central European climate. As this standard is a performance based standard, there is no specific path to achieve certification. However, the aggressive nature of the prescribed performance targets and the rigour of achieving certification typically result in an optimized building design, balancing building envelope thermal resistance levels with HVAC design, solar gains and internal loads. The Passive House standard also recognizes thermal bridging is a significant obstacle to reducing heating energy demand, which is an issue not thoroughly addressed in current Canadian building codes. Passive House certified are encouraged to be "thermal bridge free", that is a linear heat loss coefficient of less than 0.1 W/m-K anywhere throughout the envelope. In contrast, the NBC and OBC do not have specific requirements addressing thermal bridging. Reducing thermal bridging is essential to significantly reducing heating energy consumption.

6.2.2. Glazing

U-value requirements for glazing were included in both codes and Passive House. Secondary metrics for glazing units varied. The NBC 2010 uses TI as the secondary metric, however this metric is intended to predict condensation and frost potential and does not directly measure the energy performance of a glazing system. The Passive House Standard states solar transmittance (similar to SHGC) as its secondary metric, which does not fully evaluate the energy performance of a glazing system, but rather contributes to the whole-building energy balance. The ER metric prescribed by the OBC is a more comprehensive metric that specifies glazing energy performance. The ER calculation accounts for factors such as radiation, convection, and conduction across the unit as well as SHGC, U-factor, and air leakage. Additionally, glazing systems available on the Canadian market are labelled with their ER value. Use of both U-value and ER as metrics for glazing requirements provides a more comprehensive evaluation of the energy performance of glazing units.

6.2.3. Air Tightness

Ensuring a building achieves low air leakage levels enhances the thermal comfort of occupants while reducing heating and cooling energy costs as conditioned air is not lost to the exterior and unconditioned exterior air does not infiltrate into the building. It is also a key factor in the long-term durability of the building envelope as it minimizes the potential for moisture problems within the envelope cavities. The NBC states air leakage rates for materials and components, rather than a value for the whole building as both the OBC and Passive House Standard do. Air leakage is linked to construction detailing and whole-house performance. The air leakage characteristics of a specific material used in building envelope is a single aspect of a holistic approach. Focusing on air permeance of materials only does not guarantee minimal air leakage through the building envelope. Though the 2009 OBC SB-12 included detailing requirements focused on controlling air leakage, these were removed from the 2012 version.

Certified Passive House Standard designs illustrate that construction detailing is fundamental in achieving an airtight building envelope and the air leakage level required for certification. Passive House certification requires air leakage rates are verified through testing by an approved third-party. Verification is not required for the OBC's Compliance Package method and the Performance Compliance Method only requires verification if air leakage values input for the energy simulation are less than the assumed air leakage of 2.5 ACH_{50}. Introducing a requirement for verification of whole building air leakage rates in both the NBC and OBC would have a significant impact on the energy performance of residential buildings.

6.2.4. HVAC

Requirements for increased air tightness will reduce demand on mechanical heating and ventilation systems, thus reducing the overall energy demand of the building. High efficiency furnaces are already a requirement in both the OBC and NBC. However, highly insulated building envelopes will reduce heating demand and furnace efficiency will be less important. As levels of air tightness increase, HRV's will be a required component of HVAC systems. HRV's are required in some OBC SB-12 compliance packages, but not all because of trade-offs. The NBC does not require HRV installation, but does state a minimum efficiency if one is installed. Well-designed ventilations systems will be necessary to prevent moisture problems and maintain acceptable indoor air quality levels as air tightness levels are increased.

6.3. Identification of Heating Energy Consumption Reduction Target

6.3.1. Overall Reduction Target & Compliance Dates

An overall heating consumption reduction target of 80% by 2030 was identified as a basis for introducing increased prescriptive performance levels into the building code. The level of 80% was identified as this is the minimum reduction in space heating energy consumption that was achieved when the CCHT house was modified to meet the following Passive House requirements: (i) a minimum building envelope thermal resistance of RSI 6.67 $W/m^2 \cdot K$, (ii) minimum glazing heat transfer coefficient of 0.8, and (iii) a maximum air leakage level of 0.6 ACH_{50} [36, 48]. The current energy supply mix includes approximately 20% from renewable sources, [11], therefore by reducing current consumption levels by 80% allows the remaining 20% of energy demanded to be supplied by renewable sources. Therefore, by reducing space heating energy consumption by 80%, Ontario residential homes would be net-zero grid ready and achieve optimal energy performance, as defined in Section 6.1.

The goal date of 2030 was selected considering several factors. The first is that is coincides with the current end date of Ontario's Long-Term Energy Plan. The second is the mandatory EU Directive 2010/31/EU concerning building performance, which includes a requirement for all buildings in member states to be net-zero energy by 2020, a date which would be unrealistic for Ontario to achieve the same target. The third factor is that 2030 is also the date the State of Massachusetts has targeted for all new buildings to be nearly net-zero [5]. Finally, the OBC has published requirements in the new 2012 code stating that energy efficiency requirements will be increased by 15% as of January 1, 2017. It is anticipated that implementing the reduction targets will be met with resistance since Ontario consumers pay lower energy prices compared to the EU. The mandatory compliance date of 2030 (giving an additional 10 years over the EU target date) was selected to ensure success in meeting the reduction targets, allowing time for adequate education and training of stakeholders in the residential construction industry.

6.3.2. Development of Tiered Performance Target Framework

A tiered framework was developed to assist with the implementation of the proposed increased prescriptive levels (Figure 6-1). The intent of the tiered framework is to introduce the overall 80% reduction target as a broad policy goal which is divided into smaller goals defined by each tier and implemented incrementally by mandatory compliance dates. Each tier defines a smaller reduction target to allow time for stakeholders to become familiar with the targets and overall consumption reduction goal, as well as develop and refine the construction methods and detailing required to achieve the target goals [28, 59, 60]. A mandatory compliance date for meeting the tier performance targets ensures that builders are meeting building code requirements. Tier compliance dates would also act as checkpoints to review target compliance and allow opportunities for policy review [61, 62]. Introducing all four tiers and the overall consumption reduction target at the same time allows designers and builders time to adopt and perfect the designs and methods needed to meet the tier targets while also informing them of future targets, thus giving the option to meet higher targets of mandatory compliance dates. Proposals for incentives to encourage designing and building to higher tier levels will be included in the policy implementation strategy.

6.3.3. Implementation of Tiered Framework

Four tiers were created, each representing a percentage reduction on space heating energy consumption, and thus establishing a heating demand target. The initial energy modelling (Section 5.7) assisted in establishing a baseline for the recommendations to increase prescriptive performance levels in the OBC, using the 2012 SB-12 Compliance Package J requirements as the baseline for both climate zones. This compliance package was selected as the baseline as it was found to be the most commonly used package by builders [53] and it also has a requirement for the installation of an HRV (with a minimum efficiency rating of 60%), a necessary component of the mechanical system in the Passive House's due to its low air leakage rates.

A proposed design would first be modelled to compliance package J requirements to identify the heating demand targets that subject design must meet. The CCHT house modelling results for secondary heating energy consumption were used as the baseline for the tier targets.

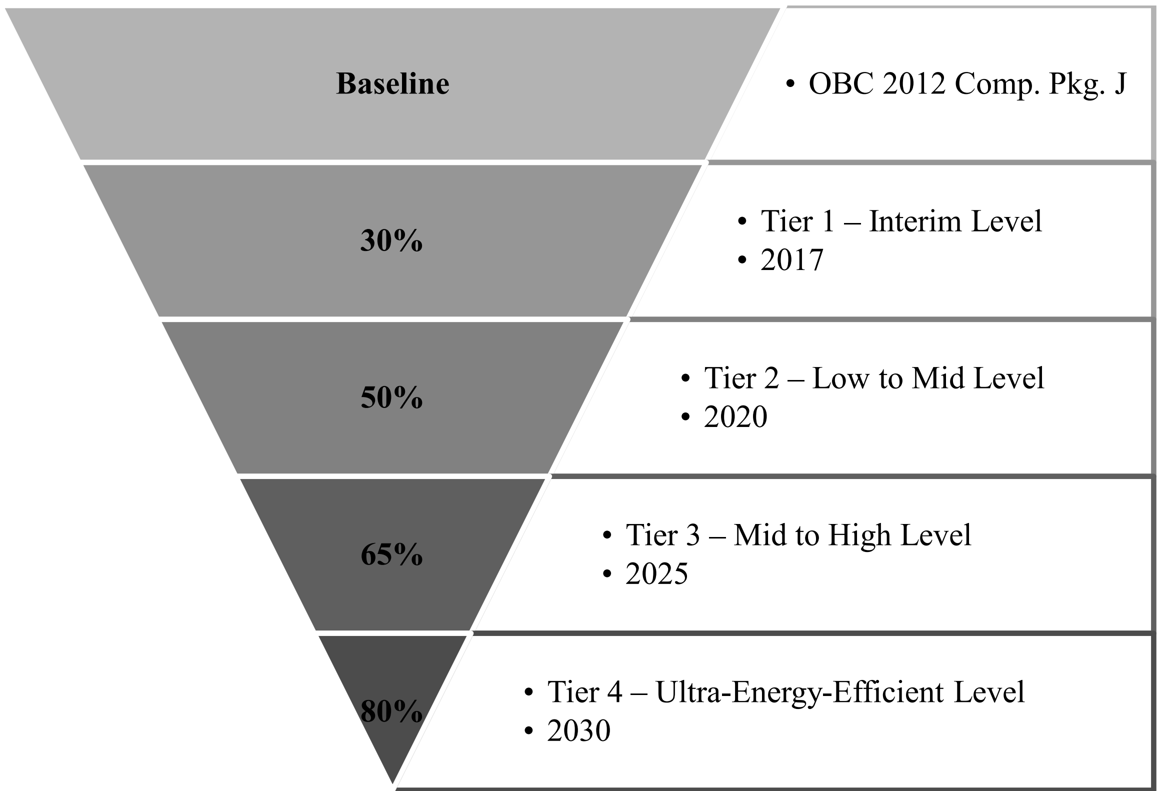


Figure 6-1 - Tier Framework for Energy Performance Targets and Mandatory Compliance Dates

Tier 1 has the greatest percent reduction, with a 30% reduction target mandatory by 2017, which is double the 15% increase in energy efficiency currently proposed by the OBC by the same date. Tier 2 has a 50% reduction target (20% more than Tier 1) mandatory by 2020. The reduction target for Tier 3 is 65% (15% more than Tier 2) mandatory by 2025. The Tier 4 reduction target is 80% (15% more than Tier 3), the ultra-energy-efficient level, achieves optimal energy performance (as defined in Section 6.1), and would be mandatory by 2030. As tier targets become mandatory, the construction methods and design details required to achieve compliance will become routinely used within industry.

6.3.4. Compliance Package Development for Tier Performance Target Compliance

A sample compliance packages for each tier was created for both Ontario climate zones. The compliance packages developed show each of the tier targets is achievable using standard construction materials and products currently available on the market.

The heating energy consumption target for each tier was determined by multiplying the results of the CCHT house modelled to OBC 2012 Compliance Package J requirements by each tier consumption target.

Tier Heating Energy Consumption Target Calculation

Annual Heating Energy Target (kWh/m^2/year) = $Q_B * (1 - Q_T)$ (Equation 3)

Where,

Q_B = Baseline Heating Energy Consumption (OBC 2012 Compliance Package J)

Q_T = Tier Heating Energy Reduction Percentage

The proposed compliance packages use a framework similar to 2012 SB-12 compliance packages and focus on the target areas identified in the initial review of the building code: opaque and glazed surfaces, HVAC, and air tightness. Table 6-1 and Table 6-2 list performance metric levels for each target area for Zone 1 and 2.

Table 6-1 - Zone 1 Compliance Package Performance Metric Levels

Component	Baseline*	Tier 1	Tier 2	Tier 3	Tier 4
Roof (RSI)**	9.85	9.64	13.63	16.16	24.62
Above Grade Wall (RSI)**	3.29	4.98	5.83	7.90	13.49
Below Grade Wall (RSI)**	2.16	3.40	5.10	6.05	10.28
Slab (RSI)**	0.00	2.54	2.54	2.54	10.16
Exposed Floor (RSI)**	5.46	5.46	6.28	6.28	6.28
Windows (U-Value)	1.59	1.31	1.19	0.80	0.60
Furnace Efficiency (AFUE)	0.95	0.97	0.97	0.97	0.97
HRV Efficiency (Sensible)	0.60	0.66	0.70	0.75	0.81
Max. Air Leakage Rate (ACH_{50})	2.50	2.00	1.50	1.00	0.60

* OBC 2012 Compliance Package J
** Effective RSI value (W/m^2·K), insulation only

Table 6-2 - Zone 2 Compliance Package Performance Metric Levels

Component	Baseline*	Tier 1	Tier 2	Tier 3	Tier 4
Roof (RSI)**	9.85	9.64	13.63	21.02	24.62
Above Grade Wall (RSI)**	3.88	4.98	9.59	11.57	13.49
Below Grade Wall (RSI)**	2.16	3.4	8.20	7.51	10.28
Slab (RSI)**	0.00	2.54	3.39	8.89	10.16
Exposed Floor (RSI)**	5.46	5.46	6.28	6.28	6.28
Windows (U-Value)	1.59	1.31	1.19	0.80	0.60
Furnace Efficiency (AFUE)	0.95	0.97	0.97	0.97	0.97
HRV Efficiency (Sensible)	0.60	0.66	0.70	0.75	0.81
Max. Air Leakage Rate (ACH_{50})	2.50	2.00	1.50	1.00	0.60

* OBC 2012 Compliance Package J
** Effective RSI value ($W/m^2 \cdot K$), insulation only

Glazing U-values, furnace and HRV efficiencies, and air leakage rates were first identified for each tier. Both glazing U-value's and HRV efficiency requirements were increased incrementally, using the requirements from the baseline (OBC Compliance Package J) and the Passive House Standard. Performance levels selected for both glazing units and HRV's are based on those currently available on the market [63]. Tier air leakage levels were also increased incrementally, using the baseline (OBC Compliance Package J) and Passive House Standard requirements as guidelines.

The furnace efficiency was kept constant for each tier level for three reasons: (i) high performance natural gas furnaces are routinely used in residential homes, (ii) the highest efficiency available on the market today is 97.1% and thus there is less potential for advancement in efficiency than other building components and systems, and (iii) the performance targets will require higher RSI values for the building envelope, thus reducing heating demand and furnace use. As well, the installation of an HRV, which is required for each tier, will further reduce the demand on the furnace. The efficiency was selected based on the highest performing unit currently available on the market [63].

Thermal resistance levels for opaque surfaces were derived from the baseline OBC levels and the Passive House levels. The CCHT House was simulated in EnergyPlus using the levels identified for the glazing U-value, HVAC and HRV efficiency's, and air leakage requirements for Tier 1 and the baseline thermal resistance levels. This identified the gap between actual heating energy consumption and the tier target. Thermal resistance values for the building envelope were increased and simulated until the Tier 1 target was met.   This same process was used for tiers 2 and 3, with thermal resistance values of the previous tier increased to meet space heating energy consumption targets. Tier 4 levels were based on the Passive House One home in Toronto that was designed to meet Passive House Standard levels [54]. Assemblies for Zone 1 compliances packages are listed in Table 6-3**.** A list of both Zone 1 and 2 compliance package assemblies are listed in Appendix E.

Table 6-3 -Tier Compliance Packages Zone 1

Assembly Type	Description Baseline	Tier 1	Tier 2	Tier 3	Tier 4
Above Grade Walls	100mm brick	100mm brick	100mm brick	100mm brick	100mm brick,
	20mm airspace	20mm airspace	20mm airspace	20mm airspace	20mm airspace
	16mm OSB	50.8mm XPS	76.2mm XPS	16mm OSB	16mm OSB
	38 x 140 x 405mm O.C. with Mineral Wool Insulation (mid-density)	16mm OSB	16mm OSB	38 x 89 x 405mm O.C. with Mineral Wool Insulation (mid-density)	38 x 140 x 405mm O.C. with Mineral Wool Insulation (mid-density)
	6 mil poly	38 x 140 x 405mm O.C. with Mineral Wool Insulation (mid-density)	38 x 140 x 405mm O.C. with Mineral Wool Insulation (mid-density)	140mm Mineral Wool insulation (mid-density) Cavity	292 mm Mineral Wool insulation (mid-density) Cavity (89mm + 203mm Batt)
		6 mil poly	6 mil poly	38 x 89 x 610mm O.C. with Mineral Wool Insulation (mid-density)	38 x 89 x 610mm O.C. with Mineral Wool Insulation (mid-density)
	12.7mm Gypsum	12.7mm Gypsum	12.7mm Gypsum	6 mil poly	6 mil poly
				12.7mm Gypsum	12.7mm Gypsum
Below Grade Walls	200mm Concrete	200mm Concrete	50.8mm XPS	200mm Concrete	200mm Concrete
	20mm Airspace	20mm Airspace	200mm Concrete	20mm Airspace	20mm Airspace
	38 x 89 x 405mm O.C. with Mineral Wool Insulation (mid-density)	38 X 140 x 405mm O.C. with Mineral Wool Insulation (mid-density)	20mm Airspace	140mm Mineral Batt Insulation (mid-density) Cavity	292mm Mineral Wool insulation (mid-density) Cavity (89mm + 203mm Batt)
	6 mil poly	6 mil poly	38 x 140 x 405mm O.C. with Mineral Wool Insulation (mid-density)	38 x 89 x 405mm O.C. with Mineral Wool Insulation (mid-density)	38 x 89 x 405mm O.C. with Mineral Wool Insulation (mid-density)
	12.7mm Gypsum	12.7mm Gypsum	6 mil poly	6 mil poly	6 mil poly
			12.7mm Gypsum	12.7mm Gypsum	12.7mm Gypsum
Roof	3mm Asphalt Shingles	3mm Asphalt Shingles	3mm Asphalt Shingles	3mm Asphalt Shingles	3mm Asphalt Shingles
	16mm OSB	16mm OSB	16mm OSB	16mm OSB	16mm OSB
	300 mm Blown Cellulose Insulation	300 mm Blown Cellulose Insulation	450 mm Blown Cellulose Insulation	550 mm Blown Cellulose Insulation	900 mm Blown Cellulose Insulation
	38 x 89mm x 610 O.C. Joists with Blown Cellulose	38 x 89 x 610mm O.C. Joists with Blown Cellulose	38 x 89 x 610mm O.C. Joists with Blown Cellulose	38 x 89 x 610mm O.C. Joists with Blown Cellulose	38 x 89 x 610mm O.C. Joists with Blown Cellulose
	12.7mm Gypsum	12.7mm Gypsum	12.7mm Gypsum	12.7mm Gypsum	12.7mm Gypsum
Slab	75mm Concrete	10mil Poly Soil Gas	10mil Poly Soil Gas	10mil Poly Soil Gas	10mil Poly Soil Gas

		Barrier	Barrier	Barrier	Barrier
		76.2mm XPS	76.2mm XPS	76.2mm XPS	304.8mm XPS
		75mm Concrete	75mm Concrete	75mm Concrete	75mm Concrete
Exposed Floor	213mm Blown Cellulose	213mm Blown Cellulose	245mm Blown Cellulose	245mm Blown Cellulose	245mm Blown Cellulose
Windows	1.59 U-value	1.31 U-value	1.19 U-value	0.8 U-value	0.6 U-value
Furnace	96% AFUE	97% AFUE	97% AFUE	97% AFUE	97% AFUE
HRV	60% Sensible Efficiency	66% Sensible Efficiency	70% Sensible Efficiency	75% Sensible Efficiency	81% Sensible Efficiency

Insulation types were kept constant throughout the tiers to maintain consistency in pricing and selected considering environmental impact, where possible. Mineral wool batt insulation was used for both above and below grade wall insulation and was selected as it is readily available and easy to install, has a lower conductivity than fibreglass batt, provides fire resistance, and is made from natural and recycled materials [64]. Extruded polystyrene (XPS) rigid insulation was used on the exterior of the above grade walls in Tiers 1 and 2 for Zone 1, and in Tiers 1 to 3 for Zone 2, as well as underneath the slab for all Tiers in both climate zones. Blown cellulose insulation was used for the roof insulation for its ease of installation and because it can be derived from recycled sources. Framing percentages calculated for the initial energy simulations were used for the single stud wall assemblies (Table 5-4) and framing percentages were calculated for double stud wall assemblies (Appendix E). Roof framing percentages were calculated using the interpolation method utilized in Section 5.5.1.2 (Appendix C).

Final compliance packages were simulated in EnergyPlus to ensure the performance target of each tier was met (Figure 6-2).

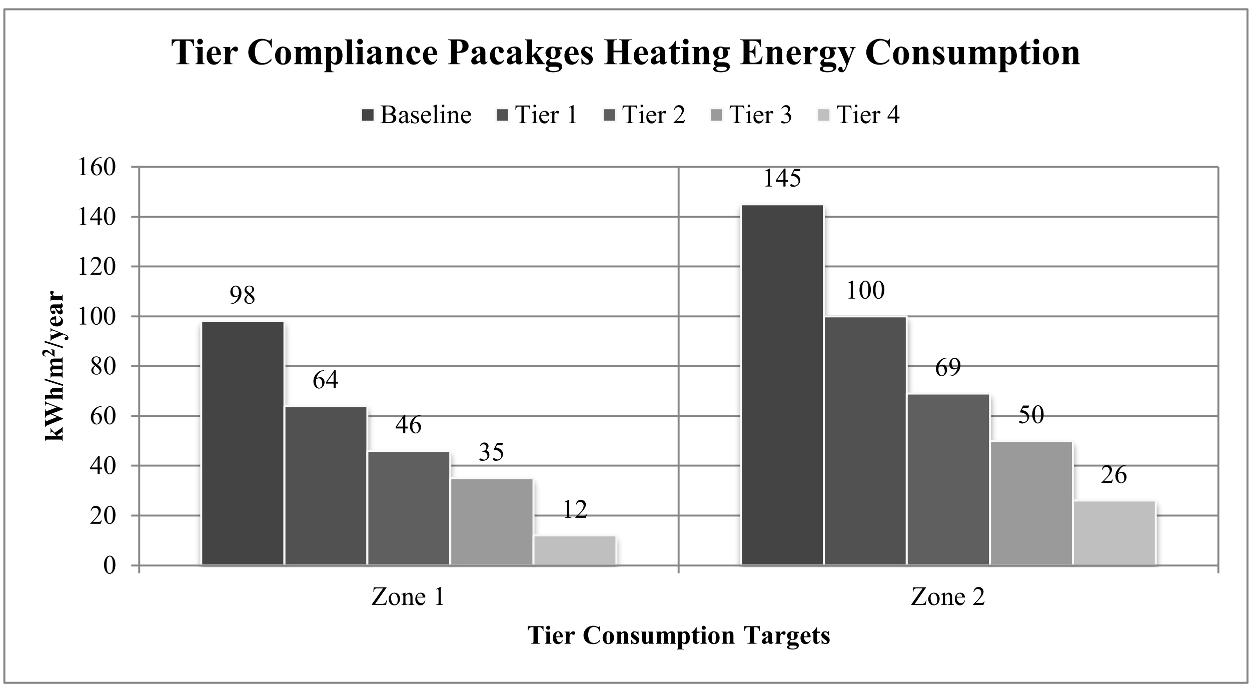


Figure 6-2 – Tier Compliance Package Simulation Results (Baseline = OBC 2012 SB12 Package J)

7. Economic Analysis

A construction cost comparison was performed identifying premiums a sample wall assembly for each of the tier reduction targets in climate zone 1. A simplified economic analysis was then performed identifying a simple payback period and return on investment for constructing to the proposed tier performance levels. Using the same approach as Gray, Richman, and Presnail [65], several fuel escalation rates were identified to examine the impact of future energy price increases on potential energy savings and payback periods. Costs for compliance packages developed for climate zone 2 were not examined as a reliable source for costs could not be secured and available costs were provided were GTA-based rates.

7.1. Cost Comparison

Capital costs were estimated with the assistance of GTA-based suppliers (windows and HVAC equipment) and a GTA-based, large-scale residential tract-home builder (building envelope) using current market rates. Envelope material costs include both supply and labour. Glazing costs are unit prices only, excluding tax and shipping. Glazing prices were identified for the average, minimum, maximum, and medium sizes of the CCHT windows. A cost for each window is determined by its size and the corresponding glazing price. Window costs and calculations are included in Appendix F. Furnace and HRV costs include the system cost and installation.

Total capital costs were calculated for each building envelope component based on the components surface area and cost per square metre. For each tier, a cost per square metre ($\$/m^2$) was calculated for each envelope component as well as for the entire envelope. A cost premium for envelope components and total construction was calculated between the baseline and each tier. Total costs ($) were calculated for all building envelope components, entire envelope, and a total tier.

Costs provided are for a per-project basis. A volume discount is not included for envelope materials costs. If discounts are given, they are negotiated per company, on a per project basis and for specific materials [66]. As most costs are based on union rates, no discount is given based on project scale [66]. For windows, furnaces, and HRV costs, volume discount rates are dependent on the scale of the project [66]. A total cost premium was identified between the tiers. All costs stated were in current dollars (not including inflation).

Table 7-1 – Total Construction Capital Costs (Present Value)

Component	Baseline	Tier 1	Tier 2	Tier 3	Tier 4
Above Grade Wall - $/m^2	$238.15	$267.11	$280.45	$374.53	$395.74
Total Cost	$51,931.32	$58,245.23	$61,155.73	$81,670.07	$86,294.01
Premium - $/m^2		$28.95	$42.30	$136.38	$157.58
Premium - %		12%	18%	57%	66%
Below Grade Wall - $/m^2	$615.59	$607.30	$633.99	$626.35	$637.12
Total Cost	$14,158.52	$13,967.90	$14,581.87	$14,406.09	$14,653.66
Premium - $/m^2		$(8.29)	$18.41	$10.76	$21.53
Premium - %		-1%	3%	2%	3%
Roof - $/m^2	$178.09	$181.32	$187.24	$190.47	$202.85
Total Cost	$23,571.03	$23,998.42	$24,781.99	$25,209.39	$26,847.75
Premium - $/m^2		$3.23	$9.15	$12.38	$24.76
Premium - %		2%	5%	7%	14%
Slab - $/m^2	$75.35	$116.38	$116.38	$116.38	$236.51
Total Cost	$8,050.97	$12,435.88	$12,435.88	$12,435.88	$25,271.43
Premium - $/m^2		$41.04	$41.04	$41.04	$161.16
Premium - %		54%	54%	54%	214%
Exposed Floor - $/m^2	$6.46	$6.46	$8.07	$8.07	$8.07
Total Cost	$176.75	$176.75	$220.94	$220.94	$220.94
Premium - $/m^2	$-	$-	$1.61	$1.61	$1.61
Premium - %		0%	25%	25%	25%
Windows (average) - $/m^2	$450.66	$570.49	$546.95	$613.01	$681.13
Total Cost	$8,973.01	$11,448.00	$12,095.47	$13,895.89	$15,439.87
Premium - $/m^2	$-	$119.84	$96.29	$162.35	$230.47
Premium - %		27%	21%	36%	51%
Furnace	$2,080.00	$3,441.71	$3,441.71	$3,441.71	$3,441.71
HRV	$1,767.00	$2,248.70	$1,898.38	$2,231.75	$2,459.00
Envelope $/m^2	$1,681.03	$1,865.79	$1,889.83	$2,045.55	$2,278.14
Envelope Total Cost ($)	$116,713.53	$131,485.81	$136,485.51	$159,051.89	$179,941.29
Total Cost	$120,560.53	$137,176.22	$141,825.60	$164,725.35	$185,842.01
Difference Over Previous Tier ($)	$-	$16,615.70	$4,649.38	$22,899.75	$21,116.66
%		14%	3%	16%	13%
Difference Over Baseline ($)	$-	$16,615.70	$21,265.08	$44,164.82	$65,281.48
%		14%	18%	37%	54%

Table 7-1 shows the following trends:

- Total costs between the tiers range from a 3% increase in cost between Tiers 1 and 2 and 17% between Tiers 2 and 3.
- Overall, Tier 1 costs the least to implement over the baseline at 14% and Tier 4 the greatest at 54%. The largest component cost increases between the tiers occur in the slab, glazing, and above grade walls, respectively.
- The costliest component in Tier 4 is the slab, whose cost per square metre is double that of Tier 3. The increased cost is a result of the RSI-value required and type of insulation (304.8mm of XPS) used to meet the heating energy consumption target. A more inexpensive option is possible, however the GTA-based developer identified XPS as a method familiar with trades, is simpler to detail, and easier to install.
- Above grade wall costs increased throughout all tiers, with the largest increase occurring between Tiers 2 and 3 where cost increased by nearly one third. The cost increases for this component are as expected due to increasing RSI values.
- Glazing prices also rise incrementally between each of the tiers, in part due to increasing performance.
- HVAC cost increases are small compared to those observed in the building envelope.

As construction methods are refined and use of selected materials and systems becomes commonplace, it is anticipated the materials and labour costs associated with building to these performance targets will decrease, however at this time it is difficult to hypothesize how much reduction will occur and when it will begin.

7.2. Economic Analysis

A simplified economic analysis was performed identifying a simple payback period and first year return on investment for each tier. This approach takes into consideration the shortcomings of the data used, as limited sources were used in identifying the construction costs for the proposed tier performance levels. A complete life cycle cost analysis would provide a more thorough examination, however due to the limitations of the cost data, a more complex analysis is not warranted at this point. A simplified economic analysis was also warranted due to the difficulty and complexity in quantifying the external benefits of reduced heating energy consumption, such as lowered greenhouse gas emissions and decreased demands on provincial energy infrastructure.

Each tier's initial investment amount is based on the tier's additional investment costs over the baseline construction costs. The discount rate is based on the current average mortgage interest rate for a 5-year fixed term mortgage with a 25-year amortization rate and the average historical inflation rate (similar to approaches used by EnerQuaility and Lio & Associates [25]). Annual payments were calculated using the following equation:

Investment Monthly Payments

$$c = \frac{rP}{1-(1+r)^{-N}} = \frac{\Pr(1+r)^{N}}{(1+r)^{N}-1} \quad \text{(Equation 4) [67]}$$

Where:

- r – monthly interest rate (decimal)
- N – number of monthly payments (loan term)
- P – principal investment
- c – monthly payment

The monthly interest rate was based on current market interest rates for a 5-year fixed term mortgage with 25-year amortization period and an average inflation rate based on historical data [68, 69]. Monthly payments were multiplied by 12 to determine total annual payments.

Annual energy costs were calculated for the baseline and tiers based on simulated annual heating energy consumption and current market rates for natural gas and electricity. Natural gas costs are calculated using current rate for gas supply charges. Electricity prices are calculated using a weighted average price based on current cost breakdowns for time-of-day usage. A discount rate of 2% was applied to both costs, based on the average historical inflation rate [69]. Total energy costs are determined for each tier and energy cost savings for each tier was calculated by subtracting each tier's energy costs from the baseline costs (Table 7-4).

Table 7-2 - Ontario Natural Gas Prices - Climate Zone 1 [70]

Charge	**Cost ($/m^3)**
Gas Supply Charge	**0.128548**
Transportation	0.055359
First 30	0.082998
Next 55	0.078377
Next 85	0.074755
Over 170	0.072058
Cost Adjustment	-0.020258
Total Annual Charge	65
Total Annual Adjustment	-6
Average Consumer Cost (Gas Supply Charge & Charge over 170m^3)	0.10

Table 7-3 - Ontario Electricity Prices [71]

	Cost	**Time Frame**	**Total Hours**	**Weight**
On-Peak	$0.118	7-11a; 5-7p	6	0.1775
Mid-Peak	$0.990	11a-5p	6	0.1775
Off-Peak	$0.063	7p-7a; weekends & holidays	12	0.645
Weighted Average Price*	$0.105			

*Weighted Average Price = (On-Peak Cost * Weight)+(Mid-Peak Cost * Weight) + (Off-Peak * Weight)

Table 7-4 – Baseline and Tier Energy Costs and Savings

		Baseline	Tier 1	Tier 2	Tier 3	Tier 4
Annual Heating Energy Use[1]	**Natural Gas (m^3)**	17,009	11,179	8,000	5,957	2,004
	Electricity (kWh)	167	144	129	120	103
Energy Prices	**Natural Gas ($0.10/$m^3$) [2]**	$2,211.14	$1,453.26	$1,040.06	$774.45	$260.46
	Electricity ($0.105/kWh) [3]	$17.54	$15.06	$13.58	$12.62	$10.78
Total Energy Costs		$2,228.68	$1,468.32	$1,053.63	$787.07	$271.24
Total Discounted Energy Costs[4]		$2,273.25	$1,497.69	$1,074.71	$802.81	$276.66
Annual Savings Over Baseline		$-	$775.57	$1,198.55	$1,470.44	$1,996.59
% Savings Over Baseline Energy Costs		0%	34%	53%	65%	88%

1 – Annual heating energy use includes all energy used to heat the building, including all furnace equipment (fans, heating coil, and HRV),
2 – Gas Supply Charge (Table 7-2)
3 – Weighted Average Price (Table 7-3)
4 – Discount Rate = 2% [69]

The annual cash flow calculation is based on the difference between annual energy savings and annual loan payments. Using the annual cash flow and initial investment, a simple payback period and the first year return on investment are calculated.

Table 7-5 - Economic Analysis of Tier Consumption Targets

Indicator	Tier 1	Tier 2	Tier 3	Tier 4
Initial Investment [1]	$16,615.70	$21,265.08	$44,164.82	$65,281.48
Annual Payments [2]	$1,155.17	$1,478.41	$3,070.47	$4,538.57
Annual Energy Cost Savings [3]	$775.57	$1,198.55	$1,470.44	$1,996.59
Annual Cash Flow [4]	$(379.61)	$(279.86)	$(1,600.03)	$(2,541.97)
Simple Payback Period (years) [5]	21.42	17.74	30.04	32.70
Return on Investment (year 1) [6]	4.67%	5.64%	3.33%	3.06%

[1] Additional investment over baseline cost.

[2] Annual investment payments based on 5% discount rate (2.99% 5 year fixed rate mortgage, 25-year term and 2% average historical inflation rate [68, 69]).

[3] Energy Savings are based on the heating energy costs for the subject tier minus the heating energy costs for the baseline (Table 7-4).

[4] Annual Cash Flow = Annual Energy Savings – Annual Payments.

[5] Simple Payback Period = Initial Investment / Annual Energy Savings.

[6] Return on Investment (year 1) = Energy Savings / Initial Investment.

All tiers have a negative cash flow throughout the duration of the amortization period. Tier 2 has the shortest payback period (just under 18 years) and largest return on investment in the first year. Despite the largest energy cost savings, Tier 4 has the longest payback period (just under 33 years) and lowest return on investment due to the high initial investment. Based on the compliance packages developed and the results of the economic analysis, Tier 2 performance levels appear the most cost effective of the four targets at this time. However, the economic analysis does not take into consideration potential increases to energy costs or account for decreased cost premiums as builders and contractors gain knowledge and experience constructing to the proposed performance levels.

Perceived risk and lack of experience were contributing factors to increased costs of building to the proposed performance levels. Although innovation leads to reduced costs, increased functionality, and growing market shares, its precise impact is difficult to quantify. Building code requirements are a significant driver of innovation and will encourage the development cost effective, code compliant building methods. Mandatory reduction targets will provide the means to force diffusion of energy efficient building products and methods at a rate faster than that dictated solely by the market. Predicting the costs to implement the higher performance targets at their future compliance dates is difficult, however it is a reasonable assumption that costs will decrease as appropriate products and construction methods become common practice.

7.3. Analysis of Future Energy Cost Increases

A series of analyses were performed showing the impact increasing energy prices and estimated future energy cost savings on tier investment paybacks. Three fuel escalation rates were identified to predict future energy costs for the baseline and four tiers based on current energy prices. Fuel escalation rates were based on those identified by the National Energy Board [72] and Ontario Ministry of Energy [2] and rounded to the nearest 0.5%. An inflation rate of 2% is used based on historical inflation rates identified by the Bank of Canada [69].

A simplified economic analysis was performed for each tier showing a simple payback period for all identified fuel escalation rates. Energy savings are plotted over a 40-year period for the baseline and each tier for the three fuel escalation rates. A 40-year period is examined with the assumption that no major building envelope upgrades would be required during this period.

Table 7-6 - Fuel Escalation and Inflation Rates

	Low	Mid	High
Fuel Escalation Rate	1.5%	3.5%	5.5%
Inflation Rate	2%	2%	2%

Table 7-7 – Simplified Economic Analysis of Tier Reduction Targets -1.5% Fuel Escalation Rate

Indicator	Tier 1	Tier 2	Tier 3	Tier 4
Initial Investment [1]	$16,615.70	$21,265.08	$44,164.82	$65,281.48
Total Investment Payments [2]	$28,879.33	$36,960.30	$76,761.78	$113,464.13
Total Energy Cost Savings [3]	$30,208.24	$46,683.25	$57,273.59	$77,766.98
Total Cash Flow [4]	$1,328.91	$9,722.95	$(19,488.20)	$(35,697.15)

[1] Additional investment over baseline cost.

[2] Annual investment payments based on 2.99% 5 year fixed rate mortgage, 25-year term and 2% average historical inflation rate [68, 69].

[3] Total Energy Savings are based on the heating energy costs for the subject tier minus the heating energy costs for the baseline (Table 7-4). Current Rates for natural gas and electricity were used to calculate energy costs (Table 7-2 and Table 7-3 Energy Costs savings also include a 2% inflation rate in addition to the fuel escalation rate.

[4] Total Cash Flow = Total Energy Savings – Total Payments

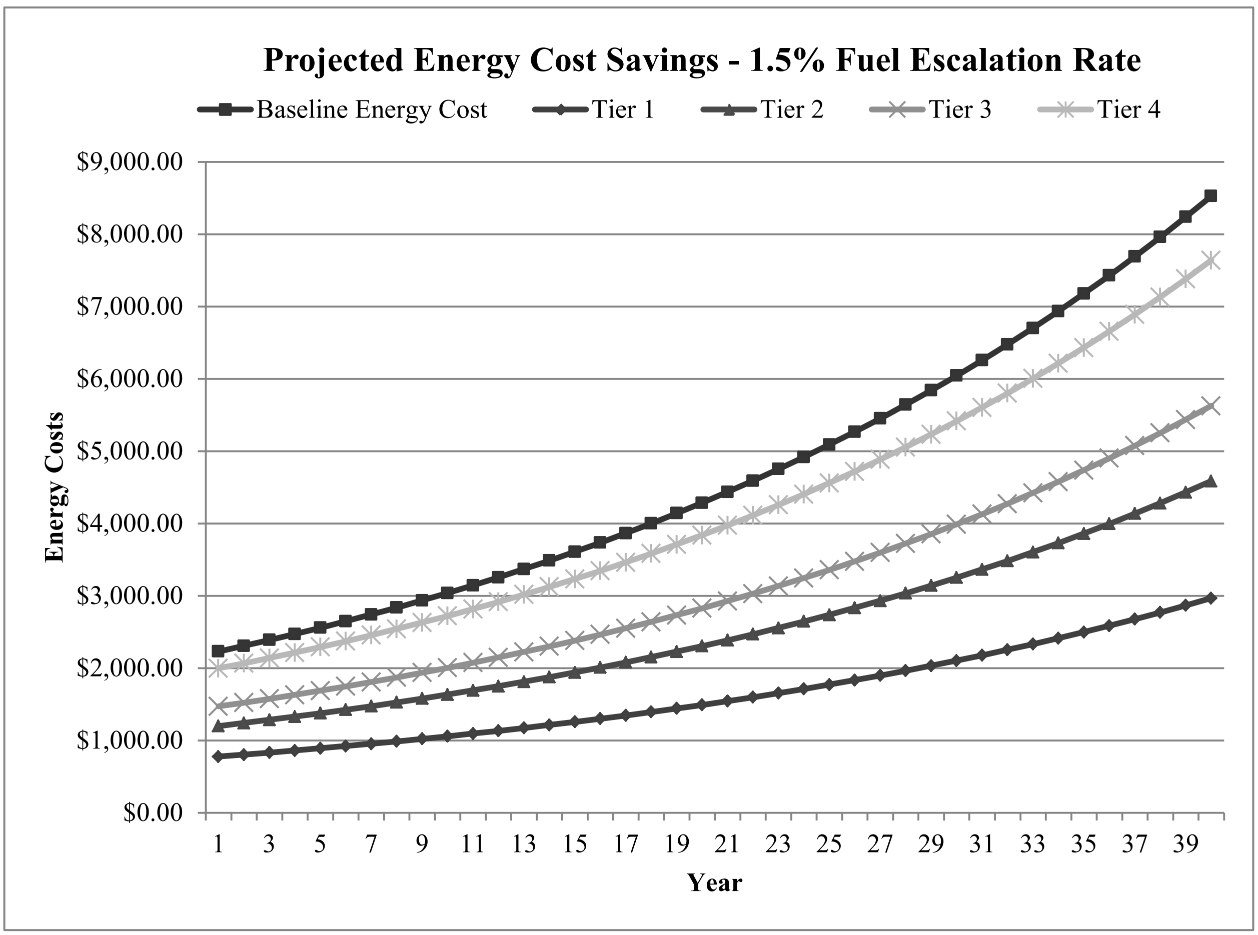


Figure 7-1 - Projected Energy Cost Savings - 2.0% Inflation Rate, 1.5% Fuel Escalation Rate

Table 7-8 – Simplified Economic Analysis of Tier Reduction Targets - 3.5% Fuel Escalation Rate

Indicator	Tier 1	Tier 2	Tier 3	Tier 4
Initial Investment[1]	$16,615.70	$21,265.08	$44,164.82	$65,281.48
Total Investment Payments[2]	$28,879.33	$36,960.30	$76,761.78	$113,464.13
Total Energy Cost Savings[3]	$39,672.28	$61,308.81	$75,217.02	$102,130.86
Total Cash Flow[4]	$10,792.95	$24,348.51	$(1,544.76)	$(11,333.27)

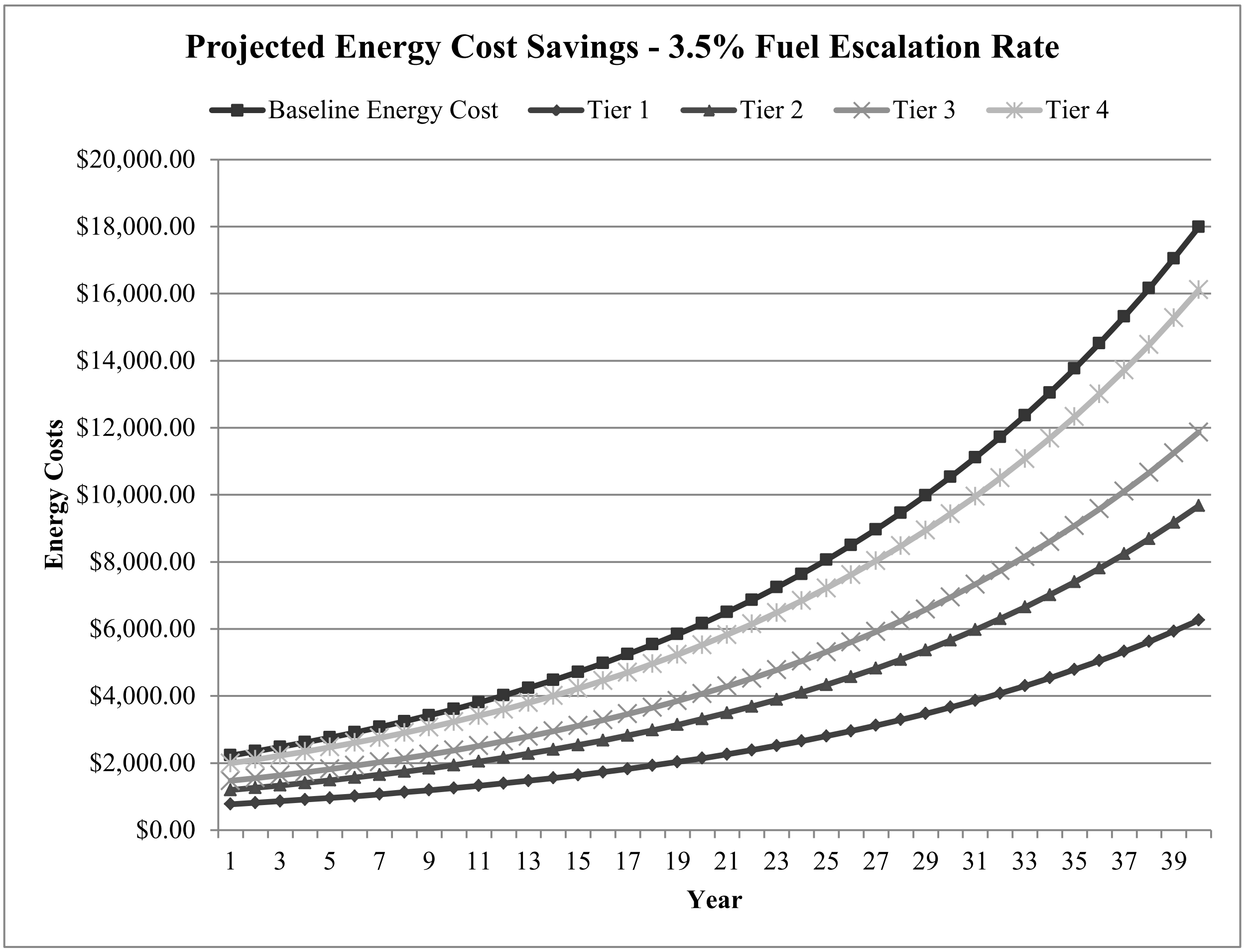


Figure 7-2 - Projected Energy Cost Savings - 2.0% Inflation Rate, 3.5% Fuel Escalation Rate

Table 7-9- Simplified Economic Analysis of Tier Reduction Targets - 2.0% Inflation Rate, 5.5% Fuel Escalation Rate

Indicator	Tier 1	Tier 2	Tier 3	Tier 4
Initial Investment [1]	$16,615.70	$21,265.08	$44,164.82	$65,281.48
Total Investment Payments [2]	$28,879.33	$36,960.30	$76,761.78	$113,464.13
Total Energy Cost Savings [3]	$52,721.41	$81,474.70	$99,957.64	$135,724.07
Total Cash Flow [4]	$23,842.08	$44,514.40	$23,195.86	$22,259.94

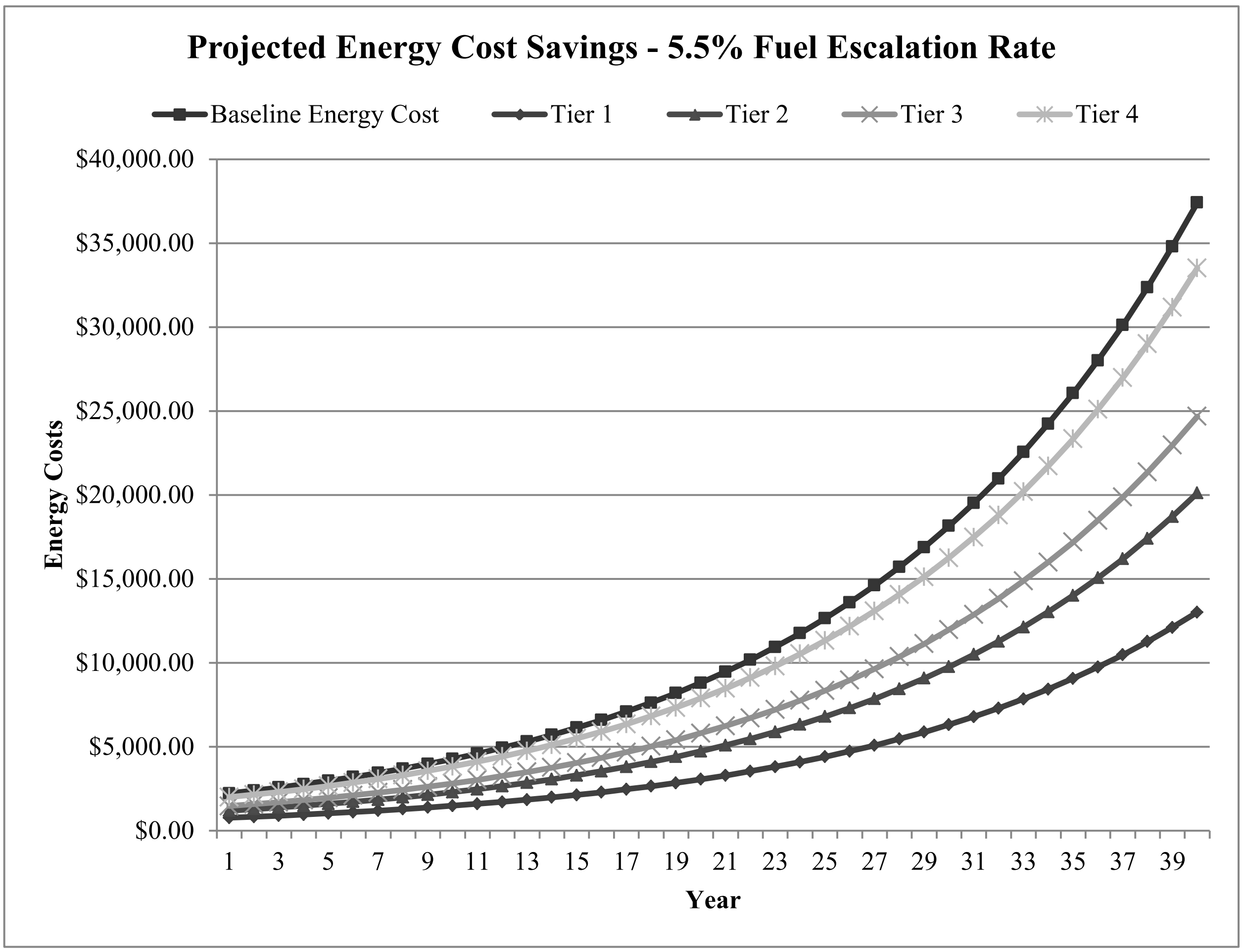


Figure 7-3 - Projected Energy Cost Savings - 2.0% Inflation Rate, 5.5% Fuel Escalation Rate

Tier 2 remains cost effective, with the largest return on investment for each fuel escalation rate and shortest payback periods. However, even a low fuel escalation rate of 1.5% significantly reduces the payback period (just under 29 years) for Tier 4. Looking at energy savings beyond the payback period, Tier 4 achieves the greatest annual increase in energy cost savings (Figure 7-4, Figure 7-5, Figure 7-6, Figure 7-7, and Figure 7-8). Tier 4 becomes more economical as fuel prices increase and returns increase in correlation to energy prices. As well, the simplified economic analysis does not account for external costs associated with energy consumption, and therefore does not include those associated costs and savings that may be achieved in addition to energy cost savings.

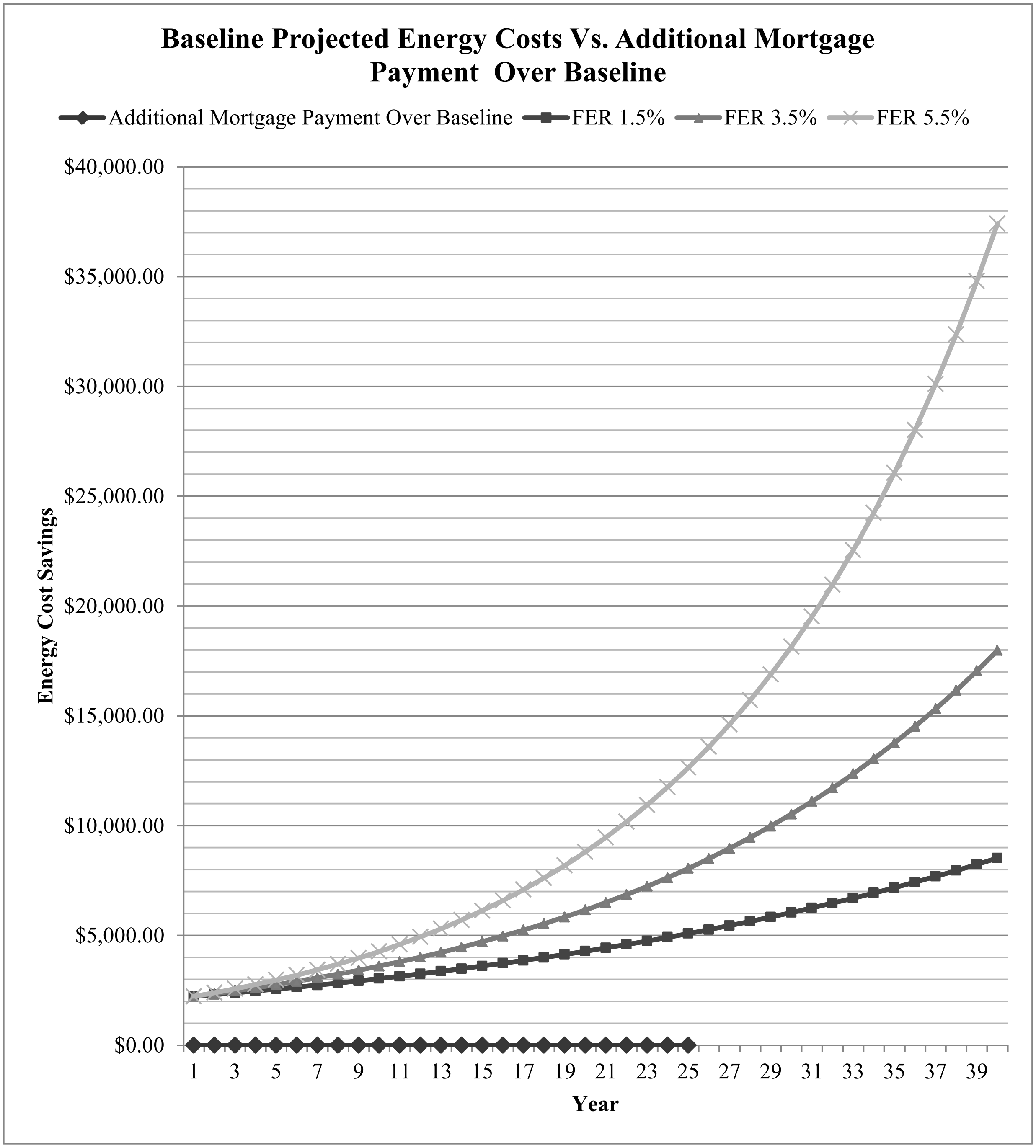


Figure 7-4 – Baseline Projected Energy Costs Vs. Additional Mortgage Payment Over Baseline

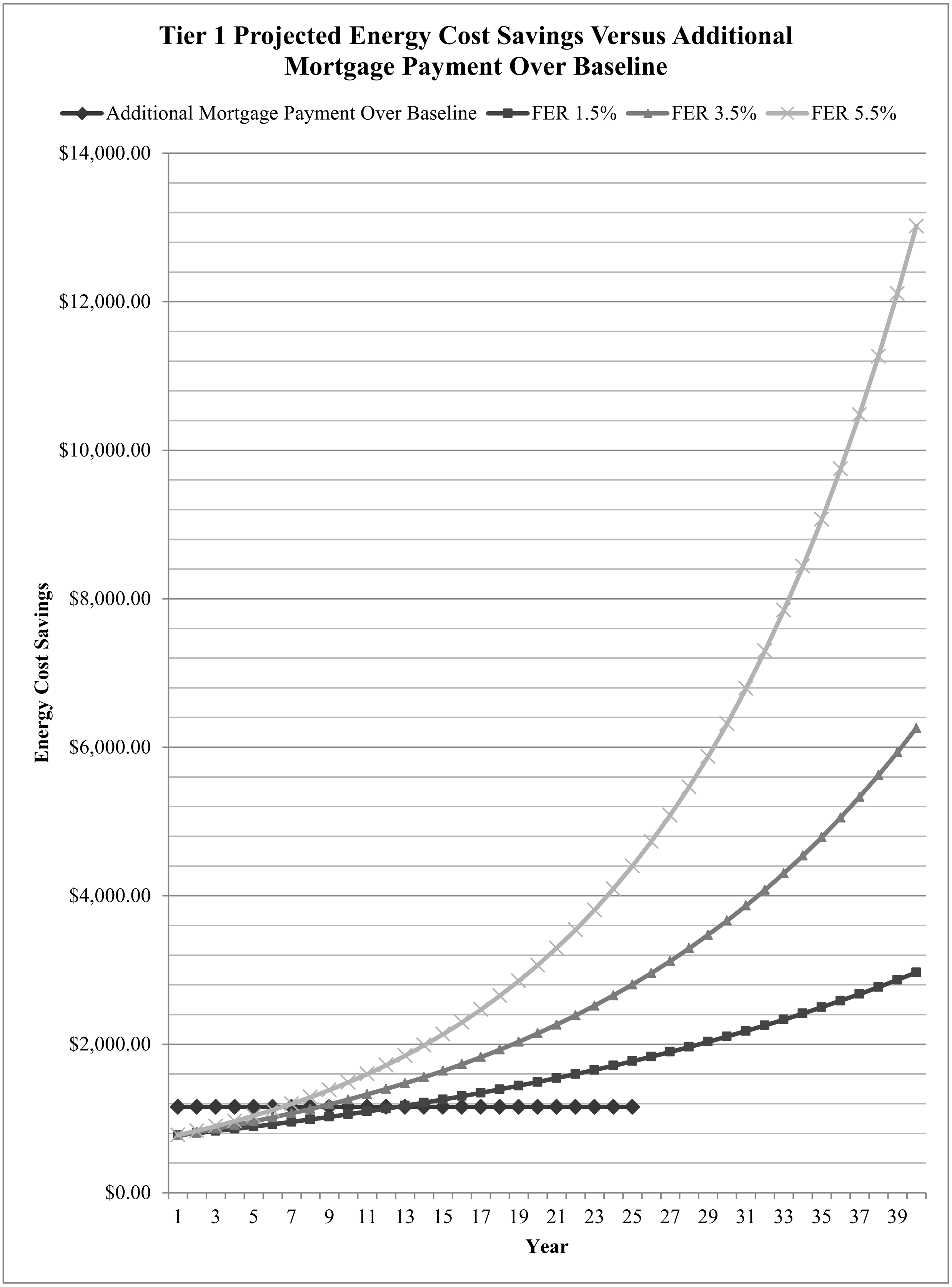


Figure 7-5 - Tier 1 Projected Energy Costs Vs. Additional Mortgage Payment Over Baseline

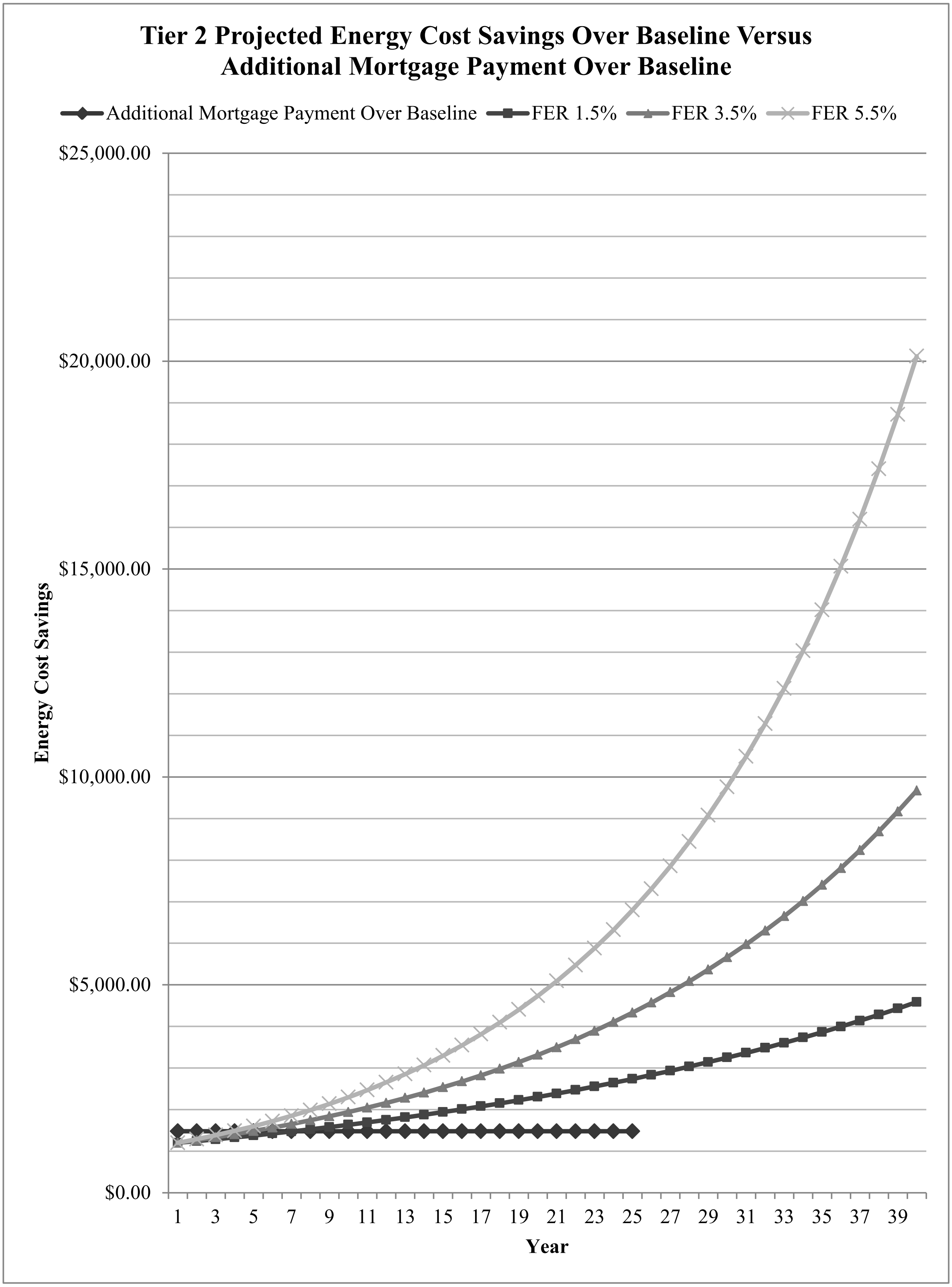


Figure 7-6 - Tier 2 Projected Energy Costs Vs. Additional Mortgage Payment Over Baseline

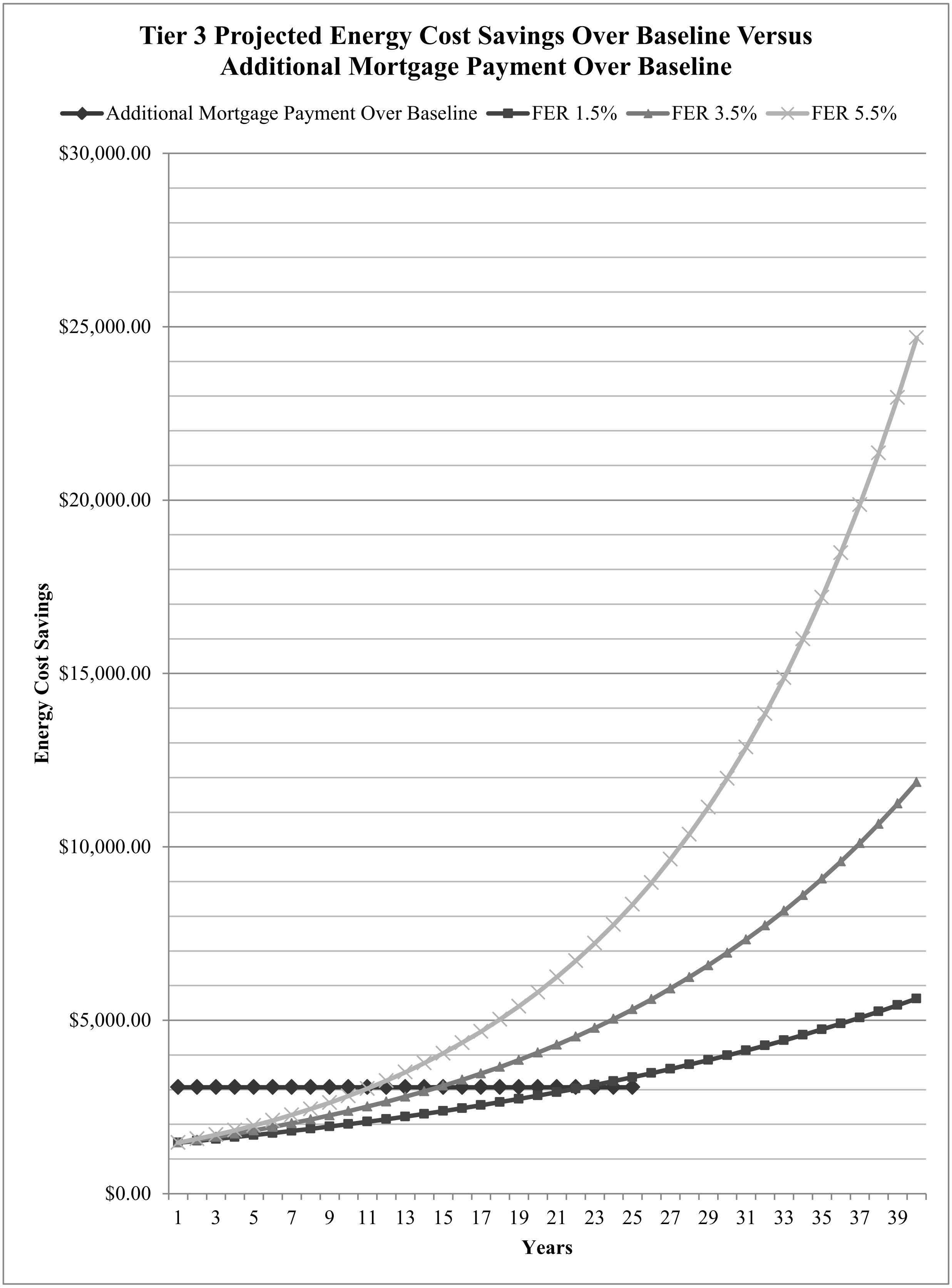


Figure 7-7 - Tier 3 Projected Energy Costs Vs. Additional Mortgage Payment Over Baseline

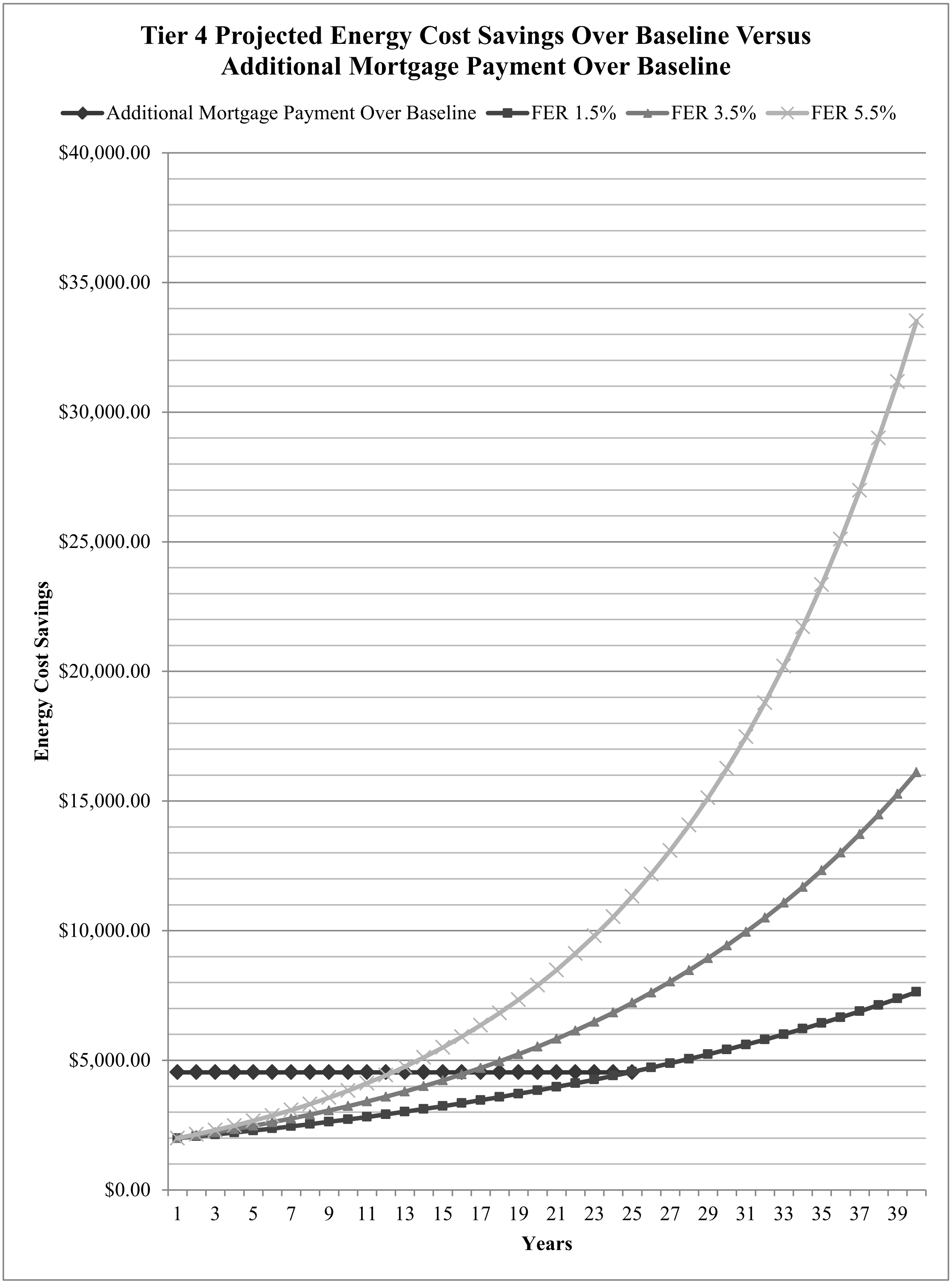


Figure 7-8 - Tier 4 Projected Energy Costs Vs. Additional Mortgage Payment Over Baseline

Fuel escalation rates result in compounding energy savings over time making payback periods difficult to calculate. Net cash flows for each tier for the three escalation rates were then examined to identify the impact of energy price increases on when positive annual net cash flows were achieved. Net cash flows were plotted for each tier for the three fuel escalation rates over a 25-year period (Figure 7-9, Figure 7-10, Figure 7-11, and Figure 7-12). Positive annual net cash flows were achieved earlier as energy prices increased. As costs to build to the higher performance targets decrease, potential energy savings will continue to increase regardless of fuel escalation rates, achieving positive net cash flows earlier, further reducing payback periods, and increasing returns on investments.

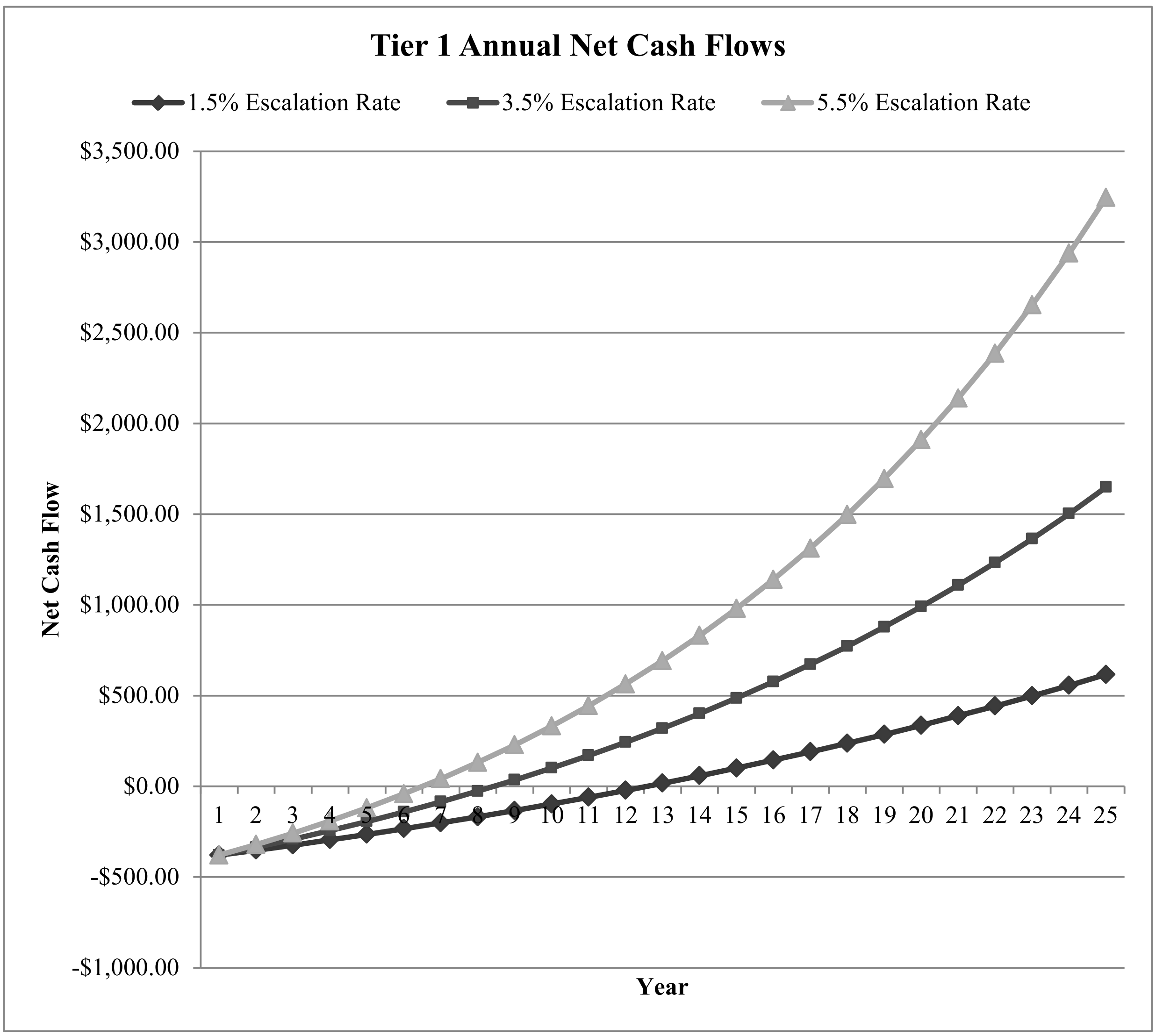


Figure 7-9 – Tier 1 Net Cash Flows at 1.5%, 3.5%, and 5.5% Energy Escalation Rates

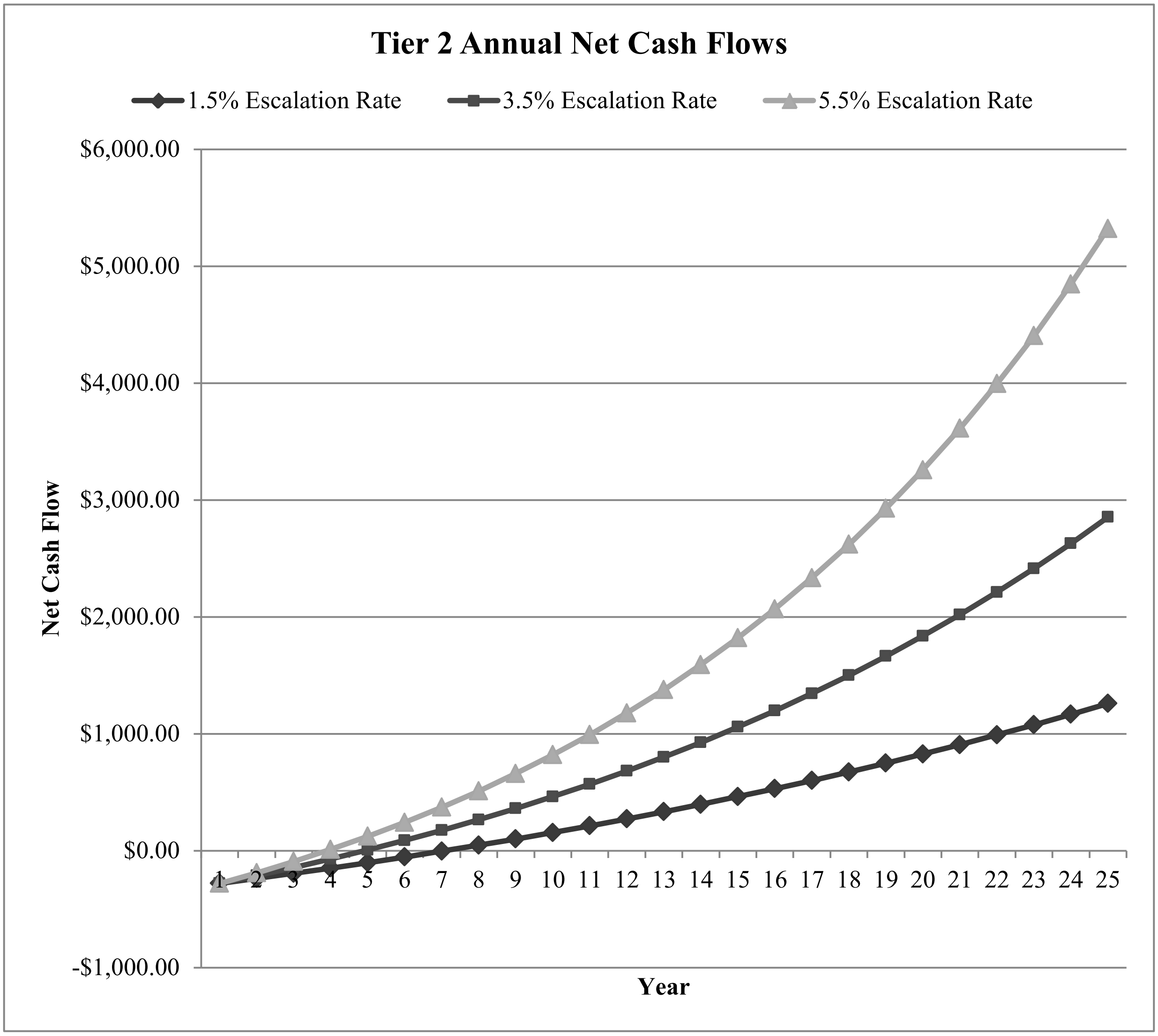


Figure 7-10 – Tier 2 Net Cash Flows at 1.5%, 3.5%, and 5.5% Energy Escalation Rates

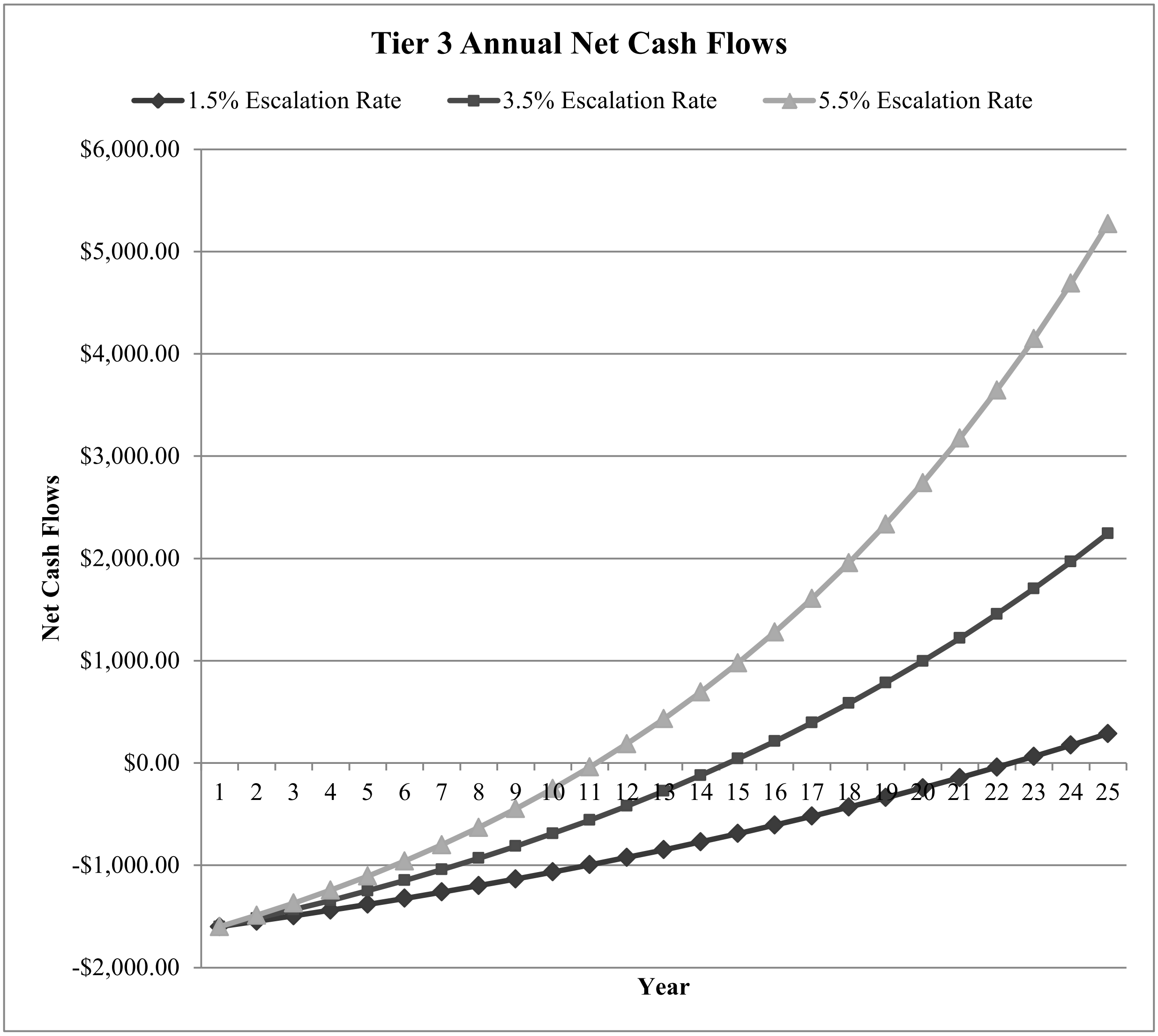


Figure 7-11 – Tier 3 Net Cash Flows at 1.5%, 3.5%, and 5.5% Energy Escalation Rates

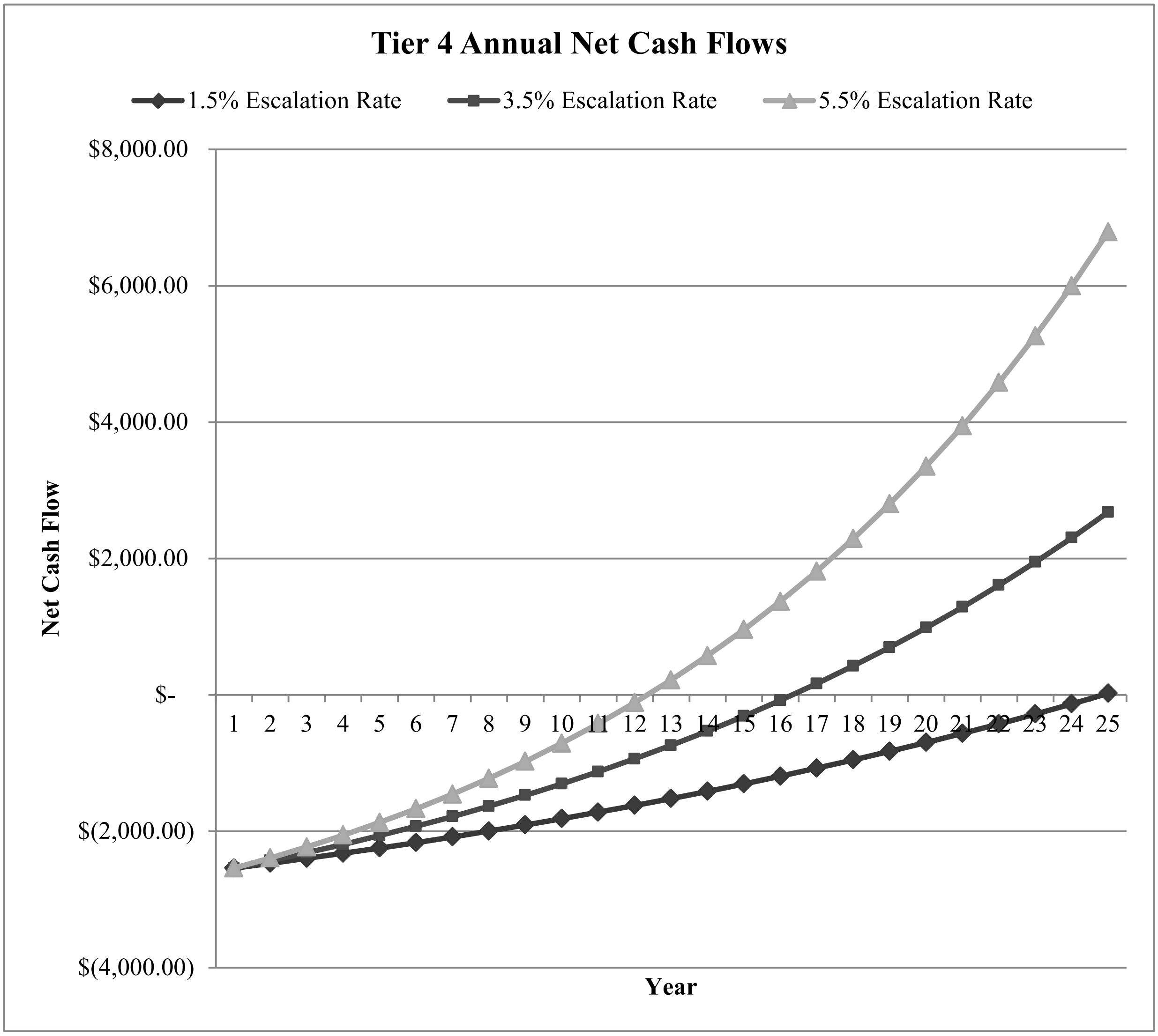


Figure 7-12 - Tier 4 Net Cash Flows at 1.5%, 3.5%, and 5.5% Energy Escalation Rates

8. Discussion

8.1. Nominal Vs. Effective RSI values and Air Leakage

As existing OBC SB-12 requirements are currently framed, building code compliance is based on fulfilling prescriptive requirements rather than the actual (predicted) energy performance of the building. Requirements for thermal resistance values are stated as nominal values. Stating minimum nominal thermal resistance requirements misrepresents a wall's actual thermal performance. Effective RSI values can vary substantially from nominal values due to framing methods, types of insulation, and thermal bridging, resulting in greater than anticipated levels of heat loss. Prescribing effective RSI values accounts for variations in framing techniques and materials used, as well as thermal bridging impacts, ensuring a more accurate representation of the thermal performance of the component.

Air leakage, a major source of heat loss, also has a substantial impact on building thermal performance. The building code does not stipulate prescriptive performance levels for air leakage, which arguably has a greater impact than insulation on heating energy consumption, depending on building typology and construction methods. To show the impact of air leakage on heating energy demand, the compliance packages developed for Tiers 1 and 4 were modelled to the five air leakage levels identified in baseline and tier targets (2.5, 2.0, 1.5, 1.0, and 0.6 ACH_{50}) (Figure 8-1). Performance levels for opaque surfaces, glazing, and HVAC efficiencies remained unchanged from those defined in each tier's proposed compliance package.

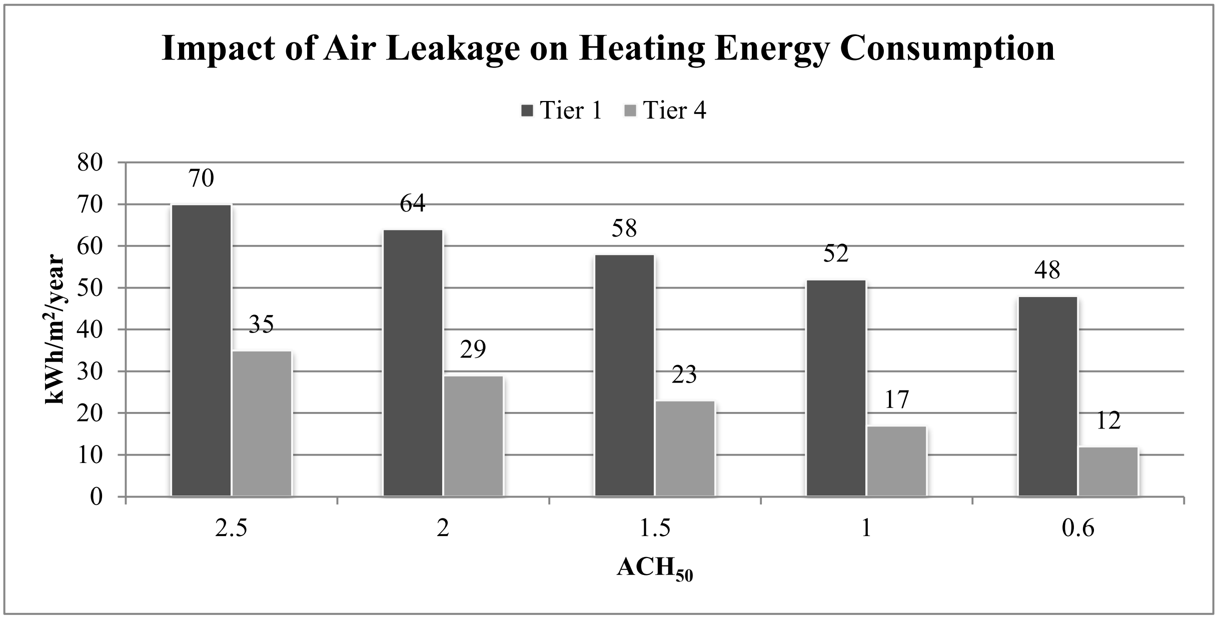


Figure 8-1 - Impact of Air Leakage on Heating Demand

Figure 8-1 shows the impact of air leakage on heating demand. Lower air leakage rates impact heating energy consumption more than thermal insulation levels – Tier 4's heating demand with an air leakage rate of 2.5 ACH_{50} was nearly triple that at 0.6 ACH_{50}. These results show that the development of stringent detailing requirements and compliance with minimum air tightness levels is needed.

The impacts of thermal bridging and air leakage on heating energy consumption reinforce the need for performance-based code compliance. Basing code compliance on minimum-prescriptive-requirements for building components focuses on individual system performance rather than whole building performance. It assumes an individual components performance equates to the performance level required for the entire building. Inclusion of mandatory predicted performance requirements for buildings is necessary to drastically reduce heating energy demand. Shifting requirements for code compliance towards performance rather than prescriptive measures will force designers to design better detailing and address thermal bridging – two key elements of Passive Houses, ensuring they achieve performance targets.

8.2. OBC Proposed 15% in Residential Energy Efficiency

Although the 2012 OBC states a 15% increase in residential energy efficiency requirements by 2017, it is not clear how this will be achieved. Proposed SB-12 compliance packages to achieve this target were published for public comment in 2011. Several packages for both compliance packages were simulated and compared to SB-12 2012 Compliance Package J (Figure 8-2

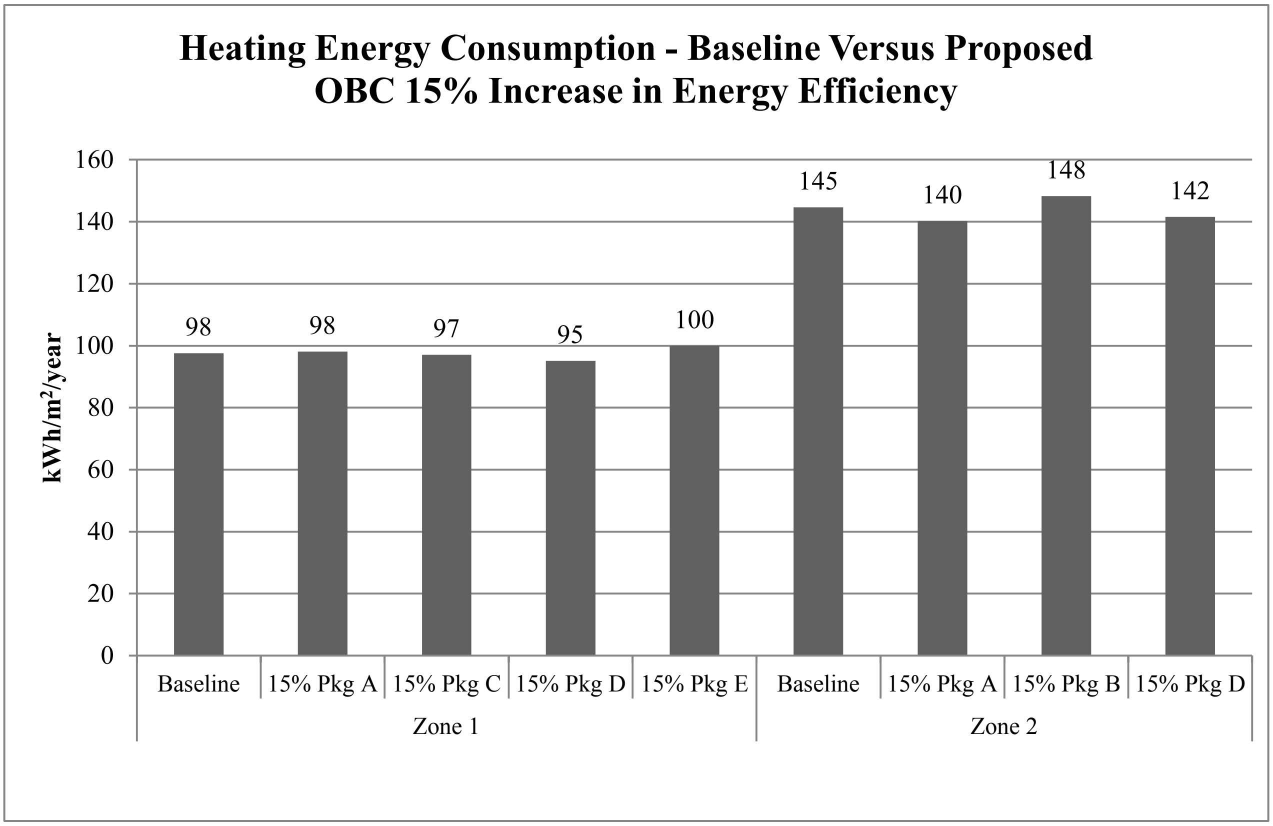


Figure 8-2 - Heating Energy Consumption - Baseline Versus Proposed OBC 15% Increase in Energy Efficiency

Results showed that there was little or no improvement in heating energy consumption compared to 2012 levels. Difference between the proposed compliance packages and OBC 2012 Compliance Package J include:

- Increased RSI values for building envelope components (roof, below grade walls, and slab) for both climate zones,
- Continuous insulation (exterior) for above and below grade walls in Zone 1 packages A, C, and E, and Zone 2 packages A, B, and D.
- Increased space heating equipment and HRV efficiency for Zone 1 packages C and D. And increase HRV efficiency for Zone 2 packages B and D.

For Zone 1, the differences in heating energy consumption between OBC 2012 Compliance Package J and proposed Compliance Packages A and E can be attributed to the combination of lower furnace and HRV efficiencies specified (94%, 90%, and 92% for furnaces; 60%, 55% and 60% for HRVs). Proposed Compliance Packages C and D both had higher HRV efficiency requirements (75%) compared to 2012 Compliance Package J (60%), as well as higher requirements for opaque surfaces. For Zone 2, it must be noted that RSI values for the above and below grade walls exceeded building code requirements due to the framing size and insulation types used to meet code requirements. The differences between OBC 2012 Compliance Package J and proposed Compliance Package B can be attributed to the difference in furnace efficiency. The improved performance of proposed package A can be attributed to the higher RSI value and continuous insulation requirement for below grade walls, and for proposed package D, to the higher HRV efficiency (70%, compared to 60% for OBC 2012).

Intent to increase air leakage requirements is unclear. Reducing air leakage levels would have a more substantial impact on heating energy consumption than the methods used in the proposed compliance packages. The proposed compliance packages as they are currently framed will not achieve the intended 15% target when simulated using the reference house used in this research.

8.3. Development of Prescriptive Requirements Based on a Archetype House

The development of prescriptive requirements and policy based on a reference or archetype house is problematic. Although the archetype house was based on a variety of housing types, the final archetype house was modelled as a single detached home. Thus, the combination of performance metric levels identified in the compliance packages is not guaranteed to meet the intended performance level when applied to other building designs or types. There are a number of factors influencing heating energy performance specific to the design of a building and the site it is located on. Mandatory energy simulations for individual homes (or a group of similar homes) would assist in identifying the predicted performance of a design and allow design modifications to be made before construction. Development of overall performance requirements is a more suitable indicator of predicted energy performance and ensures heating energy consumption targets are met.

8.4. Trade-Offs Between Prescriptive Requirements

The 2012 SB-12 compliance packages were developed partially based on capital costs [26]. Between compliance packages, trade-offs occur between RSI-values for building envelope components and HVAC equipment efficiencies. However, building envelopes and HVAC equipment have very different replacement periods. It is generally assumed the building envelope will maintain performance levels throughout the life of the building. In contrast, furnaces require annual maintenance and need replacement every 15 to 20 years, if properly maintained [73]. Although there are significant cost differences between envelope upgrades and HVAC systems, it can be more cost effective to invest now in a better performing envelope. The building envelope investment retains its value over the life span of the building. As well, furnace efficiencies are already high (in the upper 90's), and significant improvements in efficiency are theoretically impossible as 100% is the upper limit for combustion based heating appliances. It is also more probable homeowners are willing to invest in HVAC replacements or upgrades than building envelope upgrades in the future. Figure 8-3 shows small changes in furnace efficiency will have a smaller impact in heating energy consumption than increases in thermal resistance and air leakage. A highly insulated building envelope will also result in lower HVAC costs as systems are downsized.

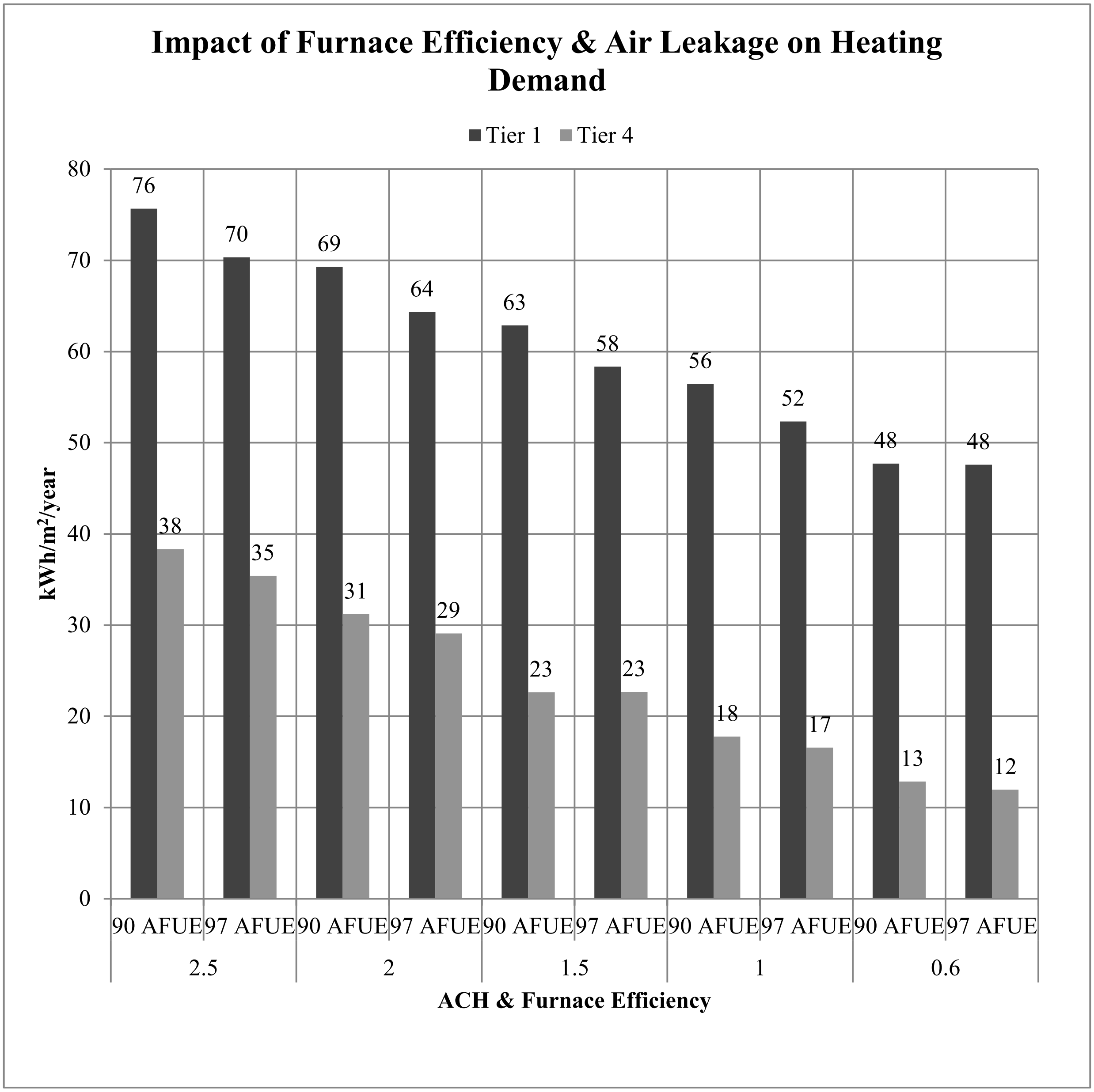


Figure 8-3 -Impact of Furnace Efficiency & Air Leakage on Heating Demand (Climate Zone 1)

8.5. Cost of Proposed Sample Compliance Packages

The proposed sample compliance packages developed are also only one possible design solution meeting the intended targets. Following analysis of the costs provided by the large tract homebuilder, more cost effective alternatives are possible but beyond the scope of this research. Actual construction costs of meeting performance targets will depend on the materials used. Cost premiums in the above grade walls and slab are partially due to the use of XPS. The cost premium of using XPS is most significant in the Tier 4 slab, which cost nearly double that of

Tier 3. Some ultra-energy-efficient projects are designed using rigid expanded polystyrene (EPS) to insulate the slab due to its reduced cost and environmental impact [74, 75]. EPS is also a viable option for exterior insulation in place of XPS, slightly reducing above grade insulation costs. Using EPS in place of XPS for the Tier 4 slab reduced slab costs by 32%. Incremental costs for EPS over Tier 3 were only 7% and down to a 48% increase over the baseline (from 54% with XPS). Selection of appropriate insulation materials to achieve the proposed performance targets will be crucial in achieving both cost effective and ultra energy efficient buildings.

The construction capital costs of the proposed compliances packages developed are based on current costs at the time of study and current methods and mind-set of one representative large tract home builder. Therefore, the costs are not representative of an industry average. Perceived risk and lack of experience are an influencing factor on the estimated costs. The tract-home builders current costs are optimized to build to current building code requirements. Their unfamiliarity with building to the proposed tier performance targets contributed to higher cost premiums in comparison to the baseline costs. Other developers may have more experience in building the proposed assemblies and thus have lower estimated costs than those identified in this work. It is very important to report that several North American Passive House builders, for example, are able to complete projects that are marginally more expensive than conventional construction in the same locations [74, 76, 77].

The implementation of the proposed performance targets will stimulate market transformation and innovation as all builders will be required to meet the same minimum performance standards. As builders and trades familiarize themselves with the techniques required to meet the proposed performance targets, the level of perceived risk diminishes. Adoption of the performance targets by large tract builders early in the framework implementation process will also play an important role in reducing costs due to the large scale of their projects. The desire to maintain profit margins also drives market transformation and innovation. The precise amounts and rates at which prices decrease are difficult to predict and incorporate into the economic analyses of the proposed performance levels.

8.6. Barriers to Implementation

It is also important to consider the long-term benefits of the proposed framework and preliminary implementation strategy. Energy savings and associated reductions in greenhouse gas emissions due to reduced heating demand of residential buildings are certain. However, the uncertainty of future energy supplies and costs makes predicting actual cost savings difficult. Future energy cost savings correlate with changes in energy prices. The scope of tong-term benefits must broaden, and include environmental and social impacts in addition to economic. Reducing energy consumptions results in decreased environmental degradation (due to fossil fuel extraction and consumption) and greenhouse gas emissions. It also leads to greater energy security and resiliency in the face of supply disruptions occurring due to extreme weather events. These are benefits that continue throughout the lifecycle of the building.

Split incentives between the builder and buyer also impede reaching proposed consumption targets. Buyers may be unwilling to absorb added capital costs associated with ultra-energy-efficient housing unless well versed in the benefits. Builders may see reduced profit margins if buyers are reluctant to absorb the cost premiums associated with higher performance housing. Educational tools and government-based financial incentives are crucial in addressing cost issues and minimizing resistance from the residential construction industry in the early stages of the framework implementation.

The greatest barrier to achieving the heating energy reduction target within the proposed timeframe is cost. Availability of information on the performance and cost effectiveness of building envelope materials is crucial. Cost effective solutions are achieved quicker if more projects are encouraged to adopt the overall target early on in the implementation process. Implementation of conservation efforts is also more cost effective in the long term, in comparison to both monetary and environmental costs associated with producing energy. Investments in ultra energy efficient homes now will mean decreased energy demand throughout the lifespan of the building. This will reduce provincial expenditures relating to energy infrastructures as well as decrease the environmental impact of the residential building sector by lowering greenhouse gas emissions.

The implementation of the supporting policy tools, particularly the development and introduction of educational tools and financial incentives, will be key in successfully achieving the overall reduction target by 2030.

9. Preliminary Implementation Strategy

The goal of the proposed tiered framework is to achieve an 80% reduction in residential heating energy consumption, using 2012 OBC SB-12 requirements (specifically Compliance Package J for heating equipment with greater than 90% efficiency) as a baseline. The intent is to achieve this target by 2030, supported by the implementation of the proposed framework into Ontario building policy. An implementation strategy and supporting policy tools are needed to successfully achieve this target.

Building energy performance is dictated by building standards, as they are legislated, and economics, as higher energy costs will incentivize decreased consumption [78]. Studies have found that when greater emphasis is placed on performance over defined prescriptive objectives, innovation within the construction industry is enhanced [79, 80]. The goal of the proposed tiered framework is to emphasize building energy performance through mandated targets. The intention of the prescriptive compliance packages is to act as a supporting measure as industry becomes familiar the requirements, and adopts the appropriate design and construction methods to achieve the targets cost effectively.

Improving energy efficiency involves five key elements[79]: incentives, information, initiative, innovation, and investment. Each element faces various barriers, some of which were identified in this research. These include:

- Split incentives between home builders and buyers,
- Lack of awareness, knowledge and expertise,
- Uncertainties and risk,
- High capital costs compared to conventional construction, and
- Focus on short term cost benefits.

Additionally, the development and implementation of policies focused on energy efficiency require the following [60]:

- Clear goals and directions for implementation,
- Capacity to balance between flexibility and continuity

- Involvement of stakeholders,
- Determine qualitative targets and clear timelines, and
- Monitoring and evaluations procedures of the results and outcomes.

The International Energy Agency (IEA) identified several different policy measures and sub-categories commonly used in member countries to address energy efficiency, such as [62]:

- Regulation: Building Codes and Minimum Equipment Energy Performance Standards
- Information: Labelling, Education and Training, and Demonstration; and
- Economic: Subsides, Tax Exemptions, Reduced-interest Loans, and Grants

Based on the outcome of the economic analysis and the current provincial policy structure, an implementation strategy was developed and supporting policy measures focusing on education and training, financial incentives, and monitoring and evaluation procedures.

9.1. Implementation of Tiered Framework

The objective of the tiered framework is to implement the overall energy reduction target in stages. In addition to a separate reduction target, each tier has a mandatory compliance date:

- Tier 1 – 2017 (30% reduction),
- Tier 2 – 2020 (50% reduction),
- Tier 3 – 2025 (65% reduction), and
- Tier 4 – 2030 (80% reduction).

The intent is that all performance targets are simultaneously made public, along with prescriptive compliance packages for the tier targets. Each tier has a corresponding set of compliance packages intended to meet the performance target. This allows a transition period in anticipation of the new requirements having significant stakeholder impacts, such as comprehensive training and the development and use of new design methods, materials, and components. Incremental implementation of the prescriptive/performance targets also allows designers and builders to familiarize themselves with the targets and establish cost effective solutions to meet the targets by their mandatory compliance dates.

It is proposed that the tiered framework and associated compliance packages be implemented through the OBC using both the existing SB-12 prescriptive (i.e. compliance package) approach and the performance (i.e. energy simulation) based approach. At present, OBC compliance is achieved by either following one of three compliance paths outlined in SB-12 (prescriptive, performance, or other approved method) or achieving a minimum EnerGuide 80 rating [24]. An initial energy simulation will be required for a proposed design before receipt of a building permit. The 2012 SB-12's performance compliance path requires two annual energy simulations to compare simulated energy use of the proposed building design to that of an applicable compliance package. In a similar fashion, it is proposed that two annual energy simulations (with an optional third) are required as part of the proposed framework.

The first annual energy simulation establishes the baseline of heating energy consumption by modelling the proposed building design to the 2012 OBC-SB-12 Compliance Package J requirements. Once the baseline consumption is established, heating energy consumption targets would be calculated using the baseline results and the required reduction target percentage for the selected tier (Equation 3).

Once a tier performance target is identified, a corresponding compliance package would be selected. Following the format of the existing OBC prescriptive approach, prescriptive requirements are presented in the compliance package for envelope components, HVAC efficiencies and air leakage rates. Sets of compliance packages designed to meet each of the four tiers' performance targets would be published along with the tiered framework for both OBC defined climate zones. The compliance packages act as minimum prescriptive requirements, with emphasis placed on meeting the reduction target based on the preliminary energy simulation results. As a result, final designs may vary from the prescriptive requirements proposed in the compliance package. As each target becomes mandatory, compliance packages associated with that tier performance target will not achieve building code compliance and be removed from the building code. For example, once Tier 2 performance requirements become mandatory in 2020, compliance packages meeting Tier 1 requirements would then no longer be applicable.

Because compliance packages are developed based on a reference house (or archetype house in the 2012 SB-12 requirements), the packages do not account for impacts variations in building design, orientation, and site have on heating energy consumption. Energy simulations ensure the appropriate design modifications accounting for these factors are made to the envelope and HVAC system and that the heating energy consumption targets are met.

The second required annual energy simulation confirms that the tier heating energy performance target is met. Any significant changes to the building design from the compliance package requirements would require additional energy simulations (optional third annual energy simulation). Submission of the two annual energy simulations is a proposed requirement as part of the initial permit documentation process to be mandated by the OBC.

In addition to energy simulations, mandatory air leakage testing is recommended for code compliance. Two blower door tests are suggested. The first blower door test is required upon completion of the full air barrier systems (including windows). The second blower door test is recommended upon substantial completion of the building. These construction stages correspond with existing inspection requirements. Under Section 1.3.5 of the Ontario Building Code act, inspections are required at the point of substantial completion of the air barrier, and may also be required upon substantial completion of the HVAC system (Division C) [24]. A requirement for blower door test at these two inspection points is recommended. The blower door tests requirement would assists with reaching the heating energy target by ensuring the air leakage targets are met. The blower door tests are a low cost (approximately $250 per test [66]) requirement potentially resulting in substantial cost savings, as the results identify any further detailing needed to meet the ACH rate for code compliance. Blower door test results are to be submitted as parts of the final permit requirements.

It is also recommended that as-constructed drawings be deemed mandatory under the OBC (currently, building inspectors can request as-constructed drawings but they are not required as part of the permitting) [81]. The final energy simulation results, heating energy performance target achieved, and air leakage rate will determine compliance with building code. The as-constructed drawings and results of the blower door test and final energy simulation can then used to generate an energy performance certificate, issued once the building is completed and deemed code compliant.

9.2. Education and Training

The proposed framework and implementation strategy will impact a wide range of stakeholders, including architects, builders and contractors, inspectors, and municipalities. To make sure stakeholders are prepared for the implementation of the tiered framework and proposed performance targets, it is recommended workshops and information sessions are held prior to implementation addressing questions and concerns regarding the proposed changes. The creation of educational content specific to the new proposed requirements and amended existing requirements is key to informing municipalities, industry, and code officials of the new and amended requirements. Utilizing existing education tools is proposed, such as the Ministry of Municipal Affairs and Housing (MMAH) and Ontario Building Officials Association's (OBOA) building code workshops, self-study manuals, in-classroom training, and detailed technical courses [82]. Development of best practice guides, and workshops/training sessions on design elements and construction methods are necessary to successfully achieve the energy performance targets. Recommended topics covered by the best practice guides and workshops/training sessions include: energy simulation procedures, detailing methods and air tightness, HRV's, thermal bridging, and double-stud walls.

Constructing demonstration houses built to Tier 4 performance targets also serves as an educational tool for both public and industry. Documenting the design and construction of Tier 4 homes shows the process of building to the new requirements and the benefits of building ultra energy efficient homes. Experiences and knowledge gained from constructing the first group of homes built to Tier 4 performance targets also provides information necessary to develop workshops, training sessions, and best practices guides for the construction techniques and methods relating to detailing methods, double stud walls, window selection and placement, and thermal bridging.

9.3. Financial Incentives

Introduction of financial incentives concurrently with the implementation of the tiered framework is crucial. From the results of the economic analysis, it is reasonable to conclude early projects achieving the higher tier performances targets will likely experience higher construction costs than those constructed in the future. The higher construction costs are partially associated with availability of suitable materials and components, but are primarily a result of the learning curve of builders and trades in acquiring and adopting the knowledge and skills needed when building ultra energy efficient homes.

The Canada Mortgage and Housing Corporation (CMHC) offers a 10% mortgage loan insurance premium refund and a premium refund for longer amortization periods for the purchase of energy efficient homes with an EnerGuide 82 ratings or a CMHC eligible energy efficient building program (Energy Star, R-2000, LEED Canada for Homes, or GreenHouse in Ontario) [83]. Currently, the incentive conditions coincide with the OBC's proposed 15% increase in energy efficient to be implemented in 2017. The requirements to achieve this incentive could be adjusted to coincide with the tier consumption targets and their implementation dates.

One proposal is reducing property taxes for projects that adopt Tiers 2 through 4 ahead of their mandatory compliance dates. The tax break begins at the time of construction and extends until the time at which the achieved tier performance target becomes mandatory. For example, a home built to Tier 4 requirements in 2017 is subject to reduced property tax rates until 2030; a home built to Tier 2 requirements in 2017 receives reduced property tax rates until 2020.

Another recommendation is the development of a grant programs for houses designed to achieve Tier 4 targets and constructed by 2017. For example, a grant of $15,000, contingent on final energy modelling and blower door test results would be provided to homeowners upon substantial construction completion. Based on the Tier 4 construction costs calculated in Section 7.1, the simple payback period is decrease to 25 years and a 4% first year return on investment is achieved. Although the grant program would be an added expense, benefits would be gained to assist with implementation of the tiered framework, The first homes built to Tier 4 consumption targets can then act as demonstration houses, serving as an educational tool for both public and industry detailing the process of building to the new requirements, as well as the benefits of building ultra energy efficient homes. Experience and knowledge gained from these first Tier 4 homes serves to inform the development of workshops, training sessions, and best practices guides on construction techniques relating to detailing methods, double stud walls, and thermal bridging.

9.4. Monitoring and Evaluation

Monitoring of the on-going implementation of the tiered framework is necessary to verify the province is on track to meet the 80% heating energy reduction target. Requiring submission of energy simulation and blower door test results confirms projects are achieving compliance with the heating energy consumption targets. Creation of a database for the simulation results and energy performance certificates/labels assists in tracking trends in what consumption targets are being met. This information can be used to assess the effectiveness of the implementation strategy and related policy tools. A policy review should occur in advance of each tier's mandatory compliance date. Modifications to the building code and policy tools can then be made as needed to make sure that the overall heating energy reduction target is met by 2030.

The proposed preliminary implementation strategy utilizes existing policy, training/education, and monitoring procedures. Using existing frameworks reduces costs and time associated with the implementation, such as:

- The costs to create a new performance compliance path,
- Development of a new education and training framework for building code officials, and
- Significantly modifying the permitting process.

However, the additional enforcement measures proposed in the implementation strategy, specifically the mandatory blower door tests and submission of additional documentation to support performance claims, likely results in added administration costs. It is also important to consider added costs related to the framework implementation and policy tools for the proposed performance targets are likely offset by cost savings associated with decreased energy consumption, such as costs associated with upgrading and expanding energy infrastructures and related environmental costs.

10. Further Research

Several issues outside the research scope requiring further investigation were identified n the completion of this work:

- The 2012 OBC SB-12 requirements for thermal resistance values of the building envelope components are stated as nominal values. Effective RSI-values can vary significantly than nominal code stated values. Although the NBC has proposed reframing requirements for thermal resistance as effective values, the OBC have not published plans to do so. Further investigation into average framing percentages for commonly used building assemblies and framing techniques are needed due to the significant impact on a building's overall thermal performance.
- Requirements for maximum air leakage levels and detailing methods are also not included in current building code requirements. Air leakage is a significant source of heat loss, even in highly insulated buildings. Additional development of effective detailing methods is necessary to achieve the air leakage levels proposed in the tiered framework, as well as an investigation of average Ontario residential air leakage rates based on house vintage, type, and climate zone.
- An investigation into the share of energy dedicated to cooling is also needed. Overheating is a possible issue with Tier 4 homes that could be mitigated with properly designed ventilation system. The impact of shading should also be considered when looking at the impact of overheating and cooling energy consumption. Additional energy simulations should be carried out to further examine these issues.
- The compliance packages proposed in this work were based on the CCHT House, which was designed and constructed to represent typical tract built construction. The approach was similar to the development of OBC SB-12 compliance packages, which were based on an archetype house developed from averages of newly constructed homes in Ontario. Compliance packages in the 2012 SB-12 outline prescriptive requirements that are intended to meet or exceed an EnerGuide 80. However the compliance packages were developed based on the design specifications of the archetype house. Houses following compliance package requirements are assumed to also an EnerGuide 80 rating, though verification is not required. The appropriateness of developing prescriptive requirements

on an archetype house requires further investigation. A survey of the range in Ontario housing characteristics would also be beneficial in the development of future prescriptive performance requirements. Ontario residential homes built to the SB-12 compliance packages requirements should be modelled to determine their EnerGuide ratings to ensure the intended EnerGuide 80 was met and identify deviations performance levels.

- This research has focused on the heating energy consumption of single-family homes, and is part of a larger project. Further work looking at the heating energy consumption of other residential building types falling under Part 9 of the OBC is needed.
- The development of a calculation method to identify energy consumption targets and minimum thermal resistance requirements for individual buildings is also needed. Levels identified for energy consumption targets and thermal resistance requirements would then be specific to a building and ensure the overall performance target is met. This would further move towards performance based compliance rather prescriptive compliance measures as well as develop requirements specific to a particular design.
- To further support reaching the proposed 80% heating energy reduction target, further development of more cost effective building assemblies to reach the proposed targets is required. The environmental impact of proposed materials should be considered in the development of the assemblies.
- The development of a design and framework for building energy performance certificate or labels is also an area needing development. Jurisdictions such as the EU and Australia who have already established labelling frameworks could be looked to for guidance in the development of criteria and formatting for labels and/or certificates. EnerGuide ratings could also be used in the development of labelling/ certification criteria.
- Creation of energy performance requirements for existing homes is also an area that needs to be addressed. The existing residential building stock forms a substantial portion of Ontario's energy consumption. Implementation of requirements and supporting financial incentives targeting existing houses will lead to even greater reductions in energy consumption and have a larger impact on future energy consumption than new construction. Canadian building codes are largely focused on new construction, the long lifecycle of buildings warrants that recommendations from this research need to be

extended to the existing building stock to encompass all sectors of the residential building stock, and thus achieve more significant energy savings and environmental impact.

11. Conclusions

The intent of this work was to develop an approach to achieve an 80% reduction in Ontario residential heating energy consumption by 2030. The work illustrates that existing building code requirements and an aggressive voluntary performance standard such as Passive House can be used to develop a framework for residential heating energy performance targets. A supporting implementation strategy was developed utilizing the existing provincial policy structure. Recommendations for policy tools were made based on the results of the cost analyses and international precedents in energy efficiency regulations.

Current OBC and NBC prescriptive requirements were examined to identify the performance metrics and levels used for four target areas: opaque surfaces, glazing, HVAC efficiency, and air leakage. Requirements were then compared to those levels designed to achieve Passive House Standard certification. Types of performance metrics used for each of the four targets areas were similar between the two codes and Passive House, however the metric levels were less rigorous in the OBC and NBC. Neither the OBC and NBC have requirements for maximum air leakage values nor is verification of air leakage levels required for buildings, unlike Passive House where third party verification is required to achieve certification. Air leakage has a significant impact on heating energy consumption and is not directly addressed by current building code requirements. Overall, the OBC and NBC requirements focus on minimum prescriptive values of the various building components, whereas Passive House focuses on the overall energy performance of the building.

Performance metrics for the OBC, NBC, and Passive House levels were simulated for both OBC defined climate zones using the EnergyPlus CCHT Twin House model. Results of energy simulations of the OBC and NBC showed significantly higher heating energy consumption compared to that of Passive House levels. A level of optimal energy performance and goal date was identified to significantly reduce Ontario heating energy consumption based on the results of the initial energy simulations. Optimal energy performance was defined as a building whose annual heating energy consumption was equal to or less than the level of renewables in the energy supply mix, based on 2012 data (approximately 20%). This level of heating energy consumption was similar to that of the Passive House levels, which were approximately 80% less than OBC 2012 SB-12 Compliance Package J. A target date of 2030 was identified to achieve the 80% reduction in heating energy consumption. To achieve the heating energy reduction target by 2030, a tiered framework of smaller incremental performance targets and mandatory compliance dates was developed. The tiered framework uses OBC 2012 SB-12 Compliance Package J as a baseline and Passive House levels as the benchmark for Tier 4, an ultra energy efficient level.

Sample compliance packages were then developed for the four tiers for both OBC defined climate zones. The sample compliance packages provided one possible design solution to meet each of the tier heating energy performance targets and were modelled on the existing OBC compliance package framework. An economic analysis was carried out for climate Zone 1 compliance packages, involving the following steps:

- Total construction costs were identified for the baseline and each tier based on prices identified with the assistance of a GTA-based large-scale tract homebuilder and GTA-based suppliers. An additional investment over baseline costs was calculated for each tier.
- Annual energy cost savings was calculated for each tier based on current energy costs (January 2013) at the time of study and baseline energy costs.
- A simple payback period and first year return on investment were calculated for each tier, based on the additional investment, subsequent annual payments, and annual energy cost savings.
- A series of fuel escalation rates were identified to explore the impact of rising energy prices on payback periods over the mortgage amortization period.

The results of the construction costs showed a significant cost premium between the baseline and Tier 4, with above grade walls and the slab showing the greatest increases in cost. The added costs for these components can be attributed to the types of insulation used, particularly in exterior applications. The proposed envelope assemblies were designed based on familiarity of materials and ease of installation, rather than on cost effectiveness. Further investigation into more cost effective assemblies achieving the same levels of performance is needed to increase the economic viability of building to Tier 4 performance levels now.

The uncertainty of actual fuel escalation rates also makes it difficult to predict energy cost savings and subsequent payback periods and returns on investments. The range of fuel escalation rates found energy cost savings increase at a rate similar to increasing energy prices. Therefore, it can be assumed energy cost savings increase with time. Due to the long life span of building envelopes, investments in more energy efficient building envelopes now will continue to produce energy savings throughout the lifespan of the building.

A strategy to implement the framework of consumption targets was then developed based on existing Ontario policy structures. The framework of consumption targets and sets of corresponding compliance packages would be introduced into the building code at the same time. This accounts for the learning curve anticipated with the introduction of the new requirements as well as allowing stakeholders to pursue higher tier targets ahead of their compliance dates. As each tier becomes mandatory, the compliance packages associated with that tier would no longer be applicable. Mandatory energy simulations and blower door test are recommended as part of the permitting and inspection process to ensure performance targets are met.

The greatest barriers to successfully implementing the framework and meeting the 80% reduction target for heating energy consumption are lack of knowledge and perceived risks relating to costs. Policy tools to support the implementation and adoption of the performance levels ahead of compliance dates were identified to assist with overcoming these barriers. The development of extensive education initiatives is recommended. Proposed initiatives include workshops and information sessions for stakeholders before implementation to address questions and receive feedback. It is also suggested educational content specific to the proposed framework be developed for use as part of the MMAH and OBOA's building code education and training programs. Collaborations between industry and academia for the development of best practice guides and construction of demonstration houses will play a critical role in educating both the public and industry. The information gathered throughout the construction process of the demonstration houses act to overcome the misconceptions of ultra efficient housing relating to time, construction methods and materials, and subsequent cost premiums.

Increased costs over conventional construction are anticipated during the anticipated industry learning curve in the early stages of implementation. The introduction of financial incentives is an important element in reducing costs and encouraging stakeholders to achieve higher tier performance levels ahead of mandatory compliance dates. Lower property taxes are proposed for those adopting Tiers 2 through 4 ahead of their mandatory compliance dates. The reduced tax rates would remain effective until the achieved tier's mandatory compliance dates. The development of a grant program to encourage adoption of Tier 4 performance levels by 2017 is also needed. The first homes built to near Passive House Standard levels could then also act as demonstration houses and used in the development of the recommended best practice guides.

On-going monitoring and evaluation of the implementation of the framework and policy tools is necessary to ensure the province is on track to meet the 80% reduction target by 2030. The creation of a database tracking the predicted heating energy performance of new residential buildings is recommended. The database would be used to assess the effectiveness of the implementation strategy and related policy tools, and identify issues that need to be addressed.

The effects of efficiency, and inefficiency, are persistent and accumulate over time (U.S. Energy Information Administration, 2012). Although Ontario is one of a few provinces with specific energy efficiency requirements in their provincial building code, significant changes to requirements are needed. Plans to further increases energy efficiency requirements in the building code are conservative, with only a 15% increase on 2012 requirements planned for 2017. Identifying a long-term energy reduction goal and developing supporting frameworks and policy are needed for Ontario to achieve deep energy savings and conservation goals. Views on energy use must broaden beyond monetary costs, and include environmental and social costs as well. Consideration of long-term benefits beyond capital costs must be included in the development of future building code requirements and building policy. Interest in residential energy efficiency among industry and homebuyers, although growing, it is not at levels required to achieve the substantial energy savings needed to mitigate the increasing impacts of climate change [60]. Ontario must adopt more stringent performance requirements now to achieve deep energy savings and minimize environmental impacts in the future.

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Appendices

Appendix A Sample EnergyPlus IDF File

Passive House Climate Zone 1 with HRV

```
!- CCHT REFERENCE HOUSE
!- CREATED BY HAYES ZIRNHELT
!- MAY 2011
!- Updated Dec 2011 - Mar 2012
!-   ===========  ALL OBJECTS IN CLASS: VERSION ===========

  Version,7.0;

!-   ===========  ALL OBJECTS IN CLASS: SIMULATIONCONTROL ===========

  SimulationControl,
    No,                      !- Do Zone Sizing Calculation
    No,                      !- Do System Sizing Calculation
    No,                      !- Do Plant Sizing Calculation
    No,                      !- Run Simulation for Sizing Periods
    Yes;                     !- Run Simulation for Weather File Run Periods

!-   ===========  ALL OBJECTS IN CLASS: BUILDING ===========

  Building,
    CCHT REFERENCE HOUSE,    !- Name
    0,                       !- North Axis {deg}
    Suburbs,                 !- Terrain
    0.04,                    !- Loads Convergence Tolerance Value
    0.4,                     !- Temperature Convergence Tolerance Value {deltaC}
    FullExteriorwithreflections,  !- Solar Distribution
    100,                     !- Maximum Number of Warmup Days
    6;                       !- Minimum Number of Warmup Days

!-   ===========  ALL OBJECTS IN CLASS: SHADOWCALCULATION ===========

  ShadowCalculation,
    20,                      !- Calculation Frequency
    15000;                   !- Maximum Figures in Shadow Overlap Calculations

!-   ===========  ALL OBJECTS IN CLASS: SURFACECONVECTIONALGORITHM:INSIDE ===========

  SurfaceConvectionAlgorithm:Inside,AdaptiveConvectionAlgorithm;

!-   ===========  ALL OBJECTS IN CLASS: SURFACECONVECTIONALGORITHM:OUTSIDE ===========

  SurfaceConvectionAlgorithm:Outside,AdaptiveConvectionAlgorithm;

!-   ===========  ALL OBJECTS IN CLASS: HEATBALANCEALGORITHM ===========

  HeatBalanceAlgorithm,ConductionTransferFunction,200;

!-   ===========  ALL OBJECTS IN CLASS: ZONECAPACITANCEMULTIPLIER:RESEARCHSPECIAL ===========

  ZoneCapacitanceMultiplier:ResearchSpecial,
    1,                       !- Temperature Capacity Multiplier
    1,                       !- Humidity Capacity Multiplier
    1;                       !- Carbon Dioxide Capacity Multiplier

!-   ===========  ALL OBJECTS IN CLASS: TIMESTEP ===========

  Timestep,20;

!-   ===========  ALL OBJECTS IN CLASS: CONVERGENCELIMITS ===========

  ConvergenceLimits,
    0,                       !- Minimum System Timestep {minutes}
    20;                      !- Maximum HVAC Iterations

!-   ===========  ALL OBJECTS IN CLASS: RUNPERIOD ===========

  RunPeriod,
    EPW 2002-2003 Annual Sim,!- Name
```

```
    11,                      !- Begin Month
    1,                       !- Begin Day of Month
    10,                      !- End Month
    31,                      !- End Day of Month
    UseWeatherFile,          !- Day of Week for Start Day
    No,                      !- Use Weather File Holidays and Special Days
    No,                      !- Use Weather File Daylight Saving Period
    Yes,                     !- Apply Weekend Holiday Rule
    Yes,                     !- Use Weather File Rain Indicators
    Yes,                     !- Use Weather File Snow Indicators
    1;                       !- Number of Times Runperiod to be Repeated

!-   ===========  ALL OBJECTS IN CLASS: RUNPERIODCONTROL:DAYLIGHTSAVINGTIME ===========

  RunPeriodControl:DaylightSavingTime,
    1st Sunday in April,     !- Start Date
    Last Sunday in October;  !- End Date
!
!-   ===========  ALL OBJECTS IN CLASS: SITE:GROUNDTEMPERATURE:BUILDINGSURFACE ===========
!
!   GroundHeatTransfer:Control,
!     RunBasementObject,       !- Name
!     Yes,                     !- Run Basement Preprocessor
!     No;                      !- Run Slab Preprocessor
!
!- ======= IDF FOR BASEMENT PROGRAM ================ ####
!
!   GroundHeatTransfer:Basement:SimParameters,
!     0.1,                     !- F: Multiplier for the ADI solution
!     20;                      !- IYRS: Maximum number of yearly iterations:
!
!   GroundHeatTransfer:Basement:MatlProps,
!     6,                       !- NMAT: Number of materials in this domain
!     2243,                    !- Density for Foundation Wall {kg/m3}
!     2243,                    !- density for Floor Slab {kg/m3}
!     311,                     !- density for Ceiling {kg/m3}
!     1800,                    !- density for Soil {kg/m3}
!     2000,                    !- density for Gravel {kg/m3}
!     499,                     !- density for Wood {kg/m3}
!     880,                     !- Specific heat for foundation wall {J/kg-K}
!     880,                     !- Specific heat for floor slab {J/kg-K}
!     1530,                    !- Specific heat for ceiling {J/kg-K}
!     1000,                    !- Specific heat for soil {J/kg-K}
!     720,                     !- Specific heat for gravel {J/kg-K}
!     1530,                    !- Specific heat for wood {J/kg-K}
!     1.4,                     !- Thermal conductivity for foundation wall {W/m-K}
!     1.4,                     !- Thermal conductivity for floor slab {W/m-K}
!     0.09,                    !- Thermal conductivity for ceiling {W/m-K}
!     2.2,                     !- thermal conductivity for soil {W/m-K}
!     1.9,                     !- thermal conductivity for gravel {W/m-K}
!     0.12;                    !- thermal conductivity for wood {W/m-K}
!
!   GroundHeatTransfer:Basement:Insulation,
!     0.0001,                       !- REXT: R Value of any exterior insulation {m2-K/W}
!     FALSE;                   !- INSFULL: Flag: Is the wall fully insulated?
!
!          !note typical value 0.16
!          !note typical value 0.40
!          !note typical value 0.94
!          !note typical value 0.86
!          !note typical value 6.0
!          !units cm
!          !note typical value 0.25
!          !units cm
!
!   GroundHeatTransfer:Basement:SurfaceProps,
!     0.3,                     !- ALBEDO: Surface albedo for No snow conditions
!     0.6,                     !- ALBEDO: Surface albedo for snow conditions
```

```
!     0.94,                     !- EPSLN: Surface emissivity No Snow
!     0.86,                     !- EPSLN: Surface emissivity with Snow
!     6,                        !- VEGHT: Surface roughness No snow conditions {cm}
!     0.25,                     !- VEGHT: Surface roughness Snow conditions {cm}
!     F;                        !- PET: Flag, Potential evapotranspiration on?
!
!          !note  Typically, PET is True
!          !note typical value .2]
!          !units m
!          !minimum> 0.0
!          !units m
!          !minimum> 0.0
!          !maximum 0.25
!          !units  m
!          !minimum> 0.0
!           !units m
!           !minimum> 0.0
!
!   GroundHeatTransfer:Basement:BldgData,
!     0.2,                      !- DWALL: Wall thickness {m}
!     0.075,                    !- DSLAB: Floor slab thickness {m}
!     0.3,                      !- DGRAVXY: Width of gravel pit beside basement wall {m}
!     0.075,                    !- DGRAVZN: Gravel depth extending above the floor slab {m}
!     0.15;                     !- DGRAVZP: Gravel depth below the floor slab {m}
!
!             !units m
!             !note typical value 0.1
!             !minimum> 0.0
!
!   GroundHeatTransfer:Basement:Interior,
!     TRUE,                     !- COND: Flag: Is the basement conditioned?
!     0.92,                     !- HIN: Downward convection only heat transfer coefficient {W/
m2-K}
!     4.04,                     !- HIN: Upward convection only heat transfer coefficient {W/m2-
K}
!     0.419,                    !- HIN: Horizontal convection only heat transfer coefficient {W/
m2-K}
!     6.13,                     !- HIN: Downward combined (convection and radiation) heat
transfer coefficient {W/m2-K}
!     9.26,                     !- HIN: Upward combined (convection and radiation) heat transfer
coefficient {W/m2-K}
!     0.424;                    !- HIN: Horizontal combined (convection and radiation) heat
transfer coefficient {W/m2-K}
!
!   GroundHeatTransfer:Basement:ComBldg,
!     17.5,                     !- January average temperature {C}
!     17.5,                     !- February average temperature {C}
!     18,                       !- March average temperature {C}
!     19,                       !- April average temperature {C}
!     20.75,                    !- May average temperature {C}
!     20,                       !- June average temperature {C}
!     18.75,                    !- July average temperature {C}
!     18.75,                    !- August average temperature {C}
!     18.75,                    !- September average temperature {C}
!     19.5,                     !- October average temperature {C}
!     18.75,                    !- November average temperature {C}
!     18.75,                    !- December average temperature {C}
!     1.5;                      !- Daily variation sine wave amplitude {deltaC}
!
!   GroundHeatTransfer:Basement:EquivSlab,
!     2.222,                    !- APRatio: The area to perimeter ratio for this slab {m}
!     TRUE;                     !- EquivSizing: Flag
!
!                !- note Will the dimensions of an equivalent slab be calculated (TRUE)
!                !- note or will the dimensions be input directly? (FALSE)]
!                !- note Only advanced special simulations should use FALSE.
!
!   GroundHeatTransfer:Basement:EquivAutoGrid,
```

```
!     15,                       !- CLEARANCE: Distance from outside of wall to edge of 3-D
ground domain {m}
!     0.075,                    !- SlabDepth: Thickness of the floor slab {m}
!     1.96;                     !- BaseDepth: Depth of the basement wall below grade {m}

!- ====== END BASEMENT IDF =====================
!-   ===========  ALL OBJECTS IN CLASS: SITE:GROUNDREFLECTANCE ===========

  Site:GroundReflectance,0.26,0.26,0.26,0.26,0.26,0.26,0.26,0.26,0.26,0.26,0.26,0.26;

!-   ===========  ALL OBJECTS IN CLASS: SITE:GROUNDREFLECTANCE:SNOWMODIFIER ===========

  Site:GroundReflectance:SnowModifier,
    2.31,                    !- Ground Reflected Solar Modifier
    2.31;                    !- Daylighting Ground Reflected Solar Modifier

!-   ===========  ALL OBJECTS IN CLASS: SCHEDULETYPELIMITS ===========

  ScheduleTypeLimits,
    Fraction,                !- Name
    0,                       !- Lower Limit Value
    1,                       !- Upper Limit Value
    Continuous,              !- Numeric Type
    Dimensionless;           !- Unit Type

  ScheduleTypeLimits,
    Temperature,             !- Name
    -60,                     !- Lower Limit Value
    200,                     !- Upper Limit Value
    Continuous,              !- Numeric Type
    Dimensionless;           !- Unit Type

  ScheduleTypeLimits,
    Control Type,            !- Name
    0,                       !- Lower Limit Value
    4,                       !- Upper Limit Value
    Discrete,                !- Numeric Type
    Dimensionless;           !- Unit Type

  ScheduleTypeLimits,
    On/Off,                  !- Name
    0,                       !- Lower Limit Value
    1,                       !- Upper Limit Value
    Discrete,                !- Numeric Type
    Dimensionless;           !- Unit Type

  ScheduleTypeLimits,
    Any Number,              !- Name
    -9E+99,                  !- Lower Limit Value
    9E+99,                   !- Upper Limit Value
    Continuous,              !- Numeric Type
    ;                        !- Unit Type

!-   ===========  ALL OBJECTS IN CLASS: SCHEDULE:COMPACT ===========

  Schedule:Compact,
    Zone1Control,            !- Name
    Control Type,            !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: Alldays,            !- Field 2
    Until: 24:00,1;          !- Field 3

  Schedule:Compact,
    Zone1HeatingAvail,       !- Name
    Fraction,                !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: Alldays,            !- Field 2
    Until: 24:00,1;          !- Field 3
```

```
Schedule:Compact,
  Furnace Fan Operating Mode Schedule,  !- Name
  Fraction,                !- Schedule Type Limits Name
  Through: 12/31,          !- Field 1
  For: Alldays,            !- Field 2
  Until: 24:00,0;          !- Field 3

Schedule:Compact,
  Zone1HeatingSetPoint,    !- Name
  Temperature,             !- Schedule Type Limits Name
  Through: 12/31,          !- Field 1
  For: Alldays,            !- Field 2
  Until: 24:00,21;         !- Field 3

Schedule:Compact,
  HRV_Schedule,            !- Name
  Fraction,                !- Schedule Type Limits Name
  Through: 12/31,          !- Field 1
  For: Alldays,            !- Field 2
  Until: 24:00,1;          !- Field 3

Schedule:Compact,
  HRV_Schedule_ex,            !- Name
  Fraction,                !- Schedule Type Limits Name
  Through: 12/31,          !- Field 1
  For: Alldays,            !- Field 2
  Until: 24:00,1;          !- Field 3

Schedule:Compact,
  Inf_schedule,            !- Name
  Fraction,                !- Schedule Type Limits Name
  Through: 12/31,          !- Field 1
  For:Alldays,             !- Field 2
  Until: 24:00,1;          !- Field 3

Schedule:Compact,
  Occupant Activity Schedule,  !- Name
  Any Number,              !- Schedule Type Limits Name
  Through: 12/31,          !- Field 1
  For: Alldays,            !- Field 2
  Until: 06:45,41.5,       !- Field 3
  Until: 7:00,0,           !- Field 5
  Until: 8:00,41.5,        !- Field 7
  Until: 12:00,0,          !- Field 9
  Until: 12:30,41.5,       !- Field 11
  Until: 17:30,0,          !- Field 13
  Until: 19:00,41.5,       !- Field 15
  Until: 20:00,83,         !- Field 17
  Until: 21:00,41.5,       !- Field 19
  Until: 23:00,16.5,       !- Field 21
  Until: 24:00,166;        !- Field 23

Schedule:Compact,
  Occupancy Schedule,      !- Name
  Any Number,              !- Schedule Type Limits Name
  Through: 12/31,          !- Field 1
  For: Alldays,            !- Field 2
  Until: 24:00,1;          !- Field 3

Schedule:Compact,
  2nd Floor Light Schedule,!- Name
  Fraction,                !- Schedule Type Limits Name
  Through: 12/31,          !- Field 1
  For: Alldays,            !- Field 2
  Until: 6:45,0,           !- Field 3
  Until: 7:45,1,           !- Field 5
  Until: 18:00,0,          !- Field 7
```

```
    Until: 23:00,1,          !- Field 9
    Until: 24:00,0;          !- Field 11

  Schedule:Compact,
    Main Floor Light Schedule,  !- Name
    Fraction,                !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: Alldays,            !- Field 2
    Until: 7:00,0,           !- Field 3
    Until: 8:00,1,           !- Field 5
    Until: 12:00,0,          !- Field 7
    Until: 12:15,1,          !- Field 9
    Until: 17:00,0,          !- Field 11
    Until: 19:30,1,          !- Field 13
    Until: 24:00,0;          !- Field 15

  Schedule:Compact,
    Kitchen Appliance Schedule,  !- Name
    Fraction,                !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: Alldays,            !- Field 2
    Until: 7:30,0,           !- Field 3
    Until: 7:40.2,1,         !- Field 5
    Until: 12:00,0,          !- Field 7
    Until: 12:10.2,1,        !- Field 9
    Until: 17:30,0,          !- Field 11
    Until: 17:40.2,1,        !- Field 13
    Until: 24:00,0;          !- Field 15

  Schedule:Compact,
    Kitchen Fan Schedule,    !- Name
    Fraction,                !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: Alldays,            !- Field 2
    Until: 7:30,0,           !- Field 3
    Until: 7:40.2,1,         !- Field 5
    Until: 12:00,0,          !- Field 7
    Until: 12:15,1,          !- Field 9
    Until: 17:30,0,          !- Field 11
    Until: 17:33.6,1,        !- Field 13
    Until: 24:00,0;          !- Field 15

  Schedule:Compact,
    Kitchen Stove Schedule,  !- Name
    Fraction,                !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: Alldays,            !- Field 2
    Until: 7:30,0,           !- Field 3
    Until: 7:50,1,           !- Field 5
    Until: 12:00,0,          !- Field 7
    Until: 12:15,1,          !- Field 9
    Until: 17:30,0,          !- Field 11
    Until: 18:00,1,          !- Field 13
    Until: 24:00,0;          !- Field 15

  Schedule:Compact,
    Dining Rm Appliance Schedule,  !- Name
    Fraction,                !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: Alldays,            !- Field 2
    Until: 18:00,0,          !- Field 3
    Until: 20:00,1,          !- Field 5
    Until: 24:00,0;          !- Field 7

  Schedule:Compact,
    Dryer Schedule,          !- Name
    Fraction,                !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
```

```
    For: Alldays,            !- Field 2
    Until: 19:00,0,          !- Field 3
    Until: 19:25.2,1,        !- Field 5
    Until: 24:00,0;          !- Field 7

  Schedule:Compact,
    Washing Machine Schedule,!- Name
    Fraction,                !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: Alldays,            !- Field 2
    Until: 17:00,0,          !- Field 3
    Until: 18:00,1,          !- Field 5
    Until: 24:00,0;          !- Field 7

  Schedule:Compact,
    Always On Schedule,      !- Name
    Fraction,                !- Schedule Type Limits Name
    Through: 12/31,          !- Field 1
    For: Alldays,            !- Field 2
    Until: 24:00,1;          !- Field 3

!- ======  GAINS  ===========================
!-  ========== ALL OBJECTS IN CLASS: PEOPLE =====

  People,
    Occupants,               !- Name
    Zone 1,                  !- Zone or ZoneList Name
    Occupancy Schedule,      !- Number of People Schedule Name
    People,                  !- Number of People Calculation Method
    4,                       !- Number of People
    ,                        !- People per Zone Floor Area {person/m2}
    ,                        !- Zone Floor Area per Person {m2/person}
    0.5,                     !- Fraction Radiant
    ,                        !- Sensible Heat Fraction
    Occupant Activity Schedule;  !- Activity Level Schedule Name

!-  ========== ALL OBJECTS IN CLASS: LIGHTS =====

  Lights,
    2nd floor lights,        !- Name
    Zone 1,                  !- Zone or ZoneList Name
    2nd Floor Light Schedule,!- Schedule Name
    LightingLevel,           !- Design Level Calculation Method
    410,                     !- Lighting Level {W}
    ,                        !- Watts per Zone Floor Area {W/m2}
    ,                        !- Watts per Person {W/person}
    0,                       !- Return Air Fraction
    0.95,                    !- Fraction Radiant
    0.05,                    !- Fraction Visible
    1,                       !- Fraction Replaceable
    Zone1 Lights,            !- End-Use Subcategory
    No;                      !- Return Air Fraction Calculated from Plenum Temperature

  Lights,
    Main floor lights,       !- Name
    Zone 1,                  !- Zone or ZoneList Name
    Main Floor Light Schedule,  !- Schedule Name
    LightingLevel,           !- Design Level Calculation Method
    200,                     !- Lighting Level {W}
    ,                        !- Watts per Zone Floor Area {W/m2}
    ,                        !- Watts per Person {W/person}
    0,                       !- Return Air Fraction
    0.95,                    !- Fraction Radiant
    0.05,                    !- Fraction Visible
    1,                       !- Fraction Replaceable
    Zone1 Lights,            !- End-Use Subcategory
    No;                      !- Return Air Fraction Calculated from Plenum Temperature
```

```
!-  ========== ALL OBJECTS IN CLASS: ELECTRIC EQUIPMENT =====

  ElectricEquipment,
    KitchenAppliances,       !- Name
    Zone 1,                  !- Zone or ZoneList Name
    Kitchen Appliance Schedule,  !- Schedule Name
    EquipmentLevel,          !- Design Level Calculation Method
    450,                     !- Design Level {W}
    ,                        !- Watts per Zone Floor Area {W/m2}
    ,                        !- Watts per Person {W/person}
    0,                       !- Fraction Latent
    0.3,                     !- Fraction Radiant
    0,                       !- Fraction Lost
    Appliances;              !- End-Use Subcategory

  ElectricEquipment,
    KitchenFan,              !- Name
    Zone 1,                  !- Zone or ZoneList Name
    Kitchen Fan Schedule,    !- Schedule Name
    EquipmentLevel,          !- Design Level Calculation Method
    80,                      !- Design Level {W}
    ,                        !- Watts per Zone Floor Area {W/m2}
    ,                        !- Watts per Person {W/person}
    0,                       !- Fraction Latent
    0.1,                     !- Fraction Radiant
    0,                       !- Fraction Lost
    Fan;                     !- End-Use Subcategory

  ElectricEquipment,
    KitchenStove,            !- Name
    Zone 1,                  !- Zone or ZoneList Name
    Kitchen Stove Schedule,  !- Schedule Name
    EquipmentLevel,          !- Design Level Calculation Method
    1600,                    !- Design Level {W}
    ,                        !- Watts per Zone Floor Area {W/m2}
    ,                        !- Watts per Person {W/person}
    0,                       !- Fraction Latent
    0.5,                     !- Fraction Radiant
    0,                       !- Fraction Lost
    Appliances;              !- End-Use Subcategory

  ElectricEquipment,
    DiningRoomAppliances,    !- Name
    Zone 1,                  !- Zone or ZoneList Name
    Dining Rm Appliance Schedule,  !- Schedule Name
    EquipmentLevel,          !- Design Level Calculation Method
    225,                     !- Design Level {W}
    ,                        !- Watts per Zone Floor Area {W/m2}
    ,                        !- Watts per Person {W/person}
    0,                       !- Fraction Latent
    0.3,                     !- Fraction Radiant
    0,                       !- Fraction Lost
    Appliances;              !- End-Use Subcategory

  ElectricEquipment,
    Dryer,                   !- Name
    Zone 1,                  !- Zone or ZoneList Name
    Dryer Schedule,          !- Schedule Name
    EquipmentLevel,          !- Design Level Calculation Method
    2250,                    !- Design Level {W}
    ,                        !- Watts per Zone Floor Area {W/m2}
    ,                        !- Watts per Person {W/person}
    0,                       !- Fraction Latent
    0.025,                   !- Fraction Radiant
    0.95,                    !- Fraction Lost
    Appliances;              !- End-Use Subcategory

  ElectricEquipment,
```

```
    Washing Machine,          !- Name
    Zone 1,                   !- Zone or ZoneList Name
    Washing Machine Schedule,!- Schedule Name
    EquipmentLevel,           !- Design Level Calculation Method
    400,                      !- Design Level {W}
    ,                         !- Watts per Zone Floor Area {W/m2}
    ,                         !- Watts per Person {W/person}
    0,                        !- Fraction Latent
    0.05,                     !- Fraction Radiant
    0,                        !- Fraction Lost
    Appliances;               !- End-Use Subcategory

  ElectricEquipment,
    Fridge,                   !- Name
    Zone 1,                   !- Zone or ZoneList Name
    Always On Schedule,       !- Schedule Name
    EquipmentLevel,           !- Design Level Calculation Method
    47.08,                    !- Design Level {W}
    ,                         !- Watts per Zone Floor Area {W/m2}
    ,                         !- Watts per Person {W/person}
    0,                        !- Fraction Latent
    0.1,                      !- Fraction Radiant
    0,                        !- Fraction Lost
    Appliances;               !- End-Use Subcategory

  ElectricEquipment,
    Furnace Heat Gains,       !- Name
    Zone 1,                   !- Zone or ZoneList Name
    Always On Schedule,       !- Schedule Name
    EquipmentLevel,           !- Design Level Calculation Method
    201,                      !- Design Level {W}
    ,                         !- Watts per Zone Floor Area {W/m2}
    ,                         !- Watts per Person {W/person}
    0,                        !- Fraction Latent
    0,                        !- Fraction Radiant
    0,                        !- Fraction Lost
    HVAC;                     !- End-Use Subcategory

  ElectricEquipment,
    Furnace Heat Gains 2,     !- Name
    Basement_Zone,            !- Zone or ZoneList Name
    Always On Schedule,       !- Schedule Name
    EquipmentLevel,           !- Design Level Calculation Method
    201,                      !- Design Level {W}
    ,                         !- Watts per Zone Floor Area {W/m2}
    ,                         !- Watts per Person {W/person}
    0,                        !- Fraction Latent
    0,                        !- Fraction Radiant
    0,                        !- Fraction Lost
    HVAC;                     !- End-Use Subcategory

!-  ========== ALL OBJECTS IN CLASS: HOTWATEREQUIPMENT =====

  HotWaterEquipment,
    Zone1DHW,                 !- Name
    All Living Space Zones,   !- Zone or ZoneList Name
    Always On Schedule,       !- Schedule Name
    EquipmentLevel,           !- Design Level Calculation Method
    250,                      !- Design Level {W}
    ,                         !- Watts per Zone Floor Area {W/m2}
    ,                         !- Watts per Person {W/Person}
    0.2,                      !- Fraction Latent
    0.1,                      !- Fraction Radiant
    0.6,                      !- Fraction Lost
    Zone1 DHW;                !- End-Use Subcategory

!-   ===========  ALL OBJECTS IN CLASS: MATERIAL ===========
```

```
Material,
  Concrete,              !- Name
  Rough,                    !- Roughness
  0.089,                    !- Thickness {m}
  1.13,                     !- Conductivity {W/m-K}
  2000,                     !- Density {kg/m3}
  1000,                     !- Specific Heat {J/kg-K}
  0.9,                      !- Thermal Absorptance
  0.6,                      !- Solar Absorptance
  0.6;                      !- Visible Absorptance

Material,
  Concrete 200,             !- Name
  Rough,                    !- Roughness
  0.2,                      !- Thickness {m}
  1.13,                     !- Conductivity {W/m-K}
  2000,                     !- Density {kg/m3}
  1000,                     !- Specific Heat {J/kg-K}
  0.9,                      !- Thermal Absorptance
  0.6,                      !- Solar Absorptance
  0.6;                      !- Visible Absorptance

Material,
  Tile,                     !- Name
  Rough,                    !- Roughness
  0.0127,                   !- Thickness {m}
  1.13,                     !- Conductivity {W/m-K}
  2000,                     !- Density {kg/m3}
  1000,                     !- Specific Heat {J/kg-K}
  0.9,                      !- Thermal Absorptance
  0.6,                      !- Solar Absorptance
  0.6;                      !- Visible Absorptance

Material,
  Brick,                    !- Name
  Rough,                    !- Roughness
  0.1,                      !- Thickness {m}
  0.72,                     !- Conductivity {W/m-K}
  1920,                     !- Density {kg/m3}
  800,                      !- Specific Heat {J/kg-K}
  0.9,                      !- Thermal Absorptance
  0.6,                      !- Solar Absorptance
  0.6;                      !- Visible Absorptance

Material,
  Gypsum,                   !- Name
  Rough,                    !- Roughness
  0.0127,                   !- Thickness {m}
  0.16,                     !- Conductivity {W/m-K}
  640,                      !- Density {kg/m3}
  1150,                     !- Specific Heat {J/kg-K}
  0.9,                      !- Thermal Absorptance
  0.2,                      !- Solar Absorptance
  0.6;                      !- Visible Absorptance

Material,
  OSB,                      !- Name
  Rough,                    !- Roughness
  0.016,                    !- Thickness {m}
  0.091,                    !- Conductivity {W/m-K}
  650,                      !- Density {kg/m3}
  1880,                     !- Specific Heat {J/kg-K}
  0.9,                      !- Thermal Absorptance
  0.6,                      !- Solar Absorptance
  0.6;                      !- Visible Absorptance

Material,
  XPS,                      !- Name
```

```
    Rough,                    !- Roughness
    0.3048,                      !- Thickness {m}
    0.030,                    !- Conductivity {W/m-K}
    40,                       !- Density {kg/m3}
    1470,                     !- Specific Heat {J/kg-K}
    0.9,                      !- Thermal Absorptance
    0.6,                      !- Solar Absorptance
    0.6;                      !- Visible Absorptance

  Material,
    Insulation AG-ext,            !- Name
    Rough,                    !- Roughness
    0.14,                     !- Thickness {m}
    0.0426,                   !- Conductivity {W/m-K} mineral fibre .036 adjusted for 18.3%
framing
    30,                       !- Density {kg/m3}
    840,                      !- Specific Heat {J/kg-K}
    0.9,                      !- Thermal Absorptance
    ,                         !- Solar Absorptance
    ;                         !- Visible Absorptance

  Material,
    Insulation AG-cav,            !- Name
    Rough,                    !- Roughness
    0.292,                     !- Thickness {m}
    0.0382,                   !- Conductivity {W/m-K} mineral fibre .036 adjusted for 7% framing
    30,                       !- Density {kg/m3}
    840,                      !- Specific Heat {J/kg-K}
    0.9,                      !- Thermal Absorptance
    ,                         !- Solar Absorptance
    ;                         !- Visible Absorptance

  Material,
    Insulation AG-int,            !- Name
    Rough,                    !- Roughness
    0.089,                     !- Thickness {m}
    0.0428,                   !- Conductivity {W/m-K} mineral fibre .036 adjusted for 14.4%
framing
    30,                       !- Density {kg/m3}
    840,                      !- Specific Heat {J/kg-K}
    0.9,                      !- Thermal Absorptance
    ,                         !- Solar Absorptance
    ;                         !- Visible Absorptance

  Material,
    Insulation AG-S1a-ext,          !- Name
    Rough,                    !- Roughness
    0.14,                     !- Thickness {m} mineral fibre .036  adjusted for 13% framing
    0.0432,                  !- Conductivity {W/m-K}
    30,                       !- Density {kg/m3}
    840,                      !- Specific Heat {J/kg-K}
    0.9,                      !- Thermal Absorptance
    ,                         !- Solar Absorptance
    ;                         !- Visible Absorptance

  Material,
    Insulation AG-S1a-cav,          !- Name
    Rough,                    !- Roughness
    0.292,                     !- Thickness {m} mineral fibre .036  adjusted for 15% framing
    0.0414,                  !- Conductivity {W/m-K}
    30,                       !- Density {kg/m3}
    840,                      !- Specific Heat {J/kg-K}
    0.9,                      !- Thermal Absorptance
    ,                         !- Solar Absorptance
    ;                         !- Visible Absorptance

  Material,
    Insulation AG-S1a-int,          !- Name
```

```
  Rough,                     !- Roughness
  0.089,                      !- Thickness {m} mineral fibre .036  adjusted for 20% framing
  0.0432,                   !- Conductivity {W/m-K}
  30,                        !- Density {kg/m3}
  840,                       !- Specific Heat {J/kg-K}
  0.9,                       !- Thermal Absorptance
  ,                          !- Solar Absorptance
  ;                          !- Visible Absorptance

Material,
  Insulation AG-S3a-ext,            !- Name
  Rough,                     !- Roughness
  0.14,                      !- Thickness {m} mineral fibre .036  adjusted for 18% framing
  0.0452,                   !- Conductivity {W/m-K}
  30,                        !- Density {kg/m3}
  840,                       !- Specific Heat {J/kg-K}
  0.9,                       !- Thermal Absorptance
  ,                          !- Solar Absorptance
  ;                          !- Visible Absorptance

Material,
  Insulation AG-S3a-cav,            !- Name
  Rough,                     !- Roughness
  0.292,                      !- Thickness {m} mineral fibre .036  adjusted for 22% framing
  0.0439,                   !- Conductivity {W/m-K}
  30,                        !- Density {kg/m3}
  840,                       !- Specific Heat {J/kg-K}
  0.9,                       !- Thermal Absorptance
  ,                          !- Solar Absorptance
  ;                          !- Visible Absorptance

Material,
  Insulation AG-S3a-int,            !- Name
  Rough,                     !- Roughness
  0.089,                      !- Thickness {m} mineral fibre .036  adjusted for 25% framing
  0.0452,                   !- Conductivity {W/m-K}
  30,                        !- Density {kg/m3}
  840,                       !- Specific Heat {J/kg-K}
  0.9,                       !- Thermal Absorptance
  ,                          !- Solar Absorptance
  ;                          !- Visible Absorptance

Material,
  Insulation AG-E1b-ext,            !- Name
  Rough,                     !- Roughness
  0.14,                      !- Thickness {m} mineral fibre .036  adjusted for 12% framing
  0.0427,                   !- Conductivity {W/m-K}
  30,                        !- Density {kg/m3}
  840,                       !- Specific Heat {J/kg-K}
  0.9,                       !- Thermal Absorptance
  ,                          !- Solar Absorptance
  ;                          !- Visible Absorptance

Material,
  Insulation AG-E1b-cav,            !- Name
  Rough,                     !- Roughness
  0.292,                      !- Thickness {m} mineral fibre .036  adjusted for 8% framing
  0.0387,                   !- Conductivity {W/m-K}
  30,                        !- Density {kg/m3}
  840,                       !- Specific Heat {J/kg-K}
  0.9,                       !- Thermal Absorptance
  ,                          !- Solar Absorptance
  ;                          !- Visible Absorptance

Material,
  Insulation AG-E1b-int,            !- Name
  Rough,                     !- Roughness
  0.089,                      !- Thickness {m} mineral fibre .036  adjusted for 19% framing
```

```
    0.0427,                 !- Conductivity {W/m-K}
    30,                      !- Density {kg/m3}
    840,                     !- Specific Heat {J/kg-K}
    0.9,                     !- Thermal Absorptance
    ,                        !- Solar Absorptance
    ;                        !- Visible Absorptance

 Material,
    Insulation AG-N1-ext,          !- Name
    Rough,                   !- Roughness
    0.14,                    !- Thickness {m} mineral fibre .036  adjusted for 18% framing
    0.0453,                 !- Conductivity {W/m-K}
    30,                      !- Density {kg/m3}
    840,                     !- Specific Heat {J/kg-K}
    0.9,                     !- Thermal Absorptance
    ,                        !- Solar Absorptance
    ;                        !- Visible Absorptance

 Material,
    Insulation AG-N1-cav,          !- Name
    Rough,                   !- Roughness
    0.292,                    !- Thickness {m} mineral fibre .036  adjusted for 13% framing
    0.0406,                 !- Conductivity {W/m-K}
    30,                      !- Density {kg/m3}
    840,                     !- Specific Heat {J/kg-K}
    0.9,                     !- Thermal Absorptance
    ,                        !- Solar Absorptance
    ;                        !- Visible Absorptance

 Material,
    Insulation AG-N1-int,          !- Name
    Rough,                   !- Roughness
    0.089,                    !- Thickness {m} mineral fibre .036  adjusted for 26% framing
    0.0453,                 !- Conductivity {W/m-K}
    30,                      !- Density {kg/m3}
    840,                     !- Specific Heat {J/kg-K}
    0.9,                     !- Thermal Absorptance
    ,                        !- Solar Absorptance
    ;                        !- Visible Absorptance

Material,
    Insulation AG-W1-ext,          !- Name
    Rough,                   !- Roughness
    0.14,                    !- Thickness {m} mineral fibre .036  adjusted for 1% framing
    0.0367,                 !- Conductivity {W/m-K}
    30,                      !- Density {kg/m3}
    840,                     !- Specific Heat {J/kg-K}
    0.9,                     !- Thermal Absorptance
    ,                        !- Solar Absorptance
    ;                        !- Visible Absorptance

Material,
    Insulation AG-W1-cav,          !- Name
    Rough,                   !- Roughness
    0.292,                    !- Thickness {m} mineral fibre .036  adjusted for 2% framing
    0.0367,                 !- Conductivity {W/m-K}
    30,                      !- Density {kg/m3}
    840,                     !- Specific Heat {J/kg-K}
    0.9,                     !- Thermal Absorptance
    ,                        !- Solar Absorptance
    ;                        !- Visible Absorptance

Material,
    Insulation AG-W1-int,          !- Name
    Rough,                   !- Roughness
    0.089,                    !- Thickness {m} mineral fibre .036  adjusted for 2% framing
    0.0367,                 !- Conductivity {W/m-K}
    30,                      !- Density {kg/m3}
```

```
    840,                        !- Specific Heat {J/kg-K}
    0.9,                        !- Thermal Absorptance
    ,                           !- Solar Absorptance
    ;                           !- Visible Absorptance

  Material,
    Insulation BG,              !- Name
    Rough,                      !- Roughness
    0.292,                     !- Thickness {m} mineral fibre
    0.0382,                      !- Conductivity {W/m-K}
    30,                         !- Density {kg/m3}
    840,                       !- Specific Heat {J/kg-K}
    0.9,                        !- Thermal Absorptance
    ,                           !- Solar Absorptance
    ;                           !- Visible Absorptance

  Material,
    Insulation BG-struc,              !- Name
    Rough,                      !- Roughness
    0.089,                     !- Thickness {m} mineral fibre .036  adjusted for 14.2% framing
    0.0411,                      !- Conductivity {W/m-K}
    30,                         !- Density {kg/m3}
    840,                       !- Specific Heat {J/kg-K}
    0.9,                        !- Thermal Absorptance
    ,                           !- Solar Absorptance
    ;                           !- Visible Absorptance

  Material,
    Insulation BG-N1a,              !- Name
    Rough,                      !- Roughness
    0.292,                     !- Thickness {m} mineral fibre adjusted for 24% framing
    0.0447,                      !- Conductivity {W/m-K}
    30,                         !- Density {kg/m3}
    840,                       !- Specific Heat {J/kg-K}
    0.9,                        !- Thermal Absorptance
    ,                           !- Solar Absorptance
    ;                           !- Visible Absorptance

  Material,
    Insulation BG-N1a-struc,              !- Name
    Rough,                      !- Roughness
    0.089,                     !- Thickness {m} mineral fibre adjusted for 26% framing
    0.0454,                      !- Conductivity {W/m-K}
    30,                         !- Density {kg/m3}
    840,                       !- Specific Heat {J/kg-K}
    0.9,                        !- Thermal Absorptance
    ,                           !- Solar Absorptance
    ;                           !- Visible Absorptance


  Material,
    CeilingInsulation,          !- Name
    Rough,                      !- Roughness
    0.989,                     !- Thickness {m}
    0.039,                     !- Conductivity {W/m-K} blown cellulose
     35,                         !- Density {kg/m3}
    1380,                        !- Specific Heat {J/kg-K}
    0.9,                        !- Thermal Absorptance
    ,                           !- Solar Absorptance
    ;                           !- Visible Absorptance

  Material,
    CeilingInsulation-TC,          !- Name
    Rough,                      !- Roughness
    0.9,                     !- Thickness {m}
    0.0401,                     !- Conductivity {W/m-K} blown cellulose 0.039 adjusted for 3%
framing
     35,                         !- Density {kg/m3}
```

```
    1380,                     !- Specific Heat {J/kg-K}
    0.9,                     !- Thermal Absorptance
    ,                        !- Solar Absorptance
    ;                        !- Visible Absorptance

 Material,
    CeilingInsulation-BC,       !- Name
    Rough,                   !- Roughness
    0.089,                  !- Thickness {m}
    0.0406,                  !- Conductivity {W/m-K} mineral batt 0.036 adjusted for 6.7%
framing
     35,                      !- Density {kg/m3}
    1380,                     !- Specific Heat {J/kg-K}
    0.9,                     !- Thermal Absorptance
    ,                        !- Solar Absorptance
    ;                        !- Visible Absorptance

  Material,
    GarageCeilingInsulation, !- Name
    Rough,                   !- Roughness
    0.2450,                   !- Thickness {m}
    0.039,                  !- Conductivity {W/m-K} blown cellulose
     35,                      !- Density {kg/m3}
    1380,                     !- Specific Heat {J/kg-K}
    0.9,                     !- Thermal Absorptance
    ,                        !- Solar Absorptance
    ;                        !- Visible Absorptance

  Material,
    Shingles_Asphalt,        !- Name
    Rough,                   !- Roughness
    0.003,                   !- Thickness {m}
    0.038,                   !- Conductivity {W/m-K}
    920,                     !- Density {kg/m3}
    1510,                    !- Specific Heat {J/kg-K}
    0.9,                     !- Thermal Absorptance
    0.9,                     !- Solar Absorptance
    0.9;                     !- Visible Absorptance
s
!-  ===========  ALL OBJECTS IN CLASS: MATERIAL:NoMass ==================

  Material:NoMass,
    door_material_insulated, !- Name
    MediumSmooth,            !- Roughness
    2.6,                     !- Thermal Resistance {m2-K/W}
    0.8,                     !- Thermal Absorptance
    0.4,                     !- Solar Absorptance
    0.4;                     !- Visible Absorptance

!-  ===========  ALL OBJECTS IN CLASS: MATERIAL:AIRGAP ==================

  Material:AirGap,
    AirSpace20,              !- Name
    0.16;                    !- Thermal Resistance {m2-K/W}

  Material:AirGap,
    AirSpace90horiz,         !- Name
    0.16;                    !- Thermal Resistance {m2-K/W}

  Material:AirGap,
    AirSpace90vertical,      !- Name
    0.15;                    !- Thermal Resistance {m2-K/W}

!-   ===========  ALL OBJECTS IN CLASS: WINDOWMATERIAL:Glazing ================

  WindowMaterial:Glazing,
    layer1,                  !- Name
    SpectralAverage,         !- Optical Data Type
```

```
    ,                        !- Window Glass Spectral Data Set Name
    0.00566,                !- Thickness {m}
    0.79,                   !- Solar Transmittance at Normal Incidence
    0.071,                   !- Front Side Solar Reflectance at Normal Incidence
    0.071,                   !- Back Side Solar Reflectance at Normal Incidence
    0.89,                   !- Visible Transmittance at Normal Incidence
    0.081,                   !- Front Side Visible Reflectance at Normal Incidence
    0.081,                   !- Back Side Visible Reflectance at Normal Incidence
    0,                       !- Infrared Transmittance at Normal Incidence
    0.84,                   !- Front Side Infrared Hemispherical Emissivity
    0.84,                   !- Back Side Infrared Hemispherical Emissivity
    1,                       !- Conductivity {W/m-K}
    ,                        !- Dirt Correction Factor for Solar and Visible Transmittance
    no;                      !- Solar Diffusing

  WindowMaterial:Glazing,
    layer2,                  !- Name
     SpectralAverage,         !- Optical Data Type
    ,                        !- Window Glass Spectral Data Set Name
    0.00572,                !- Thickness {m}
    0.27,                   !- Solar Transmittance at Normal Incidence
    0.055,                   !- Front Side Solar Reflectance at Normal Incidence
    0.035,                   !- Back Side Solar Reflectance at Normal Incidence
    0.70,                   !- Visible Transmittance at Normal Incidence
    0.043,                   !- Front Side Visible Reflectance at Normal Incidence
    0.065,                   !- Back Side Visible Reflectance at Normal Incidence
    0,                       !- Infrared Transmittance at Normal Incidence
    0.022,                   !- Front Side Infrared Hemispherical Emissivity
    0.84,                   !- Back Side Infrared Hemispherical Emissivity
    1,                       !- Conductivity {W/m-K}
    ,                        !- Dirt Correction Factor for Solar and Visible Transmittance
    no;                      !- Solar Diffusing

  WindowMaterial:Glazing,
    layer3,                  !- Name
     SpectralAverage,         !- Optical Data Type
    ,                        !- Window Glass Spectral Data Set Name
    0.00572,                !- Thickness {m}
    0.27,                   !- Solar Transmittance at Normal Incidence
    0.055,                   !- Front Side Solar Reflectance at Normal Incidence
    0.035,                   !- Back Side Solar Reflectance at Normal Incidence
    0.70,                   !- Visible Transmittance at Normal Incidence
    0.043,                   !- Front Side Visible Reflectance at Normal Incidence
    0.065,                   !- Back Side Visible Reflectance at Normal Incidence
    0,                       !- Infrared Transmittance at Normal Incidence
    0.022,                   !- Front Side Infrared Hemispherical Emissivity
    0.84,                   !- Back Side Infrared Hemispherical Emissivity
    1,                       !- Conductivity {W/m-K}
    ,                        !- Dirt Correction Factor for Solar and Visible Transmittance
    yes;                      !- Solar Diffusing

!-   ===========  ALL OBJECTS IN CLASS: WINDOWMATERIAL:GASMIXTURE ===========

  WindowMaterial:Gas,
    gap1,                    !- Name
    Xenon,                  !- Type
    0.015;                       !- Thickness {m}

!-  =========== ALL OBJECTS IN CLASS: WINDOWPROPERTY:FRAMEANDDIVIDER =========

  WindowProperty:FrameAndDivider,
    Tier 4 Window Zola - Frames,         !- Name
    0.088,                    !- Frame Width {m}
    ,                  !- Frame Outside Projection {m}
    ,                 !- Frame Inside Projection {m}
    1.05,                    !- Frame Conductance {W/m2-K}
    1.49,                    !- Ratio of Frame-Edge Glass Conductance to Center-Of-Glass
Conductance
```

```
    0.9,                        !- Frame Solar Absorptance
    0.9,                         !- Frame Visible Absorptance
    0.9,                         !- Frame Thermal Hemispherical Emissivity
    ,                            !- Divider Type
    ,                            !- Divider Width {m}
    ,                            !- Number of Horizontal Dividers
    ,                            !- Number of Vertical Dividers
    ,                            !- Divider Outside Projection {m}
    ,                            !- Divider Inside Projection {m}
    ,                            !- Divider Conductance {W/m2-K}
    ,                            !- Ratio of Divider-Edge Glass Conductance to Center-Of-Glass
Conductance
    ,                            !- Divider Solar Absorptance
    ,                            !- Divider Visible Absorptance
    ;                            !- Divider Thermal Hemispherical Emissivity

!-   ===========  ALL OBJECTS IN CLASS: CONSTRUCTION ===========

  Construction,
    Brick_Wall,                  !- Name
    Brick,                       !- Outside Layer
    OSB,                         !- Layer 2
    Insulation AG-ext,               !- Layer 3
    Insulation AG-cav,               !- Layer 4
  Insulation AG-int,               !- Layer 5
    Gypsum;                      !- Layer 6

 Construction,
    Brick_Wall_W,                  !- Name
    Brick,                       !- Outside Layer
    OSB,                         !- Layer 2
    Insulation AG-ext,               !- Layer 3
    Insulation AG-cav,               !- Layer 4
  Insulation AG-int,               !- Layer 5
    Gypsum;                      !- Layer 5

  Construction,
    Brick_Wall_S1a,                !- Name
    Brick,                       !- Outside Layer
    OSB,                         !- Layer 2
    Insulation AG-S1a-ext,           !- Layer 3
    Insulation AG-S1a-cav,           !- Layer 4
    Insulation AG-S1a-int,           !- Layer 5
    Gypsum;                      !- Layer 6

  Construction,
    Brick_Wall_S3a,                !- Name
    Brick,                       !- Outside Layer
    OSB,                         !- Layer 2
    Insulation AG-S3a-ext,           !- Layer 3
    Insulation AG-S3a-cav,           !- Layer 4
    Insulation AG-S3a-int,           !- Layer 5
    Gypsum;                      !- Layer 6

  Construction,
    Brick_Wall_E1b,                !- Name
    Brick,                       !- Outside Layer
    OSB,                         !- Layer 2
    Insulation AG-E1b-ext,           !- Layer 3
    Insulation AG-E1b-cav,           !- Layer 4
    Insulation AG-E1b-int,           !- Layer 5
    Gypsum;                      !- Layer 6

  Construction,
    Brick_Wall_N1,                !- Name
    Brick,                       !- Outside Layer
    OSB,                         !- Layer 2
    Insulation AG-N1-ext,            !- Layer 3
```

```
    Insulation AG-N1-cav,          !- Layer 4
    Insulation AG-N1-int,          !- Layer 5
    Gypsum;                  !- Layer 6

  Construction,
    Brick_Wall_W1,            !- Name
    Brick,                   !- Outside Layer
    OSB,                     !- Layer 2
    Insulation AG-W1-ext,          !- Layer 3
    Insulation AG-W1-cav,          !- Layer 4
    Insulation AG-W1-int,          !- Layer 5
    Gypsum;                  !- Layer 6

  Construction,
    basement_floor,          !- Name
    XPS,                     !- Outside Layer
    concrete;             !- Layer 2


  Construction,
    ceiling_insulated,       !- Name
    CeilingInsulation,       !- Outside Layer
    Gypsum;                  !- Layer 2

  Construction,
    ceiling_insulated_reverse,  !- Name
    Gypsum,                  !- Outside Layer
    CeilingInsulation;       !- Layer 2

  Construction,
    Roof_uninsulated,        !- Name
    Shingles_Asphalt,        !- Outside Layer
    OSB;                     !- Layer 2

  Construction,
    Roof_insulated,          !- Name
    Shingles_Asphalt,        !- Outside Layer
    OSB,                     !- Layer 2
    CeilingInsulation-TC,       !- Layer 3
    CeilingInsulation-BC,    !-Layer 4
    Gypsum;                  !- Layer 5

  Construction,
    Brick_Wall_Uninsulated,  !- Name
    Brick,                   !- Outside Layer
    OSB,                     !- Layer 2
    airspace20,              !- Layer 3
    OSB;                     !- Layer 4

  Construction,
    below_grade,             !- Name
   Concrete 200,              !- Outside Layer
   airspace20,           !- Layer 2
    Insulation BG,           !- Layer 3
    Insulation BG-struc,     !- Layer 4
    Gypsum;                  !- Layer 5

  Construction,
    below_grade_Nbsmt_1a,             !- Name
   Concrete 200,              !- Outside Layer
    airspace20,           !- Layer 2
    Insulation BG-N1a,       !- Layer 3
    Insulation BG-N1a-struc,     !- Layer 4
    Gypsum;                  !- Layer 5

  Construction,
    garage_ceiling,          !- Name
    GarageCeilingInsulation; !- Outside Layer
```

```
  Construction,
    interior_garage_wall,    !- Name
    Gypsum,                  !- Outside Layer
    Insulation AG-ext,           !- Layer 2
    Insulation AG-cav,           !- Layer 3
  Insulation AG-int,           !- Layer 4
    Gypsum;                  !- Layer 5

  Construction,
    interior_floor,          !- Name
    Gypsum,                  !- Outside Layer
    AirSpace90horiz,         !- Layer 2
    OSB;                     !- Layer 3

  Construction,
    interior_floor_rev,      !- Name
    OSB,                     !- Outside Layer
    AirSpace90horiz,         !- Layer 2
    Gypsum;                  !- Layer 3

  Construction,
    interior_floor_tile,     !- Name
    Gypsum,                  !- Outside Layer
    AirSpace90horiz,         !- Layer 2
    OSB,                     !- Layer 3
    Tile;                    !- Layer 4

  Construction,
    interior_floor_tile_rev, !- Name
    Tile,                    !- Outside Layer
    OSB,                     !- Layer 2
    AirSpace90horiz,         !- Layer 3
    Gypsum;                  !- Layer 4

  Construction,
    interior walls,          !- Name
    Gypsum,                  !- Outside Layer
    AirSpace90vertical,      !- Layer 2
    Gypsum;                  !- Layer 3

  Construction,
    door_insulated,          !- Name
    door_material_insulated; !- Outside Layer

 Construction,
    Tier 4 Window Zola,   !- Name
    layer1,
    gap1,
    layer2,
    gap1,
    layer3;

!-   ===========  ALL OBJECTS IN CLASS: GLOBALGEOMETRYRULES ===========

  GlobalGeometryRules,
    LowerLeftCorner,         !- Starting Vertex Position
    Counterclockwise,        !- Vertex Entry Direction
    Relative,                !- Coordinate System
    Relative,                !- Daylighting Reference Point Coordinate System
    Relative;                !- Rectangular Surface Coordinate System

!-   ===========  ALL OBJECTS IN CLASS: ZONE ===========

  Zone,
    Zone 1,                  !- Name
    0,                       !- Direction of Relative North {deg}
    0,                       !- X Origin {m}
```

```
    0,                       !- Y Origin {m}
    0,                       !- Z Origin {m}
    1,                       !- Type
    1,                       !- Multiplier
    ,                        !- Ceiling Height {m}
    686.66,                     !- Volume {m3}
    autocalculate,           !- Floor Area {m2}
    ,                        !- Zone Inside Convection Algorithm
    ,                        !- Zone Outside Convection Algorithm
    Yes;                     !- Part of Total Floor Area

  Zone,
    Basement_Zone,           !- Name
    0,                       !- Direction of Relative North {deg}
    0,                       !- X Origin {m}
    0,                       !- Y Origin {m}
    0,                       !- Z Origin {m}
    1,                       !- Type
    1,                       !- Multiplier
    2.6,                     !- Ceiling Height {m}
    ,                        !- Volume {m3}
    autocalculate,           !- Floor Area {m2}
    ,                        !- Zone Inside Convection Algorithm
    ,                        !- Zone Outside Convection Algorithm
    No;                      !- Part of Total Floor Area

  Zone,
    Attic_Zone,              !- Name
    0,                       !- Direction of Relative North {deg}
    0,                       !- X Origin {m}
    0,                       !- Y Origin {m}
    0,                       !- Z Origin {m}
    1,                       !- Type
    1,                       !- Multiplier
    ,                        !- Ceiling Height {m}
    ,                        !- Volume {m3}
    autocalculate,           !- Floor Area {m2}
    ,                        !- Zone Inside Convection Algorithm
    ,                        !- Zone Outside Convection Algorithm
    no;                      !- Part of Total Floor Area

  Zone,
    Garage_Zone,             !- Name
    0,                       !- Direction of Relative North {deg}
    0,                       !- X Origin {m}
    0,                       !- Y Origin {m}
    0,                       !- Z Origin {m}
    1,                       !- Type
    1,                       !- Multiplier
    2.77,                    !- Ceiling Height {m}
    ,                        !- Volume {m3}
    autocalculate,           !- Floor Area {m2}
    ,                        !- Zone Inside Convection Algorithm
    ,                        !- Zone Outside Convection Algorithm
    No;                      !- Part of Total Floor Area

!-   ==========  ALL OBJECTS IN CLASS: ZONELIST

  Zonelist,
    All Living Space Zones,  !- Name
    Zone 1,                  !- Zone 1 Name
    Basement_Zone;           !- Zone 2 Name

  Zonelist,
    All Unoccupied Zones,    !- Name
    Attic_Zone,              !- Zone 1 Name
    Garage_Zone;             !- Zone 2 Name
!
```

```
!-   ===========  ALL OBJECTS IN CLASS: BUILDINGSURFACE:DETAILED ===========
!- SOUTH WALLS
!
!   BuildingSurface:Detailed,
!     south wall 1a,           !- Name
!     Wall,                    !- Surface Type
!     Brick_Wall_S1a,            !- Construction Name
!     Zone 1,                  !- Zone Name
!     Outdoors,                !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     SunExposed,              !- Sun Exposure
!     WindExposed,             !- Wind Exposure
!     0.5,                     !- View Factor to Ground
!     4,                       !- Number of Vertices
!     0,0,0.64,  !- X,Y,Z ==> Vertex 1 {m}
!     4.38,0,0.64,  !- X,Y,Z ==> Vertex 2 {m}
!     4.38,0,6.64,  !- X,Y,Z ==> Vertex 3 {m}
!     0,0,6.64;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     south wall 1b,           !- Name
!     Wall,                    !- Surface Type
!     Brick_Wall_Uninsulated,  !- Construction Name
!     attic_zone,              !- Zone Name
!     Outdoors,                !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     SunExposed,              !- Sun Exposure
!     WindExposed,             !- Wind Exposure
!     0.5,                     !- View Factor to Ground
!     3,                       !- Number of Vertices
!     0,0,6.64,  !- X,Y,Z ==> Vertex 1 {m}
!     4.38,0,6.64,  !- X,Y,Z ==> Vertex 2 {m}
!     2.182,0,8.263;  !- X,Y,Z ==> Vertex 3 {m}
!
!   BuildingSurface:Detailed,
!     south bsmt wall 1,       !- Name
!     Wall,                    !- Surface Type
!     below_grade,             !- Construction Name
!     Basement_Zone,           !- Zone Name
!     Outdoors,                !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     SunExposed,              !- Sun Exposure
!     WindExposed,             !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     4,                       !- Number of Vertices
!     0,0,0,  !- X,Y,Z ==> Vertex 1 {m}
!     4.38,0,0,  !- X,Y,Z ==> Vertex 2 {m}
!     4.38,0,0.64,  !- X,Y,Z ==> Vertex 3 {m}
!     0,0,0.64;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     south bg wall 1,         !- Name
!     Wall,                    !- Surface Type
!     below_grade,             !- Construction Name
!     Basement_Zone,           !- Zone Name
!     GroundBasementPreprocessorAverageWall,  !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     NoSun,                   !- Sun Exposure
!     NoWind,                  !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     4,                       !- Number of Vertices
!     0,0,-1.96,  !- X,Y,Z ==> Vertex 1 {m}
!     4.38,0,-1.94,  !- X,Y,Z ==> Vertex 2 {m}
!     4.38,0,0,  !- X,Y,Z ==> Vertex 3 {m}
!     0,0,0;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     south wall 2a,           !- Name
```

```
!     Wall,                    !- Surface Type
!     Brick_Wall_w,            !- Construction Name
!     Zone 1,                  !- Zone Name
!     Outdoors,                !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     SunExposed,              !- Sun Exposure
!     WindExposed,             !- Wind Exposure
!     0.5,                     !- View Factor to Ground
!     4,                       !- Number of Vertices
!     4.38,1.23,0.64,  !- X,Y,Z ==> Vertex 1 {m}
!     7.8,1.23,0.64,  !- X,Y,Z ==> Vertex 2 {m}
!     7.8,1.23,3.41,  !- X,Y,Z ==> Vertex 3 {m}
!     4.38,1.23,3.41;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     south bsmt wall 2a,      !- Name
!     Wall,                    !- Surface Type
!     below_grade,             !- Construction Name
!     Basement_Zone,           !- Zone Name
!     Outdoors,                !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     SunExposed,              !- Sun Exposure
!     WindExposed,             !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     4,                       !- Number of Vertices
!     4.38,1.23,0,  !- X,Y,Z ==> Vertex 1 {m}
!     7.8,1.23,0,  !- X,Y,Z ==> Vertex 2 {m}
!     7.8,1.23,0.64,  !- X,Y,Z ==> Vertex 3 {m}
!     4.38,1.23,0.64;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     south bg wall 2a,        !- Name
!     Wall,                    !- Surface Type
!     below_grade,             !- Construction Name
!     Basement_Zone,           !- Zone Name
!     GroundBasementPreprocessorAverageWall,  !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     NoSun,                   !- Sun Exposure
!     NoWind,                  !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     4,                       !- Number of Vertices
!     4.38,1.23,-1.96,  !- X,Y,Z ==> Vertex 1 {m}
!     7.8,1.23,-1.96,  !- X,Y,Z ==> Vertex 2 {m}
!     7.8,1.23,0,  !- X,Y,Z ==> Vertex 3 {m}
!     4.38,1.23,0;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     south bg wall 2b,        !- Name
!     Wall,                    !- Surface Type
!     below_grade,             !- Construction Name
!     Basement_Zone,           !- Zone Name
!     GroundBasementPreprocessorAverageWall,  !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     NoSun,                   !- Sun Exposure
!     NoWind,                  !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     4,                       !- Number of Vertices
!     7.8,7.45,-1.96,  !- X,Y,Z ==> Vertex 1 {m}
!     12.2,7.45,-1.96,  !- X,Y,Z ==> Vertex 2 {m}
!     12.2,7.45,0.64,  !- X,Y,Z ==> Vertex 3 {m}
!     7.8,7.45,0.64;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     south wall 2b,           !- Name
!     Wall,                    !- Surface Type
!     Brick_Wall_Uninsulated,  !- Construction Name
!     Garage_Zone,             !- Zone Name
!     Outdoors,                !- Outside Boundary Condition
```

```
!     ,                        !- Outside Boundary Condition Object
!     SunExposed,              !- Sun Exposure
!     WindExposed,             !- Wind Exposure
!     0.5,                     !- View Factor to Ground
!     4,                       !- Number of Vertices
!     7.8,1.23,0.64,  !- X,Y,Z ==> Vertex 1 {m}
!     12.2,1.23,0.64,  !- X,Y,Z ==> Vertex 2 {m}
!     12.2,1.23,3.41,  !- X,Y,Z ==> Vertex 3 {m}
!     7.8,1.23,3.41;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     south wall 3a,           !- Name
!     Wall,                    !- Surface Type
!     Brick_Wall_S3a,            !- Construction Name
!     Zone 1,                  !- Zone Name
!     Outdoors,                !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     SunExposed,              !- Sun Exposure
!     WindExposed,             !- Wind Exposure
!     0.5,                     !- View Factor to Ground
!     4,                       !- Number of Vertices
!     4.38,1.23,3.41,  !- X,Y,Z ==> Vertex 1 {m}
!     9.411,1.23,3.41,  !- X,Y,Z ==> Vertex 2 {m}
!     9.411,1.23,6.64,  !- X,Y,Z ==> Vertex 3 {m}
!     4.38,1.23,6.64;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     south wall 3c,           !- Name
!     Wall,                    !- Surface Type
!     Brick_Wall,              !- Construction Name
!     Zone 1,                  !- Zone Name
!     Outdoors,                !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     SunExposed,              !- Sun Exposure
!     WindExposed,             !- Wind Exposure
!     0.5,                     !- View Factor to Ground
!     4,                       !- Number of Vertices
!     9.411,1.23,3.41,  !- X,Y,Z ==> Vertex 1 {m}
!     12.2,1.23,3.41,  !- X,Y,Z ==> Vertex 2 {m}
!     12.2,1.23,4.58,  !- X,Y,Z ==> Vertex 3 {m}
!     9.411,1.23,4.58;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     south wall 3b,           !- Name
!     Wall,                    !- Surface Type
!     Brick_Wall_Uninsulated,  !- Construction Name
!     Attic_Zone,              !- Zone Name
!     Outdoors,                !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     SunExposed,              !- Sun Exposure
!     WindExposed,             !- Wind Exposure
!     0.5,                     !- View Factor to Ground
!     3,                       !- Number of Vertices
!     6.467,1.23,6.64,  !- X,Y,Z ==> Vertex 1 {m}
!     9.411,1.23,6.64,  !- X,Y,Z ==> Vertex 2 {m}
!     7.939,1.23,7.685;  !- X,Y,Z ==> Vertex 3 {m}
!
!- SOUTH ROOFS
!
!   BuildingSurface:Detailed,
!     south roof 1,            !- Name
!     Roof,                    !- Surface Type
!     Roof_uninsulated,        !- Construction Name
!     Attic_Zone,              !- Zone Name
!     Outdoors,                !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     SunExposed,              !- Sun Exposure
!     WindExposed,             !- Wind Exposure
```

```
!     autocalculate,           !- View Factor to Ground
!     5,                       !- Number of Vertices
!     4.38,1.23,6.64,  !- X,Y,Z ==> Vertex 1 {m}
!     6.467,1.23,6.64,  !- X,Y,Z ==> Vertex 2 {m}
!     7.939,3.108,7.63,  !- X,Y,Z ==> Vertex 3 {m}
!     4.48,5.8,10.24,  !- X,Y,Z ==> Vertex 4 {m}
!     2.182,3.16,8.263;  !- X,Y,Z ==> Vertex 5 {m}
!
!   BuildingSurface:Detailed,
!     south roof 2a,           !- Name
!     Roof,                    !- Surface Type
!     Roof_insulated,          !- Construction Name
!     Zone 1,                  !- Zone Name
!     Outdoors,                !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     SunExposed,              !- Sun Exposure
!     WindExposed,             !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     4,                       !- Number of Vertices
!     9.411,1.23,4.58,  !- X,Y,Z ==> Vertex 1 {m}
!     12.2,1.23,4.58,  !- X,Y,Z ==> Vertex 2 {m}
!     12.2,3.662,6.64,  !- X,Y,Z ==> Vertex 3 {m}
!     9.411,3.662,6.64;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     south roof 2b,           !- Name
!     Roof,                    !- Surface Type
!     Roof_uninsulated,        !- Construction Name
!     Attic_Zone,              !- Zone Name
!     Outdoors,                !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     SunExposed,              !- Sun Exposure
!     WindExposed,             !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     4,                       !- Number of Vertices
!     12.2,3.662,6.64,  !- X,Y,Z ==> Vertex 1 {m}
!     9.46,6.4,9.34,  !- X,Y,Z ==> Vertex 2 {m}
!     6.414,6.4,9.34,  !- X,Y,Z ==> Vertex 3 {m}
!     9.411,3.662,6.64;  !- X,Y,Z ==> Vertex 4 {m}
!
!- EAST WALLS
!
!   BuildingSurface:Detailed,
!     east wall 1a,            !- Name
!     Wall,                    !- Surface Type
!     Brick_Wall_uninsulated,  !- Construction Name
!     Garage_Zone,             !- Zone Name
!     Outdoors,                !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     SunExposed,              !- Sun Exposure
!     WindExposed,             !- Wind Exposure
!     0.5,                     !- View Factor to Ground
!     4,                       !- Number of Vertices
!     12.2,1.23,0.64,  !- X,Y,Z ==> Vertex 1 {m}
!     12.2,7.45,0.64,  !- X,Y,Z ==> Vertex 2 {m}
!     12.2,7.45,3.41,  !- X,Y,Z ==> Vertex 3 {m}
!     12.2,1.23,3.41;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     east wall 1b,            !- Name
!     Wall,                    !- Surface Type
!     Brick_Wall_E1b,            !- Construction Name
!     Zone 1,                  !- Zone Name
!     Outdoors,                !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     SunExposed,              !- Sun Exposure
!     WindExposed,             !- Wind Exposure
!     0.5,                     !- View Factor to Ground
```

```
!     4,                        !- Number of Vertices
!     12.2,7.45,0.64,  !- X,Y,Z ==> Vertex 1 {m}
!     12.2,11.79,0.64,  !- X,Y,Z ==> Vertex 2 {m}
!     12.2,11.79,3.41,  !- X,Y,Z ==> Vertex 3 {m}
!     12.2,7.45,3.41;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     east wall 1c,             !- Name
!     Wall,                     !- Surface Type
!     Brick_Wall,               !- Construction Name
!     Zone 1,                   !- Zone Name
!     Outdoors,                 !- Outside Boundary Condition
!     ,                         !- Outside Boundary Condition Object
!     SunExposed,               !- Sun Exposure
!     WindExposed,              !- Wind Exposure
!     0.5,                      !- View Factor to Ground
!     6,                        !- Number of Vertices
!     12.2,1.23,3.41,  !- X,Y,Z ==> Vertex 1 {m}
!     12.2,11.79,3.41,  !- X,Y,Z ==> Vertex 2 {m}
!     12.2,11.79,4.58,  !- X,Y,Z ==> Vertex 3 {m}
!     12.2,9.427,6.64,  !- X,Y,Z ==> Vertex 4 {m}
!     12.2,3.662,6.64,  !- X,Y,Z ==> Vertex 5 {m}
!     12.2,1.23,4.58;  !- X,Y,Z ==> Vertex 6 {m}
!
!   BuildingSurface:Detailed,
!     east bg wall 1a,          !- Name
!     Wall,                     !- Surface Type
!     below_grade,              !- Construction Name
!     Basement_Zone,            !- Zone Name
!     GroundBasementPreprocessorAverageWall,  !- Outside Boundary Condition
!     ,                         !- Outside Boundary Condition Object
!     NoSun,                    !- Sun Exposure
!     NoWind,                   !- Wind Exposure
!     autocalculate,            !- View Factor to Ground
!     4,                        !- Number of Vertices
!     7.8,1.23,-1.96,  !- X,Y,Z ==> Vertex 1 {m}
!     7.8,7.45,-1.96,  !- X,Y,Z ==> Vertex 2 {m}
!     7.8,7.45,0.64,  !- X,Y,Z ==> Vertex 3 {m}
!     7.8,1.23,0.64;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     east bsmt wall 1b,        !- Name
!     Wall,                     !- Surface Type
!     below_grade,              !- Construction Name
!     Basement_Zone,            !- Zone Name
!     Outdoors,                 !- Outside Boundary Condition
!     ,                         !- Outside Boundary Condition Object
!     SunExposed,               !- Sun Exposure
!     WindExposed,              !- Wind Exposure
!     autocalculate,            !- View Factor to Ground
!     4,                        !- Number of Vertices
!     12.2,7.45,0,  !- X,Y,Z ==> Vertex 1 {m}
!     12.2,11.79,0,  !- X,Y,Z ==> Vertex 2 {m}
!     12.2,11.79,0.64,  !- X,Y,Z ==> Vertex 3 {m}
!     12.2,7.45,0.64;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     east bg wall 1b,          !- Name
!     Wall,                     !- Surface Type
!     below_grade,              !- Construction Name
!     Basement_Zone,            !- Zone Name
!     GroundBasementPreprocessorAverageWall,  !- Outside Boundary Condition
!     ,                         !- Outside Boundary Condition Object
!     NoSun,                    !- Sun Exposure
!     NoWind,                   !- Wind Exposure
!     autocalculate,            !- View Factor to Ground
!     4,                        !- Number of Vertices
!     12.2,7.45,-1.96,  !- X,Y,Z ==> Vertex 1 {m}
```

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!     12.2,11.79,-1.96,  !- X,Y,Z ==> Vertex 2 {m}
!     12.2,11.79,0,  !- X,Y,Z ==> Vertex 3 {m}
!     12.2,7.45,0;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     east wall 2,             !- Name
!     Wall,                    !- Surface Type
!     Brick_Wall,              !- Construction Name
!     Zone 1,                  !- Zone Name
!     Outdoors,                !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     SunExposed,              !- Sun Exposure
!     WindExposed,             !- Wind Exposure
!     0.5,                     !- View Factor to Ground
!     3,                       !- Number of Vertices
!     9.4,11.79,4.58,  !- X,Y,Z ==> Vertex 1 {m}
!     9.4,11.79,6.64,  !- X,Y,Z ==> Vertex 2 {m}
!     9.4,9.427,6.64;  !- X,Y,Z ==> Vertex 3 {m}
!
!   BuildingSurface:Detailed,
!     east wall 3,             !- Name
!     Wall,                    !- Surface Type
!     Brick_Wall,              !- Construction Name
!     Zone 1,                  !- Zone Name
!     Outdoors,                !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     SunExposed,              !- Sun Exposure
!     WindExposed,             !- Wind Exposure
!     0.5,                     !- View Factor to Ground
!     3,                       !- Number of Vertices
!     9.411,1.23,4.58,  !- X,Y,Z ==> Vertex 1 {m}
!     9.411,3.662,6.64,  !- X,Y,Z ==> Vertex 2 {m}
!     9.411,1.23,6.64;  !- X,Y,Z ==> Vertex 3 {m}
!
!   BuildingSurface:Detailed,
!     east wall 4,             !- Name
!     Wall,                    !- Surface Type
!     Brick_Wall,              !- Construction Name
!     Zone 1,                  !- Zone Name
!     Outdoors,                !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     SunExposed,              !- Sun Exposure
!     WindExposed,             !- Wind Exposure
!     0.5,                     !- View Factor to Ground
!     4,                       !- Number of Vertices
!     4.38,0,0.64,  !- X,Y,Z ==> Vertex 1 {m}
!     4.38,1.23,0.64,  !- X,Y,Z ==> Vertex 2 {m}
!     4.38,1.23,6.64,  !- X,Y,Z ==> Vertex 3 {m}
!     4.38,0,6.64;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     east bsmt wall 4,        !- Name
!     Wall,                    !- Surface Type
!     below_grade,             !- Construction Name
!     Basement_Zone,           !- Zone Name
!     Outdoors,                !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     SunExposed,              !- Sun Exposure
!     WindExposed,             !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     4,                       !- Number of Vertices
!     4.38,0,0,  !- X,Y,Z ==> Vertex 1 {m}
!     4.38,1.23,0,  !- X,Y,Z ==> Vertex 2 {m}
!     4.38,1.23,0.64,  !- X,Y,Z ==> Vertex 3 {m}
!     4.38,0,0.64;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     east bg wall 4,          !- Name
```

```
!     Wall,                    !- Surface Type
!     below_grade,             !- Construction Name
!     Basement_Zone,           !- Zone Name
!     GroundBasementPreprocessorAverageWall,  !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     NoSun,                   !- Sun Exposure
!     NoWind,                  !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     4,                       !- Number of Vertices
!     4.38,0,-1.96,  !- X,Y,Z ==> Vertex 1 {m}
!     4.38,1.23,-1.96,  !- X,Y,Z ==> Vertex 2 {m}
!     4.38,1.23,0,  !- X,Y,Z ==> Vertex 3 {m}
!     4.38,0,0;  !- X,Y,Z ==> Vertex 4 {m}
!
!- EAST ROOFS
!
!   BuildingSurface:Detailed,
!     East Roof 1,             !- Name
!     Roof,                    !- Surface Type
!     Roof_uninsulated,        !- Construction Name
!     Attic_Zone,              !- Zone Name
!     Outdoors,                !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     SunExposed,              !- Sun Exposure
!     WindExposed,             !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     3,                       !- Number of Vertices
!     12.2,3.662,6.64,  !- X,Y,Z ==> Vertex 1 {m}
!     12.2,9.427,6.64,  !- X,Y,Z ==> Vertex 2 {m}
!     9.46,6.4,9.34;  !- X,Y,Z ==> Vertex 3 {m}
!
!   BuildingSurface:Detailed,
!     East Roof 2,             !- Name
!     Roof,                    !- Surface Type
!     Roof_uninsulated,        !- Construction Name
!     Attic_Zone,              !- Zone Name
!     Outdoors,                !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     SunExposed,              !- Sun Exposure
!     WindExposed,             !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     4,                       !- Number of Vertices
!     4.38,0,6.64,  !- X,Y,Z ==> Vertex 1 {m}
!     4.38,1.2,6.64,  !- X,Y,Z ==> Vertex 2 {m}
!     2.182,3.587,8.263,  !- X,Y,Z ==> Vertex 3 {m}
!     2.182,0,8.263;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     East Roof 3,             !- Name
!     Roof,                    !- Surface Type
!     Roof_uninsulated,        !- Construction Name
!     Attic_Zone,              !- Zone Name
!     Outdoors,                !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     SunExposed,              !- Sun Exposure
!     WindExposed,             !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     6,                       !- Number of Vertices
!     9.411,1.23,6.64,  !- X,Y,Z ==> Vertex 1 {m}
!     9.411,3.662,6.64,  !- X,Y,Z ==> Vertex 2 {m}
!     6.414,6.4,9.34,  !- X,Y,Z ==> Vertex 3 {m}
!     4.48,5.8,10.24,  !- X,Y,Z ==> Vertex 4 {m}
!     7.939,3.108,7.63,  !- X,Y,Z ==> Vertex 5 {m}
!     7.939,1.23,7.685;  !- X,Y,Z ==> Vertex 6 {m}
!
!   BuildingSurface:Detailed,
!     East Roof 4,             !- Name
!     Roof,                    !- Surface Type
```

```
!     Roof_uninsulated,        !- Construction Name
!     Attic_Zone,              !- Zone Name
!     Outdoors,                !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     SunExposed,              !- Sun Exposure
!     WindExposed,             !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     5,                       !- Number of Vertices
!     9.4,9.427,6.64,  !- X,Y,Z ==> Vertex 1 {m}
!     9.4,11.79,6.64,  !- X,Y,Z ==> Vertex 2 {m}
!     4.48,7.28,10.24,  !- X,Y,Z ==> Vertex 3 {m}
!     4.48,5.8,10.24,  !- X,Y,Z ==> Vertex 4 {m}
!     6.414,6.4,9.34;  !- X,Y,Z ==> Vertex 5 {m}
!
!-North Walls
!
!   BuildingSurface:Detailed,
!     north wall 1,            !- Name
!     Wall,                    !- Surface Type
!     Brick_Wall_N1,            !- Construction Name
!     Zone 1,                  !- Zone Name
!     Outdoors,                !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     SunExposed,              !- Sun Exposure
!     WindExposed,             !- Wind Exposure
!     0.5,                     !- View Factor to Ground
!     6,                       !- Number of Vertices
!     12.2,11.79,0.64,  !- X,Y,Z ==> Vertex 1 {m}
!     0,11.79,0.64,  !- X,Y,Z ==> Vertex 2 {m}
!     0,11.79,6.64,  !- X,Y,Z ==> Vertex 3 {m}
!     9.4,11.79,6.64,  !- X,Y,Z ==> Vertex 4 {m}
!     9.4,11.79,4.586,  !- X,Y,Z ==> Vertex 5 {m}
!     12.2,11.79,4.586;  !- X,Y,Z ==> Vertex 6 {m}
!
!   BuildingSurface:Detailed,
!     north bsmt wall 1a,      !- Name
!     Wall,                    !- Surface Type
!     below_grade_Nbsmt_1a,            !- Construction Name
!     Basement_Zone,           !- Zone Name
!     Outdoors,                !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     SunExposed,              !- Sun Exposure
!     WindExposed,             !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     4,                       !- Number of Vertices
!     12.2,11.79,0,  !- X,Y,Z ==> Vertex 1 {m}
!     0,11.79,0,  !- X,Y,Z ==> Vertex 2 {m}
!     0,11.79,0.64,  !- X,Y,Z ==> Vertex 3 {m}
!     12.2,11.79,0.64;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     north bg wall 1a,        !- Name
!     Wall,                    !- Surface Type
!     below_grade,             !- Construction Name
!     Basement_Zone,           !- Zone Name
!     GroundBasementPreprocessorAverageWall,  !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     NoSun,                   !- Sun Exposure
!     NoWind,                  !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     4,                       !- Number of Vertices
!     12.2,11.79,-1.96,  !- X,Y,Z ==> Vertex 1 {m}
!     0,11.79,-1.96,  !- X,Y,Z ==> Vertex 2 {m}
!     0,11.79,0,  !- X,Y,Z ==> Vertex 3 {m}
!     12.2,11.79,0;  !- X,Y,Z ==> Vertex 4 {m}
!
!- North Roofs
!
```

```
!   BuildingSurface:Detailed,
!     North Roof 1,             !- Name
!     Roof,                     !- Surface Type
!     Roof_uninsulated,         !- Construction Name
!     Attic_Zone,               !- Zone Name
!     Outdoors,                 !- Outside Boundary Condition
!     ,                         !- Outside Boundary Condition Object
!     SunExposed,               !- Sun Exposure
!     WindExposed,              !- Wind Exposure
!     autocalculate,            !- View Factor to Ground
!     3,                        !- Number of Vertices
!     9.4,11.79,6.64,  !- X,Y,Z ==> Vertex 1 {m}
!     0,11.79,6.64,  !- X,Y,Z ==> Vertex 2 {m}
!     4.48,7.28,10.24;  !- X,Y,Z ==> Vertex 3 {m}
!
!   BuildingSurface:Detailed,
!     North Roof 2a,            !- Name
!     Roof,                     !- Surface Type
!     Roof_insulated,           !- Construction Name
!     Zone 1,                   !- Zone Name
!     Outdoors,                 !- Outside Boundary Condition
!     ,                         !- Outside Boundary Condition Object
!     SunExposed,               !- Sun Exposure
!     WindExposed,              !- Wind Exposure
!     autocalculate,            !- View Factor to Ground
!     4,                        !- Number of Vertices
!     12.2,11.79,4.586,  !- X,Y,Z ==> Vertex 1 {m}
!     9.4,11.79,4.586,  !- X,Y,Z ==> Vertex 2 {m}
!     9.4,9.427,6.64,  !- X,Y,Z ==> Vertex 3 {m}
!     12.2,9.427,6.64;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     North Roof 2b,            !- Name
!     Roof,                     !- Surface Type
!     Roof_uninsulated,         !- Construction Name
!     attic_zone,               !- Zone Name
!     Outdoors,                 !- Outside Boundary Condition
!     ,                         !- Outside Boundary Condition Object
!     SunExposed,               !- Sun Exposure
!     WindExposed,              !- Wind Exposure
!     autocalculate,            !- View Factor to Ground
!     4,                        !- Number of Vertices
!     12.2,9.427,6.64,  !- X,Y,Z ==> Vertex 1 {m}
!     9.4,9.427,6.64,  !- X,Y,Z ==> Vertex 2 {m}
!     6.414,6.4,9.34,  !- X,Y,Z ==> Vertex 3 {m}
!     9.46,6.4,9.34;  !- X,Y,Z ==> Vertex 4 {m}
!
!- West Wall
!
!   BuildingSurface:Detailed,
!     west wall 1,              !- Name
!     Wall,                     !- Surface Type
!     Brick_Wall_W1,               !- Construction Name
!     Zone 1,                   !- Zone Name
!     Outdoors,                 !- Outside Boundary Condition
!     ,                         !- Outside Boundary Condition Object
!     SunExposed,               !- Sun Exposure
!     WindExposed,              !- Wind Exposure
!     0.5,                      !- View Factor to Ground
!     4,                        !- Number of Vertices
!     0,11.79,0.64,  !- X,Y,Z ==> Vertex 1 {m}
!     0,0,0.64,  !- X,Y,Z ==> Vertex 2 {m}
!     0,0,6.64,  !- X,Y,Z ==> Vertex 3 {m}
!     0,11.79,6.64;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     west bsmt wall 1,         !- Name
!     Wall,                     !- Surface Type
```

```
!     below_grade,             !- Construction Name
!     Basement_Zone,           !- Zone Name
!     Outdoors,                !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     SunExposed,              !- Sun Exposure
!     WindExposed,             !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     4,                       !- Number of Vertices
!     0,11.79,0,  !- X,Y,Z ==> Vertex 1 {m}
!     0,0,0,  !- X,Y,Z ==> Vertex 2 {m}
!     0,0,0.64,  !- X,Y,Z ==> Vertex 3 {m}
!     0,11.79,0.64;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     west bg wall 1,          !- Name
!     Wall,                    !- Surface Type
!     below_grade,             !- Construction Name
!     Basement_Zone,           !- Zone Name
!     GroundBasementPreprocessorAverageWall,  !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     NoSun,                   !- Sun Exposure
!     NoWind,                  !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     4,                       !- Number of Vertices
!     0,11.79,-1.96,  !- X,Y,Z ==> Vertex 1 {m}
!     0,0,-1.96,  !- X,Y,Z ==> Vertex 2 {m}
!     0,0,0,  !- X,Y,Z ==> Vertex 3 {m}
!     0,11.79,0;  !- X,Y,Z ==> Vertex 4 {m}
!
!- West Roofs
!
!   BuildingSurface:Detailed,
!     west roof 1,             !- Name
!     Roof,                    !- Surface Type
!     Roof_uninsulated,        !- Construction Name
!     Attic_Zone,              !- Zone Name
!     Outdoors,                !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     SunExposed,              !- Sun Exposure
!     WindExposed,             !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     6,                       !- Number of Vertices
!     0,11.79,6.64,  !- X,Y,Z ==> Vertex 1 {m}
!     0,0,6.64,  !- X,Y,Z ==> Vertex 2 {m}
!     2.182,0,8.263,  !- X,Y,Z ==> Vertex 3 {m}
!     2.182,3.16,8.263,  !- X,Y,Z ==> Vertex 4 {m}
!     4.48,5.8,10.24,  !- X,Y,Z ==> Vertex 5 {m}
!     4.48,7.28,10.24;  !- X,Y,Z ==> Vertex 6 {m}
!
!   BuildingSurface:Detailed,
!     west roof 2,             !- Name
!     Roof,                    !- Surface Type
!     Roof_uninsulated,        !- Construction Name
!     Attic_Zone,              !- Zone Name
!     Outdoors,                !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     SunExposed,              !- Sun Exposure
!     WindExposed,             !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     3,                       !- Number of Vertices
!     6.467,1.23,6.64,  !- X,Y,Z ==> Vertex 1 {m}
!     7.939,1.23,7.685,  !- X,Y,Z ==> Vertex 2 {m}
!     7.939,3.108,7.63;  !- X,Y,Z ==> Vertex 3 {m}
!
!- BASEMENT FLOOR
!
!   BuildingSurface:Detailed,
!     basement floor 1,        !- Name
```

```
!     Floor,                    !- Surface Type
!     basement_floor,           !- Construction Name
!     basement_zone,            !- Zone Name
!     GroundBasementPreprocessorAverageFloor,  !- Outside Boundary Condition
!     ,                         !- Outside Boundary Condition Object
!     NoSun,                    !- Sun Exposure
!     NoWind,                   !- Wind Exposure
!     autocalculate,            !- View Factor to Ground
!     4,                        !- Number of Vertices
!     7.8,11.79,-1.96,  !- X,Y,Z ==> Vertex 1 {m}
!     12.2,11.79,-1.96,  !- X,Y,Z ==> Vertex 2 {m}
!     12.2,7.45,-1.96,  !- X,Y,Z ==> Vertex 3 {m}
!     7.8,7.45,-1.96;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     basement floor 2,         !- Name
!     Floor,                    !- Surface Type
!     basement_floor,           !- Construction Name
!     Basement_Zone,            !- Zone Name
!     GroundBasementPreprocessorAverageFloor,  !- Outside Boundary Condition
!     ,                         !- Outside Boundary Condition Object
!     NoSun,                    !- Sun Exposure
!     NoWind,                   !- Wind Exposure
!     autocalculate,            !- View Factor to Ground
!     6,                        !- Number of Vertices
!     0,11.79,-1.96,  !- X,Y,Z ==> Vertex 1 {m}
!     7.8,11.79,-1.96,  !- X,Y,Z ==> Vertex 2 {m}
!     7.8,1.23,-1.96,  !- X,Y,Z ==> Vertex 3 {m}
!     4.38,1.23,-1.96,  !- X,Y,Z ==> Vertex 4 {m}
!     4.38,0,-1.96,  !- X,Y,Z ==> Vertex 5 {m}
!     0,0,-1.96;  !- X,Y,Z ==> Vertex 6 {m}
!
!- INTERZONE PARTIONS & FLOORS
!- Garage
!
!   BuildingSurface:Detailed,
!     East garage int wall,     !- Name
!     Wall,                     !- Surface Type
!     interior_garage_wall,     !- Construction Name
!     Garage_Zone,              !- Zone Name
!     Surface,                  !- Outside Boundary Condition
!     West garage int wall,     !- Outside Boundary Condition Object
!     NoSun,                    !- Sun Exposure
!     NoWind,                   !- Wind Exposure
!     autocalculate,            !- View Factor to Ground
!     4,                        !- Number of Vertices
!     7.8,1.23,0.64,  !- X,Y,Z ==> Vertex 1 {m}
!     7.8,7.45,0.64,  !- X,Y,Z ==> Vertex 2 {m}
!     7.8,7.45,3.41,  !- X,Y,Z ==> Vertex 3 {m}
!     7.8,1.23,3.41;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     West garage int wall,     !- Name
!     Wall,                     !- Surface Type
!     interior_garage_wall,     !- Construction Name
!     Zone 1,                   !- Zone Name
!     Surface,                  !- Outside Boundary Condition
!     East garage int wall,     !- Outside Boundary Condition Object
!     NoSun,                    !- Sun Exposure
!     NoWind,                   !- Wind Exposure
!     autocalculate,            !- View Factor to Ground
!     4,                        !- Number of Vertices
!     7.8,7.45,0.64,  !- X,Y,Z ==> Vertex 1 {m}
!     7.8,1.23,0.64,  !- X,Y,Z ==> Vertex 2 {m}
!     7.8,1.23,3.41,  !- X,Y,Z ==> Vertex 3 {m}
!     7.8,7.45,3.41;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
```

```
!     South garage int wall,   !- Name
!     Wall,                    !- Surface Type
!     interior_garage_wall,    !- Construction Name
!     Garage_Zone,             !- Zone Name
!     Surface,                 !- Outside Boundary Condition
!     North garage int wall,   !- Outside Boundary Condition Object
!     NoSun,                   !- Sun Exposure
!     NoWind,                  !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     4,                       !- Number of Vertices
!     7.8,7.45,0.64,  !- X,Y,Z ==> Vertex 1 {m}
!     12.2,7.45,0.64,  !- X,Y,Z ==> Vertex 2 {m}
!     12.2,7.45,3.41,  !- X,Y,Z ==> Vertex 3 {m}
!     7.8,7.45,3.41;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     North garage int wall,   !- Name
!     Wall,                    !- Surface Type
!     interior_garage_wall,    !- Construction Name
!     Zone 1,                  !- Zone Name
!     Surface,                 !- Outside Boundary Condition
!     South garage int wall,   !- Outside Boundary Condition Object
!     NoSun,                   !- Sun Exposure
!     NoWind,                  !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     4,                       !- Number of Vertices
!     12.2,7.45,0.64,  !- X,Y,Z ==> Vertex 1 {m}
!     7.8,7.45,0.64,  !- X,Y,Z ==> Vertex 2 {m}
!     7.8,7.45,3.41,  !- X,Y,Z ==> Vertex 3 {m}
!     12.2,7.45,3.41;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     Garage floor,            !- Name
!     Floor,                   !- Surface Type
!     basement_floor,          !- Construction Name
!     Garage_Zone,             !- Zone Name
!     Adiabatic,               !- Outside Boundary Condition
!     ,                        !- Outside Boundary Condition Object
!     NoSun,                   !- Sun Exposure
!     NoWind,                  !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     4,                       !- Number of Vertices
!     7.8,7.45,0.64,  !- X,Y,Z ==> Vertex 1 {m}
!     12.2,7.45,0.64,  !- X,Y,Z ==> Vertex 2 {m}
!     12.2,1.23,0.64,  !- X,Y,Z ==> Vertex 3 {m}
!     7.8,1.23,0.64;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     Garage ceiling,          !- Name
!     Ceiling,                 !- Surface Type
!     garage_ceiling,          !- Construction Name
!     Garage_Zone,             !- Zone Name
!     Surface,                 !- Outside Boundary Condition
!     Garage ceiling reverse,  !- Outside Boundary Condition Object
!     NoSun,                   !- Sun Exposure
!     NoWind,                  !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     4,                       !- Number of Vertices
!     12.2,7.45,3.41,  !- X,Y,Z ==> Vertex 1 {m}
!     7.8,7.45,3.41,  !- X,Y,Z ==> Vertex 2 {m}
!     7.8,1.23,3.41,  !- X,Y,Z ==> Vertex 3 {m}
!     12.2,1.23,3.41;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     Garage ceiling reverse,  !- Name
!     Floor,                   !- Surface Type
!     garage_ceiling,          !- Construction Name
!     Zone 1,                  !- Zone Name
```

```
!     Surface,                 !- Outside Boundary Condition
!     Garage ceiling,          !- Outside Boundary Condition Object
!     NoSun,                   !- Sun Exposure
!     NoWind,                  !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     4,                       !- Number of Vertices
!     7.8,7.45,3.41,  !- X,Y,Z ==> Vertex 1 {m}
!     12.2,7.45,3.41,  !- X,Y,Z ==> Vertex 2 {m}
!     12.2,1.23,3.41,  !- X,Y,Z ==> Vertex 3 {m}
!     7.8,1.23,3.41;  !- X,Y,Z ==> Vertex 4 {m}
!
!- Main Floor
!
!   BuildingSurface:Detailed,
!     main floor 1,            !- Name
!     Floor,                   !- Surface Type
!     interior_floor,          !- Construction Name
!     Zone 1,                  !- Zone Name
!     Surface,                 !- Outside Boundary Condition
!     basement ceiling 1,      !- Outside Boundary Condition Object
!     NoSun,                   !- Sun Exposure
!     NoWind,                  !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     4,                       !- Number of Vertices
!     7.8,11.79,0.64,  !- X,Y,Z ==> Vertex 1 {m}
!     12.2,11.79,0.64,  !- X,Y,Z ==> Vertex 2 {m}
!     12.2,7.45,0.64,  !- X,Y,Z ==> Vertex 3 {m}
!     7.8,7.45,0.64;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     basement ceiling 1,      !- Name
!     Ceiling,                 !- Surface Type
!     interior_floor_rev,      !- Construction Name
!     Basement_Zone,           !- Zone Name
!     Surface,                 !- Outside Boundary Condition
!     main floor 1,            !- Outside Boundary Condition Object
!     NoSun,                   !- Sun Exposure
!     NoWind,                  !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     4,                       !- Number of Vertices
!     7.8,7.45,0.64,  !- X,Y,Z ==> Vertex 1 {m}
!     12.2,7.45,0.64,  !- X,Y,Z ==> Vertex 2 {m}
!     12.2,11.79,0.64,  !- X,Y,Z ==> Vertex 3 {m}
!     7.8,11.79,0.64;  !- X,Y,Z ==> Vertex 4 {m}
!
!   BuildingSurface:Detailed,
!     main floor 2,            !- Name
!     Floor,                   !- Surface Type
!     interior_floor_tile,     !- Construction Name
!     Zone 1,                  !- Zone Name
!     Surface,                 !- Outside Boundary Condition
!     basement ceiling 2,      !- Outside Boundary Condition Object
!     NoSun,                   !- Sun Exposure
!     NoWind,                  !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     6,                       !- Number of Vertices
!     0,11.79,0.64,  !- X,Y,Z ==> Vertex 1 {m}
!     7.8,11.79,0.64,  !- X,Y,Z ==> Vertex 2 {m}
!     7.8,1.23,0.64,  !- X,Y,Z ==> Vertex 3 {m}
!     4.38,1.23,0.64,  !- X,Y,Z ==> Vertex 4 {m}
!     4.38,0,0.64,  !- X,Y,Z ==> Vertex 5 {m}
!     0,0,0.64;  !- X,Y,Z ==> Vertex 6 {m}
!
!   BuildingSurface:Detailed,
!     basement ceiling 2,      !- Name
!     Ceiling,                 !- Surface Type
!     interior_floor_tile_rev, !- Construction Name
!     Basement_Zone,           !- Zone Name
```

```
!     Surface,                 !- Outside Boundary Condition
!     main floor 2,            !- Outside Boundary Condition Object
!     NoSun,                   !- Sun Exposure
!     NoWind,                  !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     6,                       !- Number of Vertices
!     0,0,0.64,  !- X,Y,Z ==> Vertex 1 {m}
!     4.38,0,0.64,  !- X,Y,Z ==> Vertex 2 {m}
!     4.38,1.23,0.64,  !- X,Y,Z ==> Vertex 3 {m}
!     7.8,1.23,0.64,  !- X,Y,Z ==> Vertex 4 {m}
!     7.8,11.79,0.64,  !- X,Y,Z ==> Vertex 5 {m}
!     0,11.79,0.64;  !- X,Y,Z ==> Vertex 6 {m}
!
!- Attic Floor - Upstairs ceiling
!
!   BuildingSurface:Detailed,
!     attic floor,             !- Name
!     Floor,                   !- Surface Type
!     ceiling_insulated_reverse,  !- Construction Name
!     Attic_Zone,              !- Zone Name
!     Surface,                 !- Outside Boundary Condition
!     upstairs ceiling,        !- Outside Boundary Condition Object
!     NoSun,                   !- Sun Exposure
!     NoWind,                  !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     10,                      !- Number of Vertices
!     12.2,3.662,6.64,  !- X,Y,Z ==> Vertex 1 {m}
!     9.411,3.662,6.64,  !- X,Y,Z ==> Vertex 2 {m}
!     9.411,1.23,6.64,  !- X,Y,Z ==> Vertex 3 {m}
!     4.38,1.23,6.64,  !- X,Y,Z ==> Vertex 4 {m}
!     4.38,0,6.64,  !- X,Y,Z ==> Vertex 5 {m}
!     0,0,6.64,  !- X,Y,Z ==> Vertex 6 {m}
!     0,11.79,6.64,  !- X,Y,Z ==> Vertex 7 {m}
!     9.4,11.79,6.64,  !- X,Y,Z ==> Vertex 8 {m}
!     9.4,9.427,6.64,  !- X,Y,Z ==> Vertex 9 {m}
!     12.2,9.427,6.64;  !- X,Y,Z ==> Vertex 10 {m}
!
!   BuildingSurface:Detailed,
!     upstairs ceiling,        !- Name
!     Ceiling,                 !- Surface Type
!     ceiling_insulated,       !- Construction Name
!     Zone 1,                  !- Zone Name
!     Surface,                 !- Outside Boundary Condition
!     attic floor,             !- Outside Boundary Condition Object
!     NoSun,                   !- Sun Exposure
!     NoWind,                  !- Wind Exposure
!     autocalculate,           !- View Factor to Ground
!     10,                      !- Number of Vertices
!     12.2,9.427,6.64,  !- X,Y,Z ==> Vertex 1 {m}
!     9.4,9.427,6.64,  !- X,Y,Z ==> Vertex 2 {m}
!     9.4,11.79,6.64,  !- X,Y,Z ==> Vertex 3 {m}
!     0,11.79,6.64,  !- X,Y,Z ==> Vertex 4 {m}
!     0,0,6.64,  !- X,Y,Z ==> Vertex 5 {m}
!     4.38,0,6.64,  !- X,Y,Z ==> Vertex 6 {m}
!     4.38,1.23,6.64,  !- X,Y,Z ==> Vertex 7 {m}
!     9.411,1.23,6.64,  !- X,Y,Z ==> Vertex 8 {m}
!     9.411,3.662,6.64,  !- X,Y,Z ==> Vertex 9 {m}
!     12.2,3.662,6.64;  !- X,Y,Z ==> Vertex 10 {m}

!-   ==========   ALL OBJECTS IN CLASS: INTERNAL MASS  ===========

  InternalMass,
    Upstairs Floor,          !- Name
    interior_floor,          !- Construction Name
    Zone 1,                  !- Zone Name
    170.6;                   !- Surface Area {m2}

  InternalMass,
```

```
    Main ceiling,            !- Name
    interior_floor_rev,      !- Construction Name
    Zone 1,                  !- Zone Name
    143.2;                   !- Surface Area {m2}

  InternalMass,
    Zone 1 partions,         !- Name
    interior walls,          !- Construction Name
    Zone 1,                  !- Zone Name
    270;                     !- Surface Area {m2}

!-   ======   ALL OBJECTS IN CLASS: SHADING:BUILDING:DETAILED $$$$$  =====

  Shading:Building:Detailed,
    Garage Fin Shade,        !- Name
    ,                        !- Transmittance Schedule Name
    4,                       !- Number of Vertices
    6.46,                    !- Vertex 1 X-coordinate {m}
    1.23,                    !- Vertex 1 Y-coordinate {m}
    0,                       !- Vertex 1 Z-coordinate {m}
    6.46,                    !- Vertex 2 X-coordinate {m}
    0,                       !- Vertex 2 Y-coordinate {m}
    0,                       !- Vertex 2 Z-coordinate {m}
    6.46,                    !- Vertex 3 X-coordinate {m}
    0,                       !- Vertex 3 Y-coordinate {m}
    3.41,                    !- Vertex 3 Z-coordinate {m}
    6.46,                    !- Vertex 4 X-coordinate {m}
    1.23,                    !- Vertex 4 Y-coordinate {m}
    3.41;                    !- Vertex 4 Z-coordinate {m}

!-   ======   ALL OBJECTS IN CLASS: FENESTRATIONSURFACE:DETAILED  =======
!- SOUTH WINDOWS

  FenestrationSurface:Detailed,
    south XX7,               !- Name
    Window,                  !- Surface Type
    Tier 4 Window Zola,   !- Construction Name
    south wall 1a,           !- Building Surface Name
    ,                        !- Outside Boundary Condition Object
    autocalculate,           !- View Factor to Ground
    ,                        !- Shading Control Name
    Tier 4 Window Zola - Frames,                        !- Frame and Divider Name
    1,                       !- Multiplier
    4,                       !- Number of Vertices
    0.9,0,1.34,  !- X,Y,Z ==> Vertex 1 {m}
    3.125,0,1.34,  !- X,Y,Z ==> Vertex 2 {m}
    3.125,0,2.965,  !- X,Y,Z ==> Vertex 3 {m}
    0.9,0,2.965;  !- X,Y,Z ==> Vertex 4 {m}

  FenestrationSurface:Detailed,
    south XX6,               !- Name
    Window,                  !- Surface Type
    Tier 4 Window Zola,   !- Construction Name
    south wall 1a,           !- Building Surface Name
    ,                        !- Outside Boundary Condition Object
    autocalculate,           !- View Factor to Ground
    ,                        !- Shading Control Name
    Tier 4 Window Zola - Frames,                        !- Frame and Divider Name
    1,                       !- Multiplier
    4,                       !- Number of Vertices
    0.9,0,4.268,  !- X,Y,Z ==> Vertex 1 {m}
    3.125,0,4.268,  !- X,Y,Z ==> Vertex 2 {m}
    3.125,0,5.693,  !- X,Y,Z ==> Vertex 3 {m}
    0.9,0,5.693;  !- X,Y,Z ==> Vertex 4 {m}

  FenestrationSurface:Detailed,
    south WW4,               !- Name
    Window,                  !- Surface Type
```

```
    Tier 4 Window Zola,   !- Construction Name
    south wall 3a,           !- Building Surface Name
    ,                        !- Outside Boundary Condition Object
    autocalculate,           !- View Factor to Ground
    ,                        !- Shading Control Name
    Tier 4 Window Zola - Frames,                      !- Frame and Divider Name
    1,                       !- Multiplier
    4,                       !- Number of Vertices
    6.8,1.23,4.64,  !- X,Y,Z ==> Vertex 1 {m}
    8.825,1.23,4.64,  !- X,Y,Z ==> Vertex 2 {m}
    8.825,1.23,5.665,  !- X,Y,Z ==> Vertex 3 {m}
    6.8,1.23,5.665;  !- X,Y,Z ==> Vertex 4 {m}

  FenestrationSurface:Detailed,
    south L3,                !- Name
    Window,                  !- Surface Type
    Tier 4 Window Zola,   !- Construction Name
    south wall 3a,           !- Building Surface Name
    ,                        !- Outside Boundary Condition Object
    autocalculate,           !- View Factor to Ground
    ,                        !- Shading Control Name
    Tier 4 Window Zola - Frames,                      !- Frame and Divider Name
    1,                       !- Multiplier
    4,                       !- Number of Vertices
    4.6,1.23,4.64,  !- X,Y,Z ==> Vertex 1 {m}
    6.025,1.23,4.64,  !- X,Y,Z ==> Vertex 2 {m}
    6.025,1.23,5.465,  !- X,Y,Z ==> Vertex 3 {m}
    4.6,1.23,5.465;  !- X,Y,Z ==> Vertex 4 {m}

  FenestrationSurface:Detailed,
    front door,              !- Name
    Door,                    !- Surface Type
    door_insulated,          !- Construction Name
    south wall 2a,           !- Building Surface Name
    ,                        !- Outside Boundary Condition Object
    autocalculate,           !- View Factor to Ground
    ,                        !- Shading Control Name
    Tier 4 Window Zola - Frames,                      !- Frame and Divider Name
    1,                       !- Multiplier
    4,                       !- Number of Vertices
    4.38,1.23,0.94,  !- X,Y,Z ==> Vertex 1 {m}
    5.0436,1.23,0.94,  !- X,Y,Z ==> Vertex 2 {m}
    5.0436,1.23,2.475,  !- X,Y,Z ==> Vertex 3 {m}
    4.38,1.23,2.475;  !- X,Y,Z ==> Vertex 4 {m}

  FenestrationSurface:Detailed,
    front door window 1,     !- Name
    Window,                  !- Surface Type
    Tier 4 Window Zola,   !- Construction Name
    south wall 2a,           !- Building Surface Name
    ,                        !- Outside Boundary Condition Object
    autocalculate,           !- View Factor to Ground
    ,                        !- Shading Control Name
    Tier 4 Window Zola - Frames,                      !- Frame and Divider Name
    1,                       !- Multiplier
    4,                       !- Number of Vertices
    5.2436,1.23,1.177,  !- X,Y,Z ==> Vertex 1 {m}
    5.475,1.23,1.177,  !- X,Y,Z ==> Vertex 2 {m}
    5.475,1.23,2.475,  !- X,Y,Z ==> Vertex 3 {m}
    5.2436,1.23,2.475;  !- X,Y,Z ==> Vertex 4 {m}

  FenestrationSurface:Detailed,
    front door window 2,     !- Name
    Window,                  !- Surface Type
    Tier 4 Window Zola,   !- Construction Name
    south wall 2a,           !- Building Surface Name
    ,                        !- Outside Boundary Condition Object
    autocalculate,           !- View Factor to Ground
```

```
    ,                         !- Shading Control Name
    Tier 4 Window Zola - Frames,                        !- Frame and Divider Name
    1,                        !- Multiplier
    4,                        !- Number of Vertices
    4.38,1.23,2.675,  !- X,Y,Z ==> Vertex 1 {m}
    5.475,1.23,2.675,  !- X,Y,Z ==> Vertex 2 {m}
    5.475,1.23,2.86,  !- X,Y,Z ==> Vertex 3 {m}
    4.38,1.23,2.86;  !- X,Y,Z ==> Vertex 4 {m}

  FenestrationSurface:Detailed,
    garage door,              !- Name
    Door,                     !- Surface Type
    door_insulated,           !- Construction Name
    south wall 2b,            !- Building Surface Name
    ,                         !- Outside Boundary Condition Object
    autocalculate,            !- View Factor to Ground
    ,                         !- Shading Control Name
    Tier 4 Window Zola - Frames,                        !- Frame and Divider Name
    1,                        !- Multiplier
    4,                        !- Number of Vertices
    7.8,1.23,0.64,  !- X,Y,Z ==> Vertex 1 {m}
    11.9,1.23,0.64,  !- X,Y,Z ==> Vertex 2 {m}
    11.9,1.23,2.49,  !- X,Y,Z ==> Vertex 3 {m}
    7.8,1.23,2.49;  !- X,Y,Z ==> Vertex 4 {m}

!- WEST WINDOWS

  FenestrationSurface:Detailed,
    West JJ4,                 !- Name
    Window,                   !- Surface Type
    Tier 4 Window Zola,   !- Construction Name
    West Wall 1,              !- Building Surface Name
    ,                         !- Outside Boundary Condition Object
    autocalculate,            !- View Factor to Ground
    ,                         !- Shading Control Name
    Tier 4 Window Zola - Frames,                        !- Frame and Divider Name
    1,                        !- Multiplier
    4,                        !- Number of Vertices
    0,6.025,3.64,  !- X,Y,Z ==> Vertex 1 {m}
    0,5,3.64,  !- X,Y,Z ==> Vertex 2 {m}
    0,5,4.665,  !- X,Y,Z ==> Vertex 3 {m}
    0,6.025,4.665;  !- X,Y,Z ==> Vertex 4 {m}

!- EAST WINDOWS

  FenestrationSurface:Detailed,
    East E7A,                 !- Name
    Window,                   !- Surface Type
    Tier 4 Window Zola,   !- Construction Name
    East Wall 1b,             !- Building Surface Name
    ,                         !- Outside Boundary Condition Object
    autocalculate,            !- View Factor to Ground
    ,                         !- Shading Control Name
    Tier 4 Window Zola - Frames,                        !- Frame and Divider Name
    1,                        !- Multiplier
    4,                        !- Number of Vertices
    12.2,7.614,1.537,  !- X,Y,Z ==> Vertex 1 {m}
    12.2,8.039,1.537,  !- X,Y,Z ==> Vertex 2 {m}
    12.2,8.039,3.162,  !- X,Y,Z ==> Vertex 3 {m}
    12.2,7.614,3.162;  !- X,Y,Z ==> Vertex 4 {m}

  FenestrationSurface:Detailed,
    East E7B,                 !- Name
    Window,                   !- Surface Type
    Tier 4 Window Zola,   !- Construction Name
    East Wall 1b,             !- Building Surface Name
    ,                         !- Outside Boundary Condition Object
    autocalculate,            !- View Factor to Ground
```

```
    ,                        !- Shading Control Name
    Tier 4 Window Zola - Frames,                        !- Frame and Divider Name
    1,                       !- Multiplier
    4,                       !- Number of Vertices
    12.2,10.51,1.537,  !- X,Y,Z ==> Vertex 1 {m}
    12.2,10.935,1.537,  !- X,Y,Z ==> Vertex 2 {m}
    12.2,10.935,3.162,  !- X,Y,Z ==> Vertex 3 {m}
    12.2,10.51,3.162;  !- X,Y,Z ==> Vertex 4 {m}

!- NORTH WINDOWS

  FenestrationSurface:Detailed,
    North H7a,               !- Name
    Window,                  !- Surface Type
    Tier 4 Window Zola,   !- Construction Name
    North Wall 1,            !- Building Surface Name
    ,                        !- Outside Boundary Condition Object
    autocalculate,           !- View Factor to Ground
    ,                        !- Shading Control Name
    Tier 4 Window Zola - Frames,                        !- Frame and Divider Name
    1,                       !- Multiplier
    4,                       !- Number of Vertices
    11.232,11.79,1.38,  !- X,Y,Z ==> Vertex 1 {m}
    10.407,11.79,1.38,  !- X,Y,Z ==> Vertex 2 {m}
    10.407,11.79,3.005,  !- X,Y,Z ==> Vertex 3 {m}
    11.232,11.79,3.005;  !- X,Y,Z ==> Vertex 4 {m}

  FenestrationSurface:Detailed,
    North H7b,               !- Name
    Window,                  !- Surface Type
    Tier 4 Window Zola,   !- Construction Name
    North Wall 1,            !- Building Surface Name
    ,                        !- Outside Boundary Condition Object
    autocalculate,           !- View Factor to Ground
    ,                        !- Shading Control Name
    Tier 4 Window Zola - Frames,                        !- Frame and Divider Name
    1,                       !- Multiplier
    4,                       !- Number of Vertices
    8.37,11.79,1.38,  !- X,Y,Z ==> Vertex 1 {m}
    7.545,11.79,1.38,  !- X,Y,Z ==> Vertex 2 {m}
    7.545,11.79,3.005,  !- X,Y,Z ==> Vertex 3 {m}
    8.37,11.79,3.005;  !- X,Y,Z ==> Vertex 4 {m}

  FenestrationSurface:Detailed,
    North A1a,               !- Name
    Window,                  !- Surface Type
    Tier 4 Window Zola,   !- Construction Name
    north bsmt wall 1a,      !- Building Surface Name
    ,                        !- Outside Boundary Condition Object
    autocalculate,           !- View Factor to Ground
    ,                        !- Shading Control Name
    Tier 4 Window Zola - Frames,                        !- Frame and Divider Name
    1,                       !- Multiplier
    4,                       !- Number of Vertices
    11.38,11.79,0.235,  !- X,Y,Z ==> Vertex 1 {m}
    10.18,11.79,0.235,  !- X,Y,Z ==> Vertex 2 {m}
    10.18,11.79,0.44,  !- X,Y,Z ==> Vertex 3 {m}
    11.38,11.79,0.44;  !- X,Y,Z ==> Vertex 4 {m}

  FenestrationSurface:Detailed,
    North A1b,               !- Name
    Window,                  !- Surface Type
    Tier 4 Window Zola,   !- Construction Name
    north bsmt wall 1a,      !- Building Surface Name
    ,                        !- Outside Boundary Condition Object
    autocalculate,           !- View Factor to Ground
    ,                        !- Shading Control Name
    Tier 4 Window Zola - Frames,                        !- Frame and Divider Name
```

```
    1,                        !- Multiplier
    4,                        !- Number of Vertices
    2.3,11.79,0.235,  !- X,Y,Z ==> Vertex 1 {m}
    1.1,11.79,0.235,  !- X,Y,Z ==> Vertex 2 {m}
    1.1,11.79,0.44,  !- X,Y,Z ==> Vertex 3 {m}
    2.3,11.79,0.44;  !- X,Y,Z ==> Vertex 4 {m}

  FenestrationSurface:Detailed,
    North C3,                 !- Name
    Window,                   !- Surface Type
    Tier 4 Window Zola,   !- Construction Name
    North Wall 1,             !- Building Surface Name
    ,                         !- Outside Boundary Condition Object
    autocalculate,            !- View Factor to Ground
    ,                         !- Shading Control Name
    Tier 4 Window Zola - Frames,                        !- Frame and Divider Name
    1,                        !- Multiplier
    4,                        !- Number of Vertices
    6,11.79,0.84,  !- X,Y,Z ==> Vertex 1 {m}
    4.675,11.79,0.84,  !- X,Y,Z ==> Vertex 2 {m}
    4.675,11.79,3.06,  !- X,Y,Z ==> Vertex 3 {m}
    6,11.79,3.06;  !- X,Y,Z ==> Vertex 4 {m}

  FenestrationSurface:Detailed,
    North L7,                 !- Name
    Window,                   !- Surface Type
    Tier 4 Window Zola,   !- Construction Name
    North Wall 1,             !- Building Surface Name
    ,                         !- Outside Boundary Condition Object
    autocalculate,            !- View Factor to Ground
    ,                         !- Shading Control Name
    Tier 4 Window Zola - Frames,                        !- Frame and Divider Name
    1,                        !- Multiplier
    4,                        !- Number of Vertices
    2.5,11.79,1.38,  !- X,Y,Z ==> Vertex 1 {m}
    1.075,11.79,1.38,  !- X,Y,Z ==> Vertex 2 {m}
    1.075,11.79,3.005,  !- X,Y,Z ==> Vertex 3 {m}
    2.5,11.79,3.005;  !- X,Y,Z ==> Vertex 4 {m}

  FenestrationSurface:Detailed,
    North U4,                 !- Name
    Window,                   !- Surface Type
    Tier 4 Window Zola,   !- Construction Name
    North Wall 1,             !- Building Surface Name
    ,                         !- Outside Boundary Condition Object
    autocalculate,            !- View Factor to Ground
    ,                         !- Shading Control Name
    Tier 4 Window Zola - Frames,                        !- Frame and Divider Name
    1,                        !- Multiplier
    4,                        !- Number of Vertices
    7.8,11.79,4.84,  !- X,Y,Z ==> Vertex 1 {m}
    6.785,11.79,4.84,  !- X,Y,Z ==> Vertex 2 {m}
    6.785,11.79,5.865,  !- X,Y,Z ==> Vertex 3 {m}
    7.8,11.79,5.865;  !- X,Y,Z ==> Vertex 4 {m}

  FenestrationSurface:Detailed,
    North E3,                 !- Name
    Window,                   !- Surface Type
    Tier 4 Window Zola,   !- Construction Name
    North Wall 1,             !- Building Surface Name
    ,                         !- Outside Boundary Condition Object
    autocalculate,            !- View Factor to Ground
    ,                         !- Shading Control Name
    Tier 4 Window Zola - Frames,                        !- Frame and Divider Name
    1,                        !- Multiplier
    4,                        !- Number of Vertices
    4.1,11.79,4.94,  !- X,Y,Z ==> Vertex 1 {m}
    3.675,11.79,4.94,  !- X,Y,Z ==> Vertex 2 {m}
```

```
    3.675,11.79,5.465,  !- X,Y,Z ==> Vertex 3 {m}
    4.1,11.79,5.465;  !- X,Y,Z ==> Vertex 4 {m}

  FenestrationSurface:Detailed,
    North X4,                !- Name
    Window,                  !- Surface Type
    Tier 4 Window Zola,   !- Construction Name
    North Wall 1,            !- Building Surface Name
    ,                        !- Outside Boundary Condition Object
    autocalculate,           !- View Factor to Ground
    ,                        !- Shading Control Name
    Tier 4 Window Zola - Frames,                        !- Frame and Divider Name
    1,                       !- Multiplier
    4,                       !- Number of Vertices
    2.5,11.79,4.84,  !- X,Y,Z ==> Vertex 1 {m}
    0.885,11.79,4.84,  !- X,Y,Z ==> Vertex 2 {m}
    0.885,11.79,5.865,  !- X,Y,Z ==> Vertex 3 {m}
    2.5,11.79,5.865;  !- X,Y,Z ==> Vertex 4 {m}

!-   ===========  ALL OBJECTS IN CLASS: ZONEINFILTRATION:DESIGNFLOWRATE ===========

ZoneInfiltration:DesignFlowRate,
    zone_ach,                !- A1name
    Zone 1,  !- A2 Zone or Zone List Name
    Inf_schedule,            !- Schedule Name
    AirChanges/Hour,         !- A4 Design Flow Rate Calc Method
    ,                        !- Design Flow Rate  m3/s
    ,                        !- N2 Flow Per Zone Floor Area
    ,                        !- N3 Flow per Ext Surf Area
    0.03,                   !- N4 ACH ** 0.6/20 (k-p method)
    0.606,                 !- N5 "A" Coeff  ** Using coefficients from BLAST
    0.03636,                        !- N6 "B" Coeff
    0.1177,                   !- N7 "C" Coeff
    0;                       !- N8 "D" Coeff

!-   ===========  ALL OBJECTS IN CLASS: ZoneInfiltration:FlowCoefficient  ===========

  ZoneInfiltration:FlowCoefficient,
    zone_inf_coeffs bsmt,    !- Name
    Basement_zone,           !- Zone Name
    always on schedule,      !- Schedule Name
    0.02296,                 !- Flow Coefficient
    0.078,                   !- Stack Coefficient
    0.699,                   !- Pressure Exponent
    0.17,                    !- Wind Coefficient
    0.2;                     !- Shelter Factor

!-   ===========  ALL OBJECTS IN CLASS: ZONEINFILTRATION:DESIGNFLOWRATE ===========

  ZoneInfiltration:DesignFlowRate,
    attic_ach,               !- Name
    attic_zone,              !- Zone or ZoneList Name
    Inf_schedule,            !- Schedule Name
    AirChanges/Hour,         !- Design Flow Rate Calculation Method
    ,                        !- Design Flow Rate {m3/s}
    ,                        !- Flow per Zone Floor Area {m3/s-m2}
    ,                        !- Flow per Exterior Surface Area {m3/s-m2}
    0.75,                    !- Air Changes per Hour
    0,                       !- Constant Term Coefficient
    0,                       !- Temperature Term Coefficient
    0.224,                   !- Velocity Term Coefficient
    0;                       !- Velocity Squared Term Coefficient

  ZoneInfiltration:DesignFlowRate,
    Garage_ach,              !- Name
    Garage_Zone,             !- Zone or ZoneList Name
    Inf_schedule,            !- Schedule Name
    AirChanges/Hour,         !- Design Flow Rate Calculation Method
```

```
    ,                        !- Design Flow Rate {m3/s}
    ,                        !- Flow per Zone Floor Area {m3/s-m2}
    ,                        !- Flow per Exterior Surface Area {m3/s-m2}
    0.15,                    !- Air Changes per Hour
    0,                       !- Constant Term Coefficient
    0,                       !- Temperature Term Coefficient
    0.244,                   !- Velocity Term Coefficient
    0;                       !- Velocity Squared Term Coefficient

!-   ====  HVAC ===
!-   ===========  ALL OBJECTS IN CLASS: ZONECONTROL:THERMOSTAT ===========

  ZoneControl:Thermostat,
    Zone 1 Thermostat,       !- Name
    Zone 1,                  !- Zone or ZoneList Name
    Zone1Control,            !- Control Type Schedule Name
    ThermostatSetpoint:SingleHeating,  !- Control 1 Object Type
    Setpoint Zone 1;         !- Control 1 Name

!-   ===========  ALL OBJECTS IN CLASS: THERMOSTATSETPOINT  ===========

  ThermostatSetpoint:SingleHeating,
    Setpoint Zone 1,         !- Name
    Zone1HeatingSetPoint;    !- Setpoint Temperature Schedule Name

!-   ===========  All Objects in class: AirTerminal:SingleDuct:Uncontrolled ===========

  AirTerminal:SingleDuct:Uncontrolled,
    Zone1_duct,              !- Name
    Zone1heatingAvail,       !- Availability Schedule Name
    node1,                   !- Zone Supply Air Node Name
    0.516;                   !- Maximum Air Flow Rate {m3/s}

  AirTerminal:SingleDuct:Uncontrolled,
    Basement_Zone_duct,      !- Name
    Zone1heatingAvail,       !- Availability Schedule Name
    node11,                  !- Zone Supply Air Node Name
    0.106;                   !- Maximum Air Flow Rate {m3/s}

!-   ===========  ALL OBJECTS IN CLASS: ZONEHVAC:EQUIPMENTLIST  ===========

  ZoneHVAC:EquipmentList,
    HVACequipment list zone 1,  !- Name
    AirTerminal:SingleDuct:Uncontrolled,  !- Zone Equipment 1 Object Type
    Zone1_duct,              !- Zone Equipment 1 Name
    2,                       !- Zone Equipment 1 vvvvvv Sequence
    2,                       !- Zone Equipment 1 Heating or No-Load Sequence
    ZoneHVAC:EnergyRecoveryVentilator,  !- Zone Equipment 2 Object Type
    CCHT HRV,         !- Zone Equipment 2 Name
    1,                       !- Zone Equipment 2 Cooling Sequence
    1;                       !- Zone Equipment 2 Heating or No-Load Sequence

  ZoneHVAC:EquipmentList,
    HVACequipment list basement_zone,  !- Name
    AirTerminal:SingleDuct:Uncontrolled,  !- Zone Equipment 1 Object Type
    Basement_Zone_duct,      !- Zone Equipment 1 Name
    1,                       !- Zone Equipment 1 Cooling Sequence
    1;                       !- Zone Equipment 1 Heating or No-Load Sequence

!-   ===========  ALL OBJECTS IN CLASS: ZONEHVAC:EQUIPMENTCONNECTIONS ===========

  ZoneHVAC:EquipmentConnections,
    Zone 1,                  !- Zone Name
    HVACequipment list zone 1,  !- Zone Conditioning Equipment List Name
    Zone1Inlets,             !- Zone Air Inlet Node or NodeList Name
    HRV_Exhaust_Air_Inlet_Node,  !- Zone Air Exhaust Node or NodeList Name
    zone1_air_node,          !- Zone Air Node Name
    node2;                   !- Zone Return Air Node Name
```

```
  ZoneHVAC:EquipmentConnections,
    Basement_Zone,           !- Zone Name
    HVACequipment list basement_zone,  !- Zone Conditioning Equipment List Name
    node11,                  !- Zone Air Inlet Node or NodeList Name
    ,                        !- Zone Air Exhaust Node or NodeList Name
    Basement_Zone_air_node,  !- Zone Air Node Name
    node12;                  !- Zone Return Air Node Name

!-   ======= ALL OBJECTS IN CLASS: NODE LIST ========

  NodeList,
    Zone1Inlets,             !- Name
    Node1,                   !- Node 1 Name
    HRV_Zone_Supply_Node;    !- Node 2 Name

!-   ====== ALL OBJECTS IN CLASS: OUTDOORAIR:NodeList  =====

  OutdoorAir:NodeList,
    OA Nodes,                !- Node or NodeList Name 1
    OA_Intake_Node,          !- Node or NodeList Name 2
    OA_Exhaust_Node;         !- Node or NodeList Name 3

!-   ===========  ALL OBJECTS IN CLASS: FAN:ONOFF ===========

  Fan:OnOff,
    CCHT Furnace Fan,        !- Name
    zone1heatingAvail,       !- Availability Schedule Name
    1,                       !- Fan Efficiency
    124,                     !- Pressure Rise {Pa}
    0.622,                   !- Maximum Flow Rate {m3/s}
    1,                       !- Motor Efficiency
    0,                       !- Motor In Airstream Fraction
    Node3a,                  !- Air Inlet Node Name
    node9,                   !- Air Outlet Node Name
    ,                        !- Fan Power Ratio Function of Speed Ratio Curve Name
    ,                        !- Fan Efficiency Ratio Function of Speed Ratio Curve Name
    General;                 !- End-Use Subcategory

  Fan:OnOff,
    HRV Supply Fan,          !- Name
    HRV_Schedule,            !- Availability Schedule Name
    0.7,                     !- Fan Efficiency
    125,                     !- Pressure Rise {Pa}
    0.04,                    !- Maximum Flow Rate {m3/s}
    0.9,                     !- Motor Efficiency
    1,                       !- Motor In Airstream Fraction
    HRV_Supply_Air_Node,     !- Air Inlet Node Name
    HRV_Zone_Supply_Node,    !- Air Outlet Node Name
    ,                        !- Fan Power Ratio Function of Speed Ratio Curve Name
    ,                        !- Fan Efficiency Ratio Function of Speed Ratio Curve Name
    HRV;                     !- End-Use Subcategory

  Fan:OnOff,
    HRV Exhaust Fan,         !- Name
    HRV_Schedule,            !- Availability Schedule Name
    0.7,                     !- Fan Efficiency
    125,                     !- Pressure Rise {Pa}
    0.04,                    !- Maximum Flow Rate {m3/s}
    0.9,                     !- Motor Efficiency
    1,                       !- Motor In Airstream Fraction
    HRV_Exhaust_Air_Node,    !- Air Inlet Node Name
    OA_Exhaust_Node,         !- Air Outlet Node Name
    ,                        !- Fan Power Ratio Function of Speed Ratio Curve Name
    ,                        !- Fan Efficiency Ratio Function of Speed Ratio Curve Name
    HRV;                     !- End-Use Subcategory

!-   ===========  ALL OBJECTS IN CLASS: COIL:HEATINGGAS ===========
```

```
  Coil:Heating:Gas,
    Furnace Coil,            !- Name
    Zone1HeatingSetpoint,    !- Availability Schedule Name
    0.97,                   !- Gas Burner Efficiency
    19778,                   !- Nominal Capacity {W}
    node9,                   !- Air Inlet Node Name
    node10a,                 !- Air Outlet Node Name
    ,                        !- Temperature Setpoint Node Name
    10,                      !- Parasitic Electric Load {W}
    ,                        !- Part Load Fraction Correlation Curve Name
    0;                       !- Parasitic Gas Load {W}

!-   ===========  ALL OBJECTS IN CLASS: AirLoopHVAC:Unitary:Furnace:HeatOnly ===========

  AirLoopHVAC:Unitary:Furnace:HeatOnly,
    A2Furnace,               !- Name
    zone1control,            !- Availability Schedule Name
    Node3a,                  !- Furnace Air Inlet Node Name
    node10a,                 !- Furnace Air Outlet Node Name
    Furnace Fan Operating Mode Schedule,  !- Supply Air Fan Operating Mode Schedule Name
    80,                      !- Maximum Supply Air Temperature {C}
    0.622,                   !- Supply Air Flow Rate {m3/s}
    Zone 1,                  !- Controlling Zone or Thermostat Location
    Fan:OnOff,               !- Supply Fan Object Type
    CCHT Furnace Fan,        !- Supply Fan Name
    BlowThrough,             !- Fan Placement
    Coil:Heating:Gas,        !- Heating Coil Object Type
    Furnace Coil;            !- Heating Coil Name

!-   ===========  ALL OBJECTS IN CLASS: AIRLOOPHVAC ===========

  AirLoopHVAC,
    AirLoopHVAC,             !- Name
    ,                        !- Controller List Name
    Availability Schedule Manager,  !- Availability Manager List Name
    0.622,                   !- Design Supply Air Flow Rate {m3/s}
    Inlet Branch,            !- Branch List Name
    ,                        !- Connector List Name
    node3a,                  !- Supply Side Inlet Node Name
    node3b,                  !- Demand Side Outlet Node Name
    node10b,                 !- Demand Side Inlet Node Names
    node10a;                 !- Supply Side Outlet Node Names

!-   ===========  ALL OBJECTS IN CLASS: AIRLOOPHVAC:ZONESPLITTER ===========

  AirLoopHVAC:ZoneSplitter,
    AirLoopHVAC Splitter,    !- Name
    node10b,                 !- Inlet Node Name
    node1,                   !- Outlet 1 Node Name
    node11;                  !- Outlet 2 Node Name

!-   ===========  ALL OBJECTS IN CLASS: AirLoopHVAC:SupplyPath ===========

  AirLoopHVAC:SupplyPath,
    AirLoopHVAC Supply,      !- Name
    node10b,                 !- Supply Air Path Inlet Node Name
    AirLoopHVAC:ZoneSplitter,!- Component 1 Object Type
    AirLoopHVAC Splitter;    !- Component 1 Name

!-   ===========  ALL OBJECTS IN CLASS: AirLoopHVAC:ZoneMixer ===========

  AirLoopHVAC:ZoneMixer,
    AirLoopHVAC Mixer,       !- Name
    node3b,                  !- Outlet Node Name
    node2,                   !- Inlet 1 Node Name
    node12;                  !- Inlet 2 Node Name
```

```
!-   ===========  ALL OBJECTS IN CLASS: AirLoopHVAC:ReturnPath ===========

  AirLoopHVAC:ReturnPath,
    AirLoopHVAC Return,      !- Name
    node3b,                  !- Return Air Path Outlet Node Name
    AirLoopHVAC:ZoneMixer,   !- Component 1 Object Type
    AirLoopHVAC Mixer;       !- Component 1 Name

!-   ===========  ALL OBJECTS IN CLASS: Branch ===========

  Branch,
    Branch 1,                !- Name
    0.622,                   !- Maximum Flow Rate {m3/s}
    ,                        !- Pressure Drop Curve Name
    AirLoopHVAC:Unitary:Furnace:HeatOnly,  !- Component 1 Object Type
    A2Furnace,               !- Component 1 Name
    Node3a,                  !- Component 1 Inlet Node Name
    node10a,                 !- Component 1 Outlet Node Name
    Active;                  !- Component 1 Branch Control Type

!-   ===========  ALL OBJECTS IN CLASS: BRANCHLIST ===========

  BranchList,
    Inlet Branch,            !- Name
    Branch 1;                !- Branch 1 Name

!-   ===========  ALL OBJECTS IN CLASS: AVAILABILITYMANAGER:SCHEDULED ===========

  AvailabilityManager:Scheduled,
    Availability Schedule,   !- Name
    Zone1Control;            !- Schedule Name

!-   ===========  All Objects in Class: AvailabilityManagerAssignmentList ======

  AvailabilityManagerAssignmentList,
    Availability Schedule Manager,  !- Name
    AvailabilityManager:Scheduled,  !- Availability Manager 1 Object Type
    Availability Schedule;   !- Availability Manager 1 Name

!- Heat Recovery Ventilator (Zone)
!-   ==========  ALL OBJECTS IN CLASS: ZoneHVAC:EnergyRecoveryVentilator  =======

  ZoneHVAC:EnergyRecoveryVentilator,
    CCHT HRV,         !- Name
    HRV_Schedule,            !- Availability Schedule Name
    CCHT HRV Heat Exchanger, !- Heat Exchanger Name
    0.03,                    !- Supply Air Flow Rate {m3/s}
    0.03,                    !- Exhaust Air Flow Rate {m3/s}
    HRV Supply Fan,          !- Supply Air Fan Name
    HRV Exhaust Fan;         !- Exhaust Air Fan Name

!-   ===========  ALL OBJECTS IN CLASS: HeatExchanger:AirtoAir:SensibleandLatent ===========

  HeatExchanger:AirtoAir:SensibleandLatent,
    CCHT HRV Heat Exchanger, !- Name
    HRV_Schedule_ex,            !- Availability Schedule Name
    0.03,                    !- Nominal Supply Air Flow Rate {m3/s}
    0.85,                    !- Sensible Effectiveness at 100% Heating Air Flow {dimensionless}
    0,                       !- Latent Effectiveness at 100% Heating Air Flow {dimensionless}
    0.85,                    !- Sensible Effectiveness at 75% Heating Air Flow {dimensionless}
    0,                       !- Latent Effectiveness at 75% Heating Air Flow {dimensionless}
    ,                        !- Sensible Effectiveness at 100% Cooling Air Flow {dimensionless}
    ,                        !- Latent Effectiveness at 100% Cooling Air Flow {dimensionless}
    ,                        !- Sensible Effectiveness at 75% Cooling Air Flow {dimensionless}
    ,                        !- Latent Effectiveness at 75% Cooling Air Flow {dimensionless}
    OA_Intake_Node,          !- Supply Air Inlet Node Name
    HRV_Supply_Air_Node,     !- Supply Air Outlet Node Name
    HRV_Exhaust_Air_Inlet_Node,  !- Exhaust Air Inlet Node Name
```

```
    HRV_Exhaust_Air_Node,    !- Exhaust Air Outlet Node Name
    0,                       !- Nominal Electric Power {W}
    No,                      !- Supply Air Outlet Temperature Control
    Plate,                   !- Heat Exchanger Type
    ExhaustAirRecirculation, !- Frost Control Type
    -5,                      !- Threshold Temperature {C}
    0.1,                     !- Initial Defrost Time Fraction {dimensionless}
    0.0091,                  !- Rate of Defrost Time Fraction Increase {1/K}
    Yes;                     !- Economizer Lockout

!-   ===========  ALL OBJECTS IN CLASS: OUTPUT:VARIABLEDICTIONARY ===========

  Output:VariableDictionary,IDF,Name;

!-   ===========  ALL OBJECTS IN CLASS: OUTPUT:SURFACES:LIST ===========

  Output:Surfaces:List,Details,IDF;

!-   ===========  ALL OBJECTS IN CLASS: OUTPUT:SURFACES:DRAWING ===========

  Output:Surfaces:Drawing,DXF,Triangulate3DFace;

!-   ===========  ALL OBJECTS IN CLASS: OUTPUT:CONSTRUCTIONS ===========

  Output:Constructions,Constructions,Materials;

!-   ===========  ALL OBJECTS IN CLASS: OUTPUT:VARIABLE ===========

  Output:Variable,*,Zone/Sys Air Temperature,Hourly,Zone1Control;

!-   ===========  ALL OBJECTS IN CLASS: OUTPUT:METER:METERFILEONLY ===========

  Output:Meter:MeterFileOnly,Gas:HVAC,Annual;

  Output:Meter:MeterFileOnly,Gas:HVAC,daily;

  Output:Meter:MeterFileOnly,Electricity:HVAC,Annual;

  Output:Meter:MeterFileOnly,Electricity:HVAC,daily;

!-   ===========  ALL OBJECTS IN CLASS: OUTPUT:Table:SummaryReports ===========
Output:Table:SummaryReports,
AnnualBuildingUtilityPerformanceSummary; !-Name

Output:Table:Monthly,
    End-Use Energy Consumption - Natural Gas,  !- Name
    2,                        !- Digits After Decimal
    InteriorEquipment:Gas,   !- Variable or Meter 1 Name
    Sum,            !- Aggregation Type for Variable or Meter 1
    ExteriorEquipment:Gas,   !- Variable or Meter 2 Name
    Sum,            !- Aggregation Type for Variable or Meter 2
    Heating:Gas,             !- Variable or Meter 3 Name
    Sum,            !- Aggregation Type for Variable or Meter 3
    Cooling:Gas,             !- Variable or Meter 4 Name
    Sum,            !- Aggregation Type for Variable or Meter 4
    WaterSystems:Gas,        !- Variable or Meter 5 Name
    Sum,            !- Aggregation Type for Variable or Meter 5
    Cogeneration:Gas,        !- Variable or Meter 6 Name
    Sum;            !- Aggregation Type for Variable or Meter 6

Output:Table:Monthly,
    Peak Energy End-Use - Natural Gas,  !- Name
    2,                        !- Digits After Decimal
    InteriorEquipment:Gas,   !- Variable or Meter 1 Name
    Maximum,                 !- Aggregation Type for Variable or Meter 1
    ExteriorEquipment:Gas,   !- Variable or Meter 2 Name
    Maximum,                 !- Aggregation Type for Variable or Meter 2
    Heating:Gas,             !- Variable or Meter 3 Name
```

```
    Maximum,                 !- Aggregation Type for Variable or Meter 3
    Cooling:Gas,             !- Variable or Meter 4 Name
    Maximum,                 !- Aggregation Type for Variable or Meter 4
    WaterSystems:Gas,        !- Variable or Meter 5 Name
    Maximum,                 !- Aggregation Type for Variable or Meter 5
    Cogeneration:Gas,        !- Variable or Meter 6 Name
    Maximum;                 !- Aggregation Type for Variable or Meter 6

!-   ===========  ALL OBJECTS IN CLASS: OUTPUT:DIAGNOSTICS ===========

  Output:Diagnostics,
    DisplayExtraWarnings;    !- Key 1

!-  ============  ALL OBJECTS IN CLASS: OUTPUT:SQLITE ===============

  Output:SQLite,
    Simple;                  !- Option Type
!
! -------------------------------------------------------------
! New objects created from ExpandObjects
! -------------------------------------------------------------
!

BuildingSurface:Detailed,
  south wall 1a,                                              !- Name
  Wall,                                                       !- Surface Type
  Brick_Wall_S1a,                                               !- Construction Name
  Zone 1,                                                     !- Zone Name
  Outdoors,                                                   !- Outside Boundary Condition
  ,                                                           !- Outside Boundary Condition Object
  SunExposed,                                                 !- Sun Exposure
  WindExposed,                                                !- Wind Exposure
  0.5,                                                        !- View Factor to Ground
  4,                                                          !- Number of Vertices
  0,                                                          !- Vertex 1 X-coordinate
  0,                                                          !- Vertex 1 Y-coordinate
  0.64,                                                       !- Vertex 1 Z-coordinate
  4.38,                                                       !- Vertex 2 X-coordinate
  0,                                                          !- Vertex 2 Y-coordinate
  0.64,                                                       !- Vertex 2 Z-coordinate
  4.38,                                                       !- Vertex 3 X-coordinate
  0,                                                          !- Vertex 3 Y-coordinate
  6.64,                                                       !- Vertex 3 Z-coordinate
  0,                                                          !- Vertex 4 X-coordinate
  0,                                                          !- Vertex 4 Y-coordinate
  6.64;                                                       !- Vertex 4 Z-coordinate

BuildingSurface:Detailed,
  south wall 1b,                                              !- Name
  Wall,                                                       !- Surface Type
  Brick_Wall_Uninsulated,                                     !- Construction Name
  attic_zone,                                                 !- Zone Name
  Outdoors,                                                   !- Outside Boundary Condition
  ,                                                           !- Outside Boundary Condition Object
  SunExposed,                                                 !- Sun Exposure
  WindExposed,                                                !- Wind Exposure
  0.5,                                                        !- View Factor to Ground
  3,                                                          !- Number of Vertices
  0,                                                          !- Vertex 1 X-coordinate
  0,                                                          !- Vertex 1 Y-coordinate
  6.64,                                                       !- Vertex 1 Z-coordinate
  4.38,                                                       !- Vertex 2 X-coordinate
  0,                                                          !- Vertex 2 Y-coordinate
  6.64,                                                       !- Vertex 2 Z-coordinate
  2.182,                                                      !- Vertex 3 X-coordinate
  0,                                                          !- Vertex 3 Y-coordinate
  8.263;                                                      !- Vertex 3 Z-coordinate
```

```
BuildingSurface:Detailed,
  south bsmt wall 1,                         !- Name
  Wall,                                      !- Surface Type
  below_grade,                               !- Construction Name
  Basement_Zone,                             !- Zone Name
  Outdoors,                                  !- Outside Boundary Condition
  ,                                          !- Outside Boundary Condition Object
  SunExposed,                                !- Sun Exposure
  WindExposed,                               !- Wind Exposure
  autocalculate,                             !- View Factor to Ground
  4,                                         !- Number of Vertices
  0,                                         !- Vertex 1 X-coordinate
  0,                                         !- Vertex 1 Y-coordinate
  0,                                         !- Vertex 1 Z-coordinate
  4.38,                                      !- Vertex 2 X-coordinate
  0,                                         !- Vertex 2 Y-coordinate
  0,                                         !- Vertex 2 Z-coordinate
  4.38,                                      !- Vertex 3 X-coordinate
  0,                                         !- Vertex 3 Y-coordinate
  0.64,                                      !- Vertex 3 Z-coordinate
  0,                                         !- Vertex 4 X-coordinate
  0,                                         !- Vertex 4 Y-coordinate
  0.64;                                      !- Vertex 4 Z-coordinate

BuildingSurface:Detailed,
  south bg wall 1,                           !- Name
  Wall,                                      !- Surface Type
  below_grade,                               !- Construction Name
  Basement_Zone,                             !- Zone Name
  OtherSideCoefficients,                     !- Outside Boundary Condition
  surfPropOthSdCoefBasementAvgWall,          !- Outside Boundary Condition Object
  NoSun,                                     !- Sun Exposure
  NoWind,                                    !- Wind Exposure
  autocalculate,                             !- View Factor to Ground
  4,                                         !- Number of Vertices
  0,                                         !- Vertex 1 X-coordinate
  0,                                         !- Vertex 1 Y-coordinate
  -1.96,                                     !- Vertex 1 Z-coordinate
  4.38,                                      !- Vertex 2 X-coordinate
  0,                                         !- Vertex 2 Y-coordinate
  -1.94,                                     !- Vertex 2 Z-coordinate
  4.38,                                      !- Vertex 3 X-coordinate
  0,                                         !- Vertex 3 Y-coordinate
  0,                                         !- Vertex 3 Z-coordinate
  0,                                         !- Vertex 4 X-coordinate
  0,                                         !- Vertex 4 Y-coordinate
  0;                                         !- Vertex 4 Z-coordinate

BuildingSurface:Detailed,
  south wall 2a,                             !- Name
  Wall,                                      !- Surface Type
  Brick_Wall_w,                              !- Construction Name
  Zone 1,                                    !- Zone Name
  Outdoors,                                  !- Outside Boundary Condition
  ,                                          !- Outside Boundary Condition Object
  SunExposed,                                !- Sun Exposure
  WindExposed,                               !- Wind Exposure
  0.5,                                       !- View Factor to Ground
  4,                                         !- Number of Vertices
  4.38,                                      !- Vertex 1 X-coordinate
  1.23,                                      !- Vertex 1 Y-coordinate
  0.64,                                      !- Vertex 1 Z-coordinate
  7.8,                                       !- Vertex 2 X-coordinate
  1.23,                                      !- Vertex 2 Y-coordinate
  0.64,                                      !- Vertex 2 Z-coordinate
  7.8,                                       !- Vertex 3 X-coordinate
  1.23,                                      !- Vertex 3 Y-coordinate
  3.41,                                      !- Vertex 3 Z-coordinate
```

```
  4.38,                                  !- Vertex 4 X-coordinate
  1.23,                                  !- Vertex 4 Y-coordinate
  3.41;                                  !- Vertex 4 Z-coordinate

BuildingSurface:Detailed,
  south bsmt wall 2a,                    !- Name
  Wall,                                  !- Surface Type
  below_grade,                           !- Construction Name
  Basement_Zone,                         !- Zone Name
  Outdoors,                              !- Outside Boundary Condition
  ,                                      !- Outside Boundary Condition Object
  SunExposed,                            !- Sun Exposure
  WindExposed,                           !- Wind Exposure
  autocalculate,                         !- View Factor to Ground
  4,                                     !- Number of Vertices
  4.38,                                  !- Vertex 1 X-coordinate
  1.23,                                  !- Vertex 1 Y-coordinate
  0,                                     !- Vertex 1 Z-coordinate
  7.8,                                   !- Vertex 2 X-coordinate
  1.23,                                  !- Vertex 2 Y-coordinate
  0,                                     !- Vertex 2 Z-coordinate
  7.8,                                   !- Vertex 3 X-coordinate
  1.23,                                  !- Vertex 3 Y-coordinate
  0.64,                                  !- Vertex 3 Z-coordinate
  4.38,                                  !- Vertex 4 X-coordinate
  1.23,                                  !- Vertex 4 Y-coordinate
  0.64;                                  !- Vertex 4 Z-coordinate

BuildingSurface:Detailed,
  south bg wall 2a,                      !- Name
  Wall,                                  !- Surface Type
  below_grade,                           !- Construction Name
  Basement_Zone,                         !- Zone Name
  OtherSideCoefficients,                 !- Outside Boundary Condition
  surfPropOthSdCoefBasementAvgWall,      !- Outside Boundary Condition Object
  NoSun,                                 !- Sun Exposure
  NoWind,                                !- Wind Exposure
  autocalculate,                         !- View Factor to Ground
  4,                                     !- Number of Vertices
  4.38,                                  !- Vertex 1 X-coordinate
  1.23,                                  !- Vertex 1 Y-coordinate
  -1.96,                                 !- Vertex 1 Z-coordinate
  7.8,                                   !- Vertex 2 X-coordinate
  1.23,                                  !- Vertex 2 Y-coordinate
  -1.96,                                 !- Vertex 2 Z-coordinate
  7.8,                                   !- Vertex 3 X-coordinate
  1.23,                                  !- Vertex 3 Y-coordinate
  0,                                     !- Vertex 3 Z-coordinate
  4.38,                                  !- Vertex 4 X-coordinate
  1.23,                                  !- Vertex 4 Y-coordinate
  0;                                     !- Vertex 4 Z-coordinate

BuildingSurface:Detailed,
  south bg wall 2b,                      !- Name
  Wall,                                  !- Surface Type
  below_grade,                           !- Construction Name
  Basement_Zone,                         !- Zone Name
  OtherSideCoefficients,                 !- Outside Boundary Condition
  surfPropOthSdCoefBasementAvgWall,      !- Outside Boundary Condition Object
  NoSun,                                 !- Sun Exposure
  NoWind,                                !- Wind Exposure
  autocalculate,                         !- View Factor to Ground
  4,                                     !- Number of Vertices
  7.8,                                   !- Vertex 1 X-coordinate
  7.45,                                  !- Vertex 1 Y-coordinate
  -1.96,                                 !- Vertex 1 Z-coordinate
  12.2,                                  !- Vertex 2 X-coordinate
  7.45,                                  !- Vertex 2 Y-coordinate
```

```
  -1.96,                                                  !- Vertex 2 Z-coordinate
  12.2,                                                   !- Vertex 3 X-coordinate
  7.45,                                                   !- Vertex 3 Y-coordinate
  0.64,                                                   !- Vertex 3 Z-coordinate
  7.8,                                                    !- Vertex 4 X-coordinate
  7.45,                                                   !- Vertex 4 Y-coordinate
  0.64;                                                   !- Vertex 4 Z-coordinate

BuildingSurface:Detailed,
  south wall 2b,                                          !- Name
  Wall,                                                   !- Surface Type
  Brick_Wall_Uninsulated,                                 !- Construction Name
  Garage_Zone,                                            !- Zone Name
  Outdoors,                                               !- Outside Boundary Condition
  ,                                                       !- Outside Boundary Condition Object
  SunExposed,                                             !- Sun Exposure
  WindExposed,                                            !- Wind Exposure
  0.5,                                                    !- View Factor to Ground
  4,                                                      !- Number of Vertices
  7.8,                                                    !- Vertex 1 X-coordinate
  1.23,                                                   !- Vertex 1 Y-coordinate
  0.64,                                                   !- Vertex 1 Z-coordinate
  12.2,                                                   !- Vertex 2 X-coordinate
  1.23,                                                   !- Vertex 2 Y-coordinate
  0.64,                                                   !- Vertex 2 Z-coordinate
  12.2,                                                   !- Vertex 3 X-coordinate
  1.23,                                                   !- Vertex 3 Y-coordinate
  3.41,                                                   !- Vertex 3 Z-coordinate
  7.8,                                                    !- Vertex 4 X-coordinate
  1.23,                                                   !- Vertex 4 Y-coordinate
  3.41;                                                   !- Vertex 4 Z-coordinate

BuildingSurface:Detailed,
  south wall 3a,                                          !- Name
  Wall,                                                   !- Surface Type
  Brick_Wall_S3a,                                           !- Construction Name
  Zone 1,                                                 !- Zone Name
  Outdoors,                                               !- Outside Boundary Condition
  ,                                                       !- Outside Boundary Condition Object
  SunExposed,                                             !- Sun Exposure
  WindExposed,                                            !- Wind Exposure
  0.5,                                                    !- View Factor to Ground
  4,                                                      !- Number of Vertices
  4.38,                                                   !- Vertex 1 X-coordinate
  1.23,                                                   !- Vertex 1 Y-coordinate
  3.41,                                                   !- Vertex 1 Z-coordinate
  9.411,                                                  !- Vertex 2 X-coordinate
  1.23,                                                   !- Vertex 2 Y-coordinate
  3.41,                                                   !- Vertex 2 Z-coordinate
  9.411,                                                  !- Vertex 3 X-coordinate
  1.23,                                                   !- Vertex 3 Y-coordinate
  6.64,                                                   !- Vertex 3 Z-coordinate
  4.38,                                                   !- Vertex 4 X-coordinate
  1.23,                                                   !- Vertex 4 Y-coordinate
  6.64;                                                   !- Vertex 4 Z-coordinate

BuildingSurface:Detailed,
  south wall 3c,                                          !- Name
  Wall,                                                   !- Surface Type
  Brick_Wall,                                             !- Construction Name
  Zone 1,                                                 !- Zone Name
  Outdoors,                                               !- Outside Boundary Condition
  ,                                                       !- Outside Boundary Condition Object
  SunExposed,                                             !- Sun Exposure
  WindExposed,                                            !- Wind Exposure
  0.5,                                                    !- View Factor to Ground
  4,                                                      !- Number of Vertices
  9.411,                                                  !- Vertex 1 X-coordinate
```

```
    1.23,                                    !- Vertex 1 Y-coordinate
    3.41,                                    !- Vertex 1 Z-coordinate
    12.2,                                    !- Vertex 2 X-coordinate
    1.23,                                    !- Vertex 2 Y-coordinate
    3.41,                                    !- Vertex 2 Z-coordinate
    12.2,                                    !- Vertex 3 X-coordinate
    1.23,                                    !- Vertex 3 Y-coordinate
    4.58,                                    !- Vertex 3 Z-coordinate
    9.411,                                   !- Vertex 4 X-coordinate
    1.23,                                    !- Vertex 4 Y-coordinate
    4.58;                                    !- Vertex 4 Z-coordinate

  BuildingSurface:Detailed,
    south wall 3b,                           !- Name
    Wall,                                    !- Surface Type
    Brick_Wall_Uninsulated,                  !- Construction Name
    Attic_Zone,                              !- Zone Name
    Outdoors,                                !- Outside Boundary Condition
    ,                                        !- Outside Boundary Condition Object
    SunExposed,                              !- Sun Exposure
    WindExposed,                             !- Wind Exposure
    0.5,                                     !- View Factor to Ground
    3,                                       !- Number of Vertices
    6.467,                                   !- Vertex 1 X-coordinate
    1.23,                                    !- Vertex 1 Y-coordinate
    6.64,                                    !- Vertex 1 Z-coordinate
    9.411,                                   !- Vertex 2 X-coordinate
    1.23,                                    !- Vertex 2 Y-coordinate
    6.64,                                    !- Vertex 2 Z-coordinate
    7.939,                                   !- Vertex 3 X-coordinate
    1.23,                                    !- Vertex 3 Y-coordinate
    7.685;                                   !- Vertex 3 Z-coordinate

  BuildingSurface:Detailed,
    south roof 1,                            !- Name
    Roof,                                    !- Surface Type
    Roof_uninsulated,                        !- Construction Name
    Attic_Zone,                              !- Zone Name
    Outdoors,                                !- Outside Boundary Condition
    ,                                        !- Outside Boundary Condition Object
    SunExposed,                              !- Sun Exposure
    WindExposed,                             !- Wind Exposure
    autocalculate,                           !- View Factor to Ground
    5,                                       !- Number of Vertices
    4.38,                                    !- Vertex 1 X-coordinate
    1.23,                                    !- Vertex 1 Y-coordinate
    6.64,                                    !- Vertex 1 Z-coordinate
    6.467,                                   !- Vertex 2 X-coordinate
    1.23,                                    !- Vertex 2 Y-coordinate
    6.64,                                    !- Vertex 2 Z-coordinate
    7.939,                                   !- Vertex 3 X-coordinate
    3.108,                                   !- Vertex 3 Y-coordinate
    7.63,                                    !- Vertex 3 Z-coordinate
    4.48,                                    !- Vertex 4 X-coordinate
    5.8,                                     !- Vertex 4 Y-coordinate
    10.24,                                   !- Vertex 4 Z-coordinate
    2.182,                                   !- Vertex 5 X-coordinate
    3.16,                                    !- Vertex 5 Y-coordinate
    8.263;                                   !- Vertex 5 Z-coordinate

  BuildingSurface:Detailed,
    south roof 2a,                           !- Name
    Roof,                                    !- Surface Type
    Roof_insulated,                          !- Construction Name
    Zone 1,                                  !- Zone Name
    Outdoors,                                !- Outside Boundary Condition
    ,                                        !- Outside Boundary Condition Object
    SunExposed,                              !- Sun Exposure
```

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  WindExposed,                              !- Wind Exposure
  autocalculate,                            !- View Factor to Ground
  4,                                        !- Number of Vertices
  9.411,                                    !- Vertex 1 X-coordinate
  1.23,                                     !- Vertex 1 Y-coordinate
  4.58,                                     !- Vertex 1 Z-coordinate
  12.2,                                     !- Vertex 2 X-coordinate
  1.23,                                     !- Vertex 2 Y-coordinate
  4.58,                                     !- Vertex 2 Z-coordinate
  12.2,                                     !- Vertex 3 X-coordinate
  3.662,                                    !- Vertex 3 Y-coordinate
  6.64,                                     !- Vertex 3 Z-coordinate
  9.411,                                    !- Vertex 4 X-coordinate
  3.662,                                    !- Vertex 4 Y-coordinate
  6.64;                                     !- Vertex 4 Z-coordinate

BuildingSurface:Detailed,
  south roof 2b,                            !- Name
  Roof,                                     !- Surface Type
  Roof_uninsulated,                         !- Construction Name
  Attic_Zone,                               !- Zone Name
  Outdoors,                                 !- Outside Boundary Condition
  ,                                         !- Outside Boundary Condition Object
  SunExposed,                               !- Sun Exposure
  WindExposed,                              !- Wind Exposure
  autocalculate,                            !- View Factor to Ground
  4,                                        !- Number of Vertices
  12.2,                                     !- Vertex 1 X-coordinate
  3.662,                                    !- Vertex 1 Y-coordinate
  6.64,                                     !- Vertex 1 Z-coordinate
  9.46,                                     !- Vertex 2 X-coordinate
  6.4,                                      !- Vertex 2 Y-coordinate
  9.34,                                     !- Vertex 2 Z-coordinate
  6.414,                                    !- Vertex 3 X-coordinate
  6.4,                                      !- Vertex 3 Y-coordinate
  9.34,                                     !- Vertex 3 Z-coordinate
  9.411,                                    !- Vertex 4 X-coordinate
  3.662,                                    !- Vertex 4 Y-coordinate
  6.64;                                     !- Vertex 4 Z-coordinate

BuildingSurface:Detailed,
  east wall 1a,                             !- Name
  Wall,                                     !- Surface Type
  Brick_Wall_uninsulated,                   !- Construction Name
  Garage_Zone,                              !- Zone Name
  Outdoors,                                 !- Outside Boundary Condition
  ,                                         !- Outside Boundary Condition Object
  SunExposed,                               !- Sun Exposure
  WindExposed,                              !- Wind Exposure
  0.5,                                      !- View Factor to Ground
  4,                                        !- Number of Vertices
  12.2,                                     !- Vertex 1 X-coordinate
  1.23,                                     !- Vertex 1 Y-coordinate
  0.64,                                     !- Vertex 1 Z-coordinate
  12.2,                                     !- Vertex 2 X-coordinate
  7.45,                                     !- Vertex 2 Y-coordinate
  0.64,                                     !- Vertex 2 Z-coordinate
  12.2,                                     !- Vertex 3 X-coordinate
  7.45,                                     !- Vertex 3 Y-coordinate
  3.41,                                     !- Vertex 3 Z-coordinate
  12.2,                                     !- Vertex 4 X-coordinate
  1.23,                                     !- Vertex 4 Y-coordinate
  3.41;                                     !- Vertex 4 Z-coordinate

BuildingSurface:Detailed,
  east wall 1b,                             !- Name
  Wall,                                     !- Surface Type
  Brick_Wall_E1b,                             !- Construction Name
```

```
    Zone 1,                                                 !- Zone Name
    Outdoors,                                               !- Outside Boundary Condition
    ,                                                       !- Outside Boundary Condition Object
    SunExposed,                                             !- Sun Exposure
    WindExposed,                                            !- Wind Exposure
    0.5,                                                    !- View Factor to Ground
    4,                                                      !- Number of Vertices
    12.2,                                                   !- Vertex 1 X-coordinate
    7.45,                                                   !- Vertex 1 Y-coordinate
    0.64,                                                   !- Vertex 1 Z-coordinate
    12.2,                                                   !- Vertex 2 X-coordinate
    11.79,                                                  !- Vertex 2 Y-coordinate
    0.64,                                                   !- Vertex 2 Z-coordinate
    12.2,                                                   !- Vertex 3 X-coordinate
    11.79,                                                  !- Vertex 3 Y-coordinate
    3.41,                                                   !- Vertex 3 Z-coordinate
    12.2,                                                   !- Vertex 4 X-coordinate
    7.45,                                                   !- Vertex 4 Y-coordinate
    3.41;                                                   !- Vertex 4 Z-coordinate

  BuildingSurface:Detailed,
    east wall 1c,                                           !- Name
    Wall,                                                   !- Surface Type
    Brick_Wall,                                             !- Construction Name
    Zone 1,                                                 !- Zone Name
    Outdoors,                                               !- Outside Boundary Condition
    ,                                                       !- Outside Boundary Condition Object
    SunExposed,                                             !- Sun Exposure
    WindExposed,                                            !- Wind Exposure
    0.5,                                                    !- View Factor to Ground
    6,                                                      !- Number of Vertices
    12.2,                                                   !- Vertex 1 X-coordinate
    1.23,                                                   !- Vertex 1 Y-coordinate
    3.41,                                                   !- Vertex 1 Z-coordinate
    12.2,                                                   !- Vertex 2 X-coordinate
    11.79,                                                  !- Vertex 2 Y-coordinate
    3.41,                                                   !- Vertex 2 Z-coordinate
    12.2,                                                   !- Vertex 3 X-coordinate
    11.79,                                                  !- Vertex 3 Y-coordinate
    4.58,                                                   !- Vertex 3 Z-coordinate
    12.2,                                                   !- Vertex 4 X-coordinate
    9.427,                                                  !- Vertex 4 Y-coordinate
    6.64,                                                   !- Vertex 4 Z-coordinate
    12.2,                                                   !- Vertex 5 X-coordinate
    3.662,                                                  !- Vertex 5 Y-coordinate
    6.64,                                                   !- Vertex 5 Z-coordinate
    12.2,                                                   !- Vertex 6 X-coordinate
    1.23,                                                   !- Vertex 6 Y-coordinate
    4.58;                                                   !- Vertex 6 Z-coordinate

  BuildingSurface:Detailed,
    east bg wall 1a,                                        !- Name
    Wall,                                                   !- Surface Type
    below_grade,                                            !- Construction Name
    Basement_Zone,                                          !- Zone Name
    OtherSideCoefficients,                                  !- Outside Boundary Condition
    surfPropOthSdCoefBasementAvgWall,                       !- Outside Boundary Condition Object
    NoSun,                                                  !- Sun Exposure
    NoWind,                                                 !- Wind Exposure
    autocalculate,                                          !- View Factor to Ground
    4,                                                      !- Number of Vertices
    7.8,                                                    !- Vertex 1 X-coordinate
    1.23,                                                   !- Vertex 1 Y-coordinate
    -1.96,                                                  !- Vertex 1 Z-coordinate
    7.8,                                                    !- Vertex 2 X-coordinate
    7.45,                                                   !- Vertex 2 Y-coordinate
    -1.96,                                                  !- Vertex 2 Z-coordinate
    7.8,                                                    !- Vertex 3 X-coordinate
```

```
    7.45,                                   !- Vertex 3 Y-coordinate
    0.64,                                   !- Vertex 3 Z-coordinate
    7.8,                                    !- Vertex 4 X-coordinate
    1.23,                                   !- Vertex 4 Y-coordinate
    0.64;                                   !- Vertex 4 Z-coordinate

  BuildingSurface:Detailed,
    east bsmt wall 1b,                      !- Name
    Wall,                                   !- Surface Type
    below_grade,                            !- Construction Name
    Basement_Zone,                          !- Zone Name
    Outdoors,                               !- Outside Boundary Condition
    ,                                       !- Outside Boundary Condition Object
    SunExposed,                             !- Sun Exposure
    WindExposed,                            !- Wind Exposure
    autocalculate,                          !- View Factor to Ground
    4,                                      !- Number of Vertices
    12.2,                                   !- Vertex 1 X-coordinate
    7.45,                                   !- Vertex 1 Y-coordinate
    0,                                      !- Vertex 1 Z-coordinate
    12.2,                                   !- Vertex 2 X-coordinate
    11.79,                                  !- Vertex 2 Y-coordinate
    0,                                      !- Vertex 2 Z-coordinate
    12.2,                                   !- Vertex 3 X-coordinate
    11.79,                                  !- Vertex 3 Y-coordinate
    0.64,                                   !- Vertex 3 Z-coordinate
    12.2,                                   !- Vertex 4 X-coordinate
    7.45,                                   !- Vertex 4 Y-coordinate
    0.64;                                   !- Vertex 4 Z-coordinate

  BuildingSurface:Detailed,
    east bg wall 1b,                        !- Name
    Wall,                                   !- Surface Type
    below_grade,                            !- Construction Name
    Basement_Zone,                          !- Zone Name
    OtherSideCoefficients,                  !- Outside Boundary Condition
    surfPropOthSdCoefBasementAvgWall,       !- Outside Boundary Condition Object
    NoSun,                                  !- Sun Exposure
    NoWind,                                 !- Wind Exposure
    autocalculate,                          !- View Factor to Ground
    4,                                      !- Number of Vertices
    12.2,                                   !- Vertex 1 X-coordinate
    7.45,                                   !- Vertex 1 Y-coordinate
    -1.96,                                  !- Vertex 1 Z-coordinate
    12.2,                                   !- Vertex 2 X-coordinate
    11.79,                                  !- Vertex 2 Y-coordinate
    -1.96,                                  !- Vertex 2 Z-coordinate
    12.2,                                   !- Vertex 3 X-coordinate
    11.79,                                  !- Vertex 3 Y-coordinate
    0,                                      !- Vertex 3 Z-coordinate
    12.2,                                   !- Vertex 4 X-coordinate
    7.45,                                   !- Vertex 4 Y-coordinate
    0;                                      !- Vertex 4 Z-coordinate

  BuildingSurface:Detailed,
    east wall 2,                            !- Name
    Wall,                                   !- Surface Type
    Brick_Wall,                             !- Construction Name
    Zone 1,                                 !- Zone Name
    Outdoors,                               !- Outside Boundary Condition
    ,                                       !- Outside Boundary Condition Object
    SunExposed,                             !- Sun Exposure
    WindExposed,                            !- Wind Exposure
    0.5,                                    !- View Factor to Ground
    3,                                      !- Number of Vertices
    9.4,                                    !- Vertex 1 X-coordinate
    11.79,                                  !- Vertex 1 Y-coordinate
    4.58,                                   !- Vertex 1 Z-coordinate
```

```
  9.4,                                                        !- Vertex 2 X-coordinate
  11.79,                                                      !- Vertex 2 Y-coordinate
  6.64,                                                       !- Vertex 2 Z-coordinate
  9.4,                                                        !- Vertex 3 X-coordinate
  9.427,                                                      !- Vertex 3 Y-coordinate
  6.64;                                                       !- Vertex 3 Z-coordinate

BuildingSurface:Detailed,
  east wall 3,                                                !- Name
  Wall,                                                       !- Surface Type
  Brick_Wall,                                                 !- Construction Name
  Zone 1,                                                     !- Zone Name
  Outdoors,                                                   !- Outside Boundary Condition
  ,                                                           !- Outside Boundary Condition Object
  SunExposed,                                                 !- Sun Exposure
  WindExposed,                                                !- Wind Exposure
  0.5,                                                        !- View Factor to Ground
  3,                                                          !- Number of Vertices
  9.411,                                                      !- Vertex 1 X-coordinate
  1.23,                                                       !- Vertex 1 Y-coordinate
  4.58,                                                       !- Vertex 1 Z-coordinate
  9.411,                                                      !- Vertex 2 X-coordinate
  3.662,                                                      !- Vertex 2 Y-coordinate
  6.64,                                                       !- Vertex 2 Z-coordinate
  9.411,                                                      !- Vertex 3 X-coordinate
  1.23,                                                       !- Vertex 3 Y-coordinate
  6.64;                                                       !- Vertex 3 Z-coordinate

BuildingSurface:Detailed,
  east wall 4,                                                !- Name
  Wall,                                                       !- Surface Type
  Brick_Wall,                                                 !- Construction Name
  Zone 1,                                                     !- Zone Name
  Outdoors,                                                   !- Outside Boundary Condition
  ,                                                           !- Outside Boundary Condition Object
  SunExposed,                                                 !- Sun Exposure
  WindExposed,                                                !- Wind Exposure
  0.5,                                                        !- View Factor to Ground
  4,                                                          !- Number of Vertices
  4.38,                                                       !- Vertex 1 X-coordinate
  0,                                                          !- Vertex 1 Y-coordinate
  0.64,                                                       !- Vertex 1 Z-coordinate
  4.38,                                                       !- Vertex 2 X-coordinate
  1.23,                                                       !- Vertex 2 Y-coordinate
  0.64,                                                       !- Vertex 2 Z-coordinate
  4.38,                                                       !- Vertex 3 X-coordinate
  1.23,                                                       !- Vertex 3 Y-coordinate
  6.64,                                                       !- Vertex 3 Z-coordinate
  4.38,                                                       !- Vertex 4 X-coordinate
  0,                                                          !- Vertex 4 Y-coordinate
  6.64;                                                       !- Vertex 4 Z-coordinate

BuildingSurface:Detailed,
  east bsmt wall 4,                                           !- Name
  Wall,                                                       !- Surface Type
  below_grade,                                                !- Construction Name
  Basement_Zone,                                              !- Zone Name
  Outdoors,                                                   !- Outside Boundary Condition
  ,                                                           !- Outside Boundary Condition Object
  SunExposed,                                                 !- Sun Exposure
  WindExposed,                                                !- Wind Exposure
  autocalculate,                                              !- View Factor to Ground
  4,                                                          !- Number of Vertices
  4.38,                                                       !- Vertex 1 X-coordinate
  0,                                                          !- Vertex 1 Y-coordinate
  0,                                                          !- Vertex 1 Z-coordinate
  4.38,                                                       !- Vertex 2 X-coordinate
  1.23,                                                       !- Vertex 2 Y-coordinate
```

```
  0,                                                  !- Vertex 2 Z-coordinate
  4.38,                                               !- Vertex 3 X-coordinate
  1.23,                                               !- Vertex 3 Y-coordinate
  0.64,                                               !- Vertex 3 Z-coordinate
  4.38,                                               !- Vertex 4 X-coordinate
  0,                                                  !- Vertex 4 Y-coordinate
  0.64;                                               !- Vertex 4 Z-coordinate

BuildingSurface:Detailed,
  east bg wall 4,                                     !- Name
  Wall,                                               !- Surface Type
  below_grade,                                        !- Construction Name
  Basement_Zone,                                      !- Zone Name
  OtherSideCoefficients,                              !- Outside Boundary Condition
  surfPropOthSdCoefBasementAvgWall,                   !- Outside Boundary Condition Object
  NoSun,                                              !- Sun Exposure
  NoWind,                                             !- Wind Exposure
  autocalculate,                                      !- View Factor to Ground
  4,                                                  !- Number of Vertices
  4.38,                                               !- Vertex 1 X-coordinate
  0,                                                  !- Vertex 1 Y-coordinate
  -1.96,                                              !- Vertex 1 Z-coordinate
  4.38,                                               !- Vertex 2 X-coordinate
  1.23,                                               !- Vertex 2 Y-coordinate
  -1.96,                                              !- Vertex 2 Z-coordinate
  4.38,                                               !- Vertex 3 X-coordinate
  1.23,                                               !- Vertex 3 Y-coordinate
  0,                                                  !- Vertex 3 Z-coordinate
  4.38,                                               !- Vertex 4 X-coordinate
  0,                                                  !- Vertex 4 Y-coordinate
  0;                                                  !- Vertex 4 Z-coordinate

BuildingSurface:Detailed,
  East Roof 1,                                        !- Name
  Roof,                                               !- Surface Type
  Roof_uninsulated,                                   !- Construction Name
  Attic_Zone,                                         !- Zone Name
  Outdoors,                                           !- Outside Boundary Condition
  ,                                                   !- Outside Boundary Condition Object
  SunExposed,                                         !- Sun Exposure
  WindExposed,                                        !- Wind Exposure
  autocalculate,                                      !- View Factor to Ground
  3,                                                  !- Number of Vertices
  12.2,                                               !- Vertex 1 X-coordinate
  3.662,                                              !- Vertex 1 Y-coordinate
  6.64,                                               !- Vertex 1 Z-coordinate
  12.2,                                               !- Vertex 2 X-coordinate
  9.427,                                              !- Vertex 2 Y-coordinate
  6.64,                                               !- Vertex 2 Z-coordinate
  9.46,                                               !- Vertex 3 X-coordinate
  6.4,                                                !- Vertex 3 Y-coordinate
  9.34;                                               !- Vertex 3 Z-coordinate

BuildingSurface:Detailed,
  East Roof 2,                                        !- Name
  Roof,                                               !- Surface Type
  Roof_uninsulated,                                   !- Construction Name
  Attic_Zone,                                         !- Zone Name
  Outdoors,                                           !- Outside Boundary Condition
  ,                                                   !- Outside Boundary Condition Object
  SunExposed,                                         !- Sun Exposure
  WindExposed,                                        !- Wind Exposure
  autocalculate,                                      !- View Factor to Ground
  4,                                                  !- Number of Vertices
  4.38,                                               !- Vertex 1 X-coordinate
  0,                                                  !- Vertex 1 Y-coordinate
  6.64,                                               !- Vertex 1 Z-coordinate
  4.38,                                               !- Vertex 2 X-coordinate
```

```
    1.2,                                            !- Vertex 2 Y-coordinate
    6.64,                                           !- Vertex 2 Z-coordinate
    2.182,                                          !- Vertex 3 X-coordinate
    3.587,                                          !- Vertex 3 Y-coordinate
    8.263,                                          !- Vertex 3 Z-coordinate
    2.182,                                          !- Vertex 4 X-coordinate
    0,                                              !- Vertex 4 Y-coordinate
    8.263;                                          !- Vertex 4 Z-coordinate

  BuildingSurface:Detailed,
    East Roof 3,                                    !- Name
    Roof,                                           !- Surface Type
    Roof_uninsulated,                               !- Construction Name
    Attic_Zone,                                     !- Zone Name
    Outdoors,                                       !- Outside Boundary Condition
    ,                                               !- Outside Boundary Condition Object
    SunExposed,                                     !- Sun Exposure
    WindExposed,                                    !- Wind Exposure
    autocalculate,                                  !- View Factor to Ground
    6,                                              !- Number of Vertices
    9.411,                                          !- Vertex 1 X-coordinate
    1.23,                                           !- Vertex 1 Y-coordinate
    6.64,                                           !- Vertex 1 Z-coordinate
    9.411,                                          !- Vertex 2 X-coordinate
    3.662,                                          !- Vertex 2 Y-coordinate
    6.64,                                           !- Vertex 2 Z-coordinate
    6.414,                                          !- Vertex 3 X-coordinate
    6.4,                                            !- Vertex 3 Y-coordinate
    9.34,                                           !- Vertex 3 Z-coordinate
    4.48,                                           !- Vertex 4 X-coordinate
    5.8,                                            !- Vertex 4 Y-coordinate
    10.24,                                          !- Vertex 4 Z-coordinate
    7.939,                                          !- Vertex 5 X-coordinate
    3.108,                                          !- Vertex 5 Y-coordinate
    7.63,                                           !- Vertex 5 Z-coordinate
    7.939,                                          !- Vertex 6 X-coordinate
    1.23,                                           !- Vertex 6 Y-coordinate
    7.685;                                          !- Vertex 6 Z-coordinate

  BuildingSurface:Detailed,
    East Roof 4,                                    !- Name
    Roof,                                           !- Surface Type
    Roof_uninsulated,                               !- Construction Name
    Attic_Zone,                                     !- Zone Name
    Outdoors,                                       !- Outside Boundary Condition
    ,                                               !- Outside Boundary Condition Object
    SunExposed,                                     !- Sun Exposure
    WindExposed,                                    !- Wind Exposure
    autocalculate,                                  !- View Factor to Ground
    5,                                              !- Number of Vertices
    9.4,                                            !- Vertex 1 X-coordinate
    9.427,                                          !- Vertex 1 Y-coordinate
    6.64,                                           !- Vertex 1 Z-coordinate
    9.4,                                            !- Vertex 2 X-coordinate
    11.79,                                          !- Vertex 2 Y-coordinate
    6.64,                                           !- Vertex 2 Z-coordinate
    4.48,                                           !- Vertex 3 X-coordinate
    7.28,                                           !- Vertex 3 Y-coordinate
    10.24,                                          !- Vertex 3 Z-coordinate
    4.48,                                           !- Vertex 4 X-coordinate
    5.8,                                            !- Vertex 4 Y-coordinate
    10.24,                                          !- Vertex 4 Z-coordinate
    6.414,                                          !- Vertex 5 X-coordinate
    6.4,                                            !- Vertex 5 Y-coordinate
    9.34;                                           !- Vertex 5 Z-coordinate

  BuildingSurface:Detailed,
    north wall 1,                                   !- Name
```

```
  Wall,                                                        !- Surface Type
  Brick_Wall_N1,                                                !- Construction Name
  Zone 1,                                                      !- Zone Name
  Outdoors,                                                    !- Outside Boundary Condition
  ,                                                            !- Outside Boundary Condition Object
  SunExposed,                                                  !- Sun Exposure
  WindExposed,                                                 !- Wind Exposure
  0.5,                                                         !- View Factor to Ground
  6,                                                           !- Number of Vertices
  12.2,                                                        !- Vertex 1 X-coordinate
  11.79,                                                       !- Vertex 1 Y-coordinate
  0.64,                                                        !- Vertex 1 Z-coordinate
  0,                                                           !- Vertex 2 X-coordinate
  11.79,                                                       !- Vertex 2 Y-coordinate
  0.64,                                                        !- Vertex 2 Z-coordinate
  0,                                                           !- Vertex 3 X-coordinate
  11.79,                                                       !- Vertex 3 Y-coordinate
  6.64,                                                        !- Vertex 3 Z-coordinate
  9.4,                                                         !- Vertex 4 X-coordinate
  11.79,                                                       !- Vertex 4 Y-coordinate
  6.64,                                                        !- Vertex 4 Z-coordinate
  9.4,                                                         !- Vertex 5 X-coordinate
  11.79,                                                       !- Vertex 5 Y-coordinate
  4.586,                                                       !- Vertex 5 Z-coordinate
  12.2,                                                        !- Vertex 6 X-coordinate
  11.79,                                                       !- Vertex 6 Y-coordinate
  4.586;                                                       !- Vertex 6 Z-coordinate

BuildingSurface:Detailed,
  north bsmt wall 1a,                                          !- Name
  Wall,                                                        !- Surface Type
  below_grade_Nbsmt_1a,                                        !- Construction Name
  Basement_Zone,                                               !- Zone Name
  Outdoors,                                                    !- Outside Boundary Condition
  ,                                                            !- Outside Boundary Condition Object
  SunExposed,                                                  !- Sun Exposure
  WindExposed,                                                 !- Wind Exposure
  autocalculate,                                               !- View Factor to Ground
  4,                                                           !- Number of Vertices
  12.2,                                                        !- Vertex 1 X-coordinate
  11.79,                                                       !- Vertex 1 Y-coordinate
  0,                                                           !- Vertex 1 Z-coordinate
  0,                                                           !- Vertex 2 X-coordinate
  11.79,                                                       !- Vertex 2 Y-coordinate
  0,                                                           !- Vertex 2 Z-coordinate
  0,                                                           !- Vertex 3 X-coordinate
  11.79,                                                       !- Vertex 3 Y-coordinate
  0.64,                                                        !- Vertex 3 Z-coordinate
  12.2,                                                        !- Vertex 4 X-coordinate
  11.79,                                                       !- Vertex 4 Y-coordinate
  0.64;                                                        !- Vertex 4 Z-coordinate

BuildingSurface:Detailed,
  north bg wall 1a,                                            !- Name
  Wall,                                                        !- Surface Type
  below_grade,                                                 !- Construction Name
  Basement_Zone,                                               !- Zone Name
  OtherSideCoefficients,                                       !- Outside Boundary Condition
  surfPropOthSdCoefBasementAvgWall,                            !- Outside Boundary Condition Object
  NoSun,                                                       !- Sun Exposure
  NoWind,                                                      !- Wind Exposure
  autocalculate,                                               !- View Factor to Ground
  4,                                                           !- Number of Vertices
  12.2,                                                        !- Vertex 1 X-coordinate
  11.79,                                                       !- Vertex 1 Y-coordinate
  -1.96,                                                       !- Vertex 1 Z-coordinate
  0,                                                           !- Vertex 2 X-coordinate
  11.79,                                                       !- Vertex 2 Y-coordinate
```

```
  -1.96,                                                    !- Vertex 2 Z-coordinate
  0,                                                        !- Vertex 3 X-coordinate
  11.79,                                                    !- Vertex 3 Y-coordinate
  0,                                                        !- Vertex 3 Z-coordinate
  12.2,                                                     !- Vertex 4 X-coordinate
  11.79,                                                    !- Vertex 4 Y-coordinate
  0;                                                        !- Vertex 4 Z-coordinate

BuildingSurface:Detailed,
  North Roof 1,                                             !- Name
  Roof,                                                     !- Surface Type
  Roof_uninsulated,                                         !- Construction Name
  Attic_Zone,                                               !- Zone Name
  Outdoors,                                                 !- Outside Boundary Condition
  ,                                                         !- Outside Boundary Condition Object
  SunExposed,                                               !- Sun Exposure
  WindExposed,                                              !- Wind Exposure
  autocalculate,                                            !- View Factor to Ground
  3,                                                        !- Number of Vertices
  9.4,                                                      !- Vertex 1 X-coordinate
  11.79,                                                    !- Vertex 1 Y-coordinate
  6.64,                                                     !- Vertex 1 Z-coordinate
  0,                                                        !- Vertex 2 X-coordinate
  11.79,                                                    !- Vertex 2 Y-coordinate
  6.64,                                                     !- Vertex 2 Z-coordinate
  4.48,                                                     !- Vertex 3 X-coordinate
  7.28,                                                     !- Vertex 3 Y-coordinate
  10.24;                                                    !- Vertex 3 Z-coordinate

BuildingSurface:Detailed,
  North Roof 2a,                                            !- Name
  Roof,                                                     !- Surface Type
  Roof_insulated,                                           !- Construction Name
  Zone 1,                                                   !- Zone Name
  Outdoors,                                                 !- Outside Boundary Condition
  ,                                                         !- Outside Boundary Condition Object
  SunExposed,                                               !- Sun Exposure
  WindExposed,                                              !- Wind Exposure
  autocalculate,                                            !- View Factor to Ground
  4,                                                        !- Number of Vertices
  12.2,                                                     !- Vertex 1 X-coordinate
  11.79,                                                    !- Vertex 1 Y-coordinate
  4.586,                                                    !- Vertex 1 Z-coordinate
  9.4,                                                      !- Vertex 2 X-coordinate
  11.79,                                                    !- Vertex 2 Y-coordinate
  4.586,                                                    !- Vertex 2 Z-coordinate
  9.4,                                                      !- Vertex 3 X-coordinate
  9.427,                                                    !- Vertex 3 Y-coordinate
  6.64,                                                     !- Vertex 3 Z-coordinate
  12.2,                                                     !- Vertex 4 X-coordinate
  9.427,                                                    !- Vertex 4 Y-coordinate
  6.64;                                                     !- Vertex 4 Z-coordinate

BuildingSurface:Detailed,
  North Roof 2b,                                            !- Name
  Roof,                                                     !- Surface Type
  Roof_uninsulated,                                         !- Construction Name
  attic_zone,                                               !- Zone Name
  Outdoors,                                                 !- Outside Boundary Condition
  ,                                                         !- Outside Boundary Condition Object
  SunExposed,                                               !- Sun Exposure
  WindExposed,                                              !- Wind Exposure
  autocalculate,                                            !- View Factor to Ground
  4,                                                        !- Number of Vertices
  12.2,                                                     !- Vertex 1 X-coordinate
  9.427,                                                    !- Vertex 1 Y-coordinate
  6.64,                                                     !- Vertex 1 Z-coordinate
  9.4,                                                      !- Vertex 2 X-coordinate
```

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    9.427,                                                   !- Vertex 2 Y-coordinate
    6.64,                                                    !- Vertex 2 Z-coordinate
    6.414,                                                   !- Vertex 3 X-coordinate
    6.4,                                                     !- Vertex 3 Y-coordinate
    9.34,                                                    !- Vertex 3 Z-coordinate
    9.46,                                                    !- Vertex 4 X-coordinate
    6.4,                                                     !- Vertex 4 Y-coordinate
    9.34;                                                    !- Vertex 4 Z-coordinate

  BuildingSurface:Detailed,
    west wall 1,                                             !- Name
    Wall,                                                    !- Surface Type
    Brick_Wall_W1,                                             !- Construction Name
    Zone 1,                                                  !- Zone Name
    Outdoors,                                                !- Outside Boundary Condition
    ,                                                        !- Outside Boundary Condition Object
    SunExposed,                                              !- Sun Exposure
    WindExposed,                                             !- Wind Exposure
    0.5,                                                     !- View Factor to Ground
    4,                                                       !- Number of Vertices
    0,                                                       !- Vertex 1 X-coordinate
    11.79,                                                   !- Vertex 1 Y-coordinate
    0.64,                                                    !- Vertex 1 Z-coordinate
    0,                                                       !- Vertex 2 X-coordinate
    0,                                                       !- Vertex 2 Y-coordinate
    0.64,                                                    !- Vertex 2 Z-coordinate
    0,                                                       !- Vertex 3 X-coordinate
    0,                                                       !- Vertex 3 Y-coordinate
    6.64,                                                    !- Vertex 3 Z-coordinate
    0,                                                       !- Vertex 4 X-coordinate
    11.79,                                                   !- Vertex 4 Y-coordinate
    6.64;                                                    !- Vertex 4 Z-coordinate

  BuildingSurface:Detailed,
    west bsmt wall 1,                                        !- Name
    Wall,                                                    !- Surface Type
    below_grade,                                             !- Construction Name
    Basement_Zone,                                           !- Zone Name
    Outdoors,                                                !- Outside Boundary Condition
    ,                                                        !- Outside Boundary Condition Object
    SunExposed,                                              !- Sun Exposure
    WindExposed,                                             !- Wind Exposure
    autocalculate,                                           !- View Factor to Ground
    4,                                                       !- Number of Vertices
    0,                                                       !- Vertex 1 X-coordinate
    11.79,                                                   !- Vertex 1 Y-coordinate
    0,                                                       !- Vertex 1 Z-coordinate
    0,                                                       !- Vertex 2 X-coordinate
    0,                                                       !- Vertex 2 Y-coordinate
    0,                                                       !- Vertex 2 Z-coordinate
    0,                                                       !- Vertex 3 X-coordinate
    0,                                                       !- Vertex 3 Y-coordinate
    0.64,                                                    !- Vertex 3 Z-coordinate
    0,                                                       !- Vertex 4 X-coordinate
    11.79,                                                   !- Vertex 4 Y-coordinate
    0.64;                                                    !- Vertex 4 Z-coordinate

  BuildingSurface:Detailed,
    west bg wall 1,                                          !- Name
    Wall,                                                    !- Surface Type
    below_grade,                                             !- Construction Name
    Basement_Zone,                                           !- Zone Name
    OtherSideCoefficients,                                   !- Outside Boundary Condition
    surfPropOthSdCoefBasementAvgWall,                        !- Outside Boundary Condition Object
    NoSun,                                                   !- Sun Exposure
    NoWind,                                                  !- Wind Exposure
    autocalculate,                                           !- View Factor to Ground
    4,                                                       !- Number of Vertices
```

```
    0,                                                       !- Vertex 1 X-coordinate
    11.79,                                                   !- Vertex 1 Y-coordinate
    -1.96,                                                   !- Vertex 1 Z-coordinate
    0,                                                       !- Vertex 2 X-coordinate
    0,                                                       !- Vertex 2 Y-coordinate
    -1.96,                                                   !- Vertex 2 Z-coordinate
    0,                                                       !- Vertex 3 X-coordinate
    0,                                                       !- Vertex 3 Y-coordinate
    0,                                                       !- Vertex 3 Z-coordinate
    0,                                                       !- Vertex 4 X-coordinate
    11.79,                                                   !- Vertex 4 Y-coordinate
    0;                                                       !- Vertex 4 Z-coordinate

  BuildingSurface:Detailed,
    west roof 1,                                             !- Name
    Roof,                                                    !- Surface Type
    Roof_uninsulated,                                        !- Construction Name
    Attic_Zone,                                              !- Zone Name
    Outdoors,                                                !- Outside Boundary Condition
    ,                                                        !- Outside Boundary Condition Object
    SunExposed,                                              !- Sun Exposure
    WindExposed,                                             !- Wind Exposure
    autocalculate,                                           !- View Factor to Ground
    6,                                                       !- Number of Vertices
    0,                                                       !- Vertex 1 X-coordinate
    11.79,                                                   !- Vertex 1 Y-coordinate
    6.64,                                                    !- Vertex 1 Z-coordinate
    0,                                                       !- Vertex 2 X-coordinate
    0,                                                       !- Vertex 2 Y-coordinate
    6.64,                                                    !- Vertex 2 Z-coordinate
    2.182,                                                   !- Vertex 3 X-coordinate
    0,                                                       !- Vertex 3 Y-coordinate
    8.263,                                                   !- Vertex 3 Z-coordinate
    2.182,                                                   !- Vertex 4 X-coordinate
    3.16,                                                    !- Vertex 4 Y-coordinate
    8.263,                                                   !- Vertex 4 Z-coordinate
    4.48,                                                    !- Vertex 5 X-coordinate
    5.8,                                                     !- Vertex 5 Y-coordinate
    10.24,                                                   !- Vertex 5 Z-coordinate
    4.48,                                                    !- Vertex 6 X-coordinate
    7.28,                                                    !- Vertex 6 Y-coordinate
    10.24;                                                   !- Vertex 6 Z-coordinate

  BuildingSurface:Detailed,
    west roof 2,                                             !- Name
    Roof,                                                    !- Surface Type
    Roof_uninsulated,                                        !- Construction Name
    Attic_Zone,                                              !- Zone Name
    Outdoors,                                                !- Outside Boundary Condition
    ,                                                        !- Outside Boundary Condition Object
    SunExposed,                                              !- Sun Exposure
    WindExposed,                                             !- Wind Exposure
    autocalculate,                                           !- View Factor to Ground
    3,                                                       !- Number of Vertices
    6.467,                                                   !- Vertex 1 X-coordinate
    1.23,                                                    !- Vertex 1 Y-coordinate
    6.64,                                                    !- Vertex 1 Z-coordinate
    7.939,                                                   !- Vertex 2 X-coordinate
    1.23,                                                    !- Vertex 2 Y-coordinate
    7.685,                                                   !- Vertex 2 Z-coordinate
    7.939,                                                   !- Vertex 3 X-coordinate
    3.108,                                                   !- Vertex 3 Y-coordinate
    7.63;                                                    !- Vertex 3 Z-coordinate

  BuildingSurface:Detailed,
    basement floor 1,                                        !- Name
    Floor,                                                   !- Surface Type
    basement_floor,                                          !- Construction Name
```

```
    basement_zone,                          !- Zone Name
    OtherSideCoefficients,                  !- Outside Boundary Condition
    surfPropOthSdCoefBasementAvgFloor,      !- Outside Boundary Condition Object
    NoSun,                                  !- Sun Exposure
    NoWind,                                 !- Wind Exposure
    autocalculate,                          !- View Factor to Ground
    4,                                      !- Number of Vertices
    7.8,                                    !- Vertex 1 X-coordinate
    11.79,                                  !- Vertex 1 Y-coordinate
    -1.96,                                  !- Vertex 1 Z-coordinate
    12.2,                                   !- Vertex 2 X-coordinate
    11.79,                                  !- Vertex 2 Y-coordinate
    -1.96,                                  !- Vertex 2 Z-coordinate
    12.2,                                   !- Vertex 3 X-coordinate
    7.45,                                   !- Vertex 3 Y-coordinate
    -1.96,                                  !- Vertex 3 Z-coordinate
    7.8,                                    !- Vertex 4 X-coordinate
    7.45,                                   !- Vertex 4 Y-coordinate
    -1.96;                                  !- Vertex 4 Z-coordinate

  BuildingSurface:Detailed,
    basement floor 2,                       !- Name
    Floor,                                  !- Surface Type
    basement_floor,                         !- Construction Name
    Basement_Zone,                          !- Zone Name
    OtherSideCoefficients,                  !- Outside Boundary Condition
    surfPropOthSdCoefBasementAvgFloor,      !- Outside Boundary Condition Object
    NoSun,                                  !- Sun Exposure
    NoWind,                                 !- Wind Exposure
    autocalculate,                          !- View Factor to Ground
    6,                                      !- Number of Vertices
    0,                                      !- Vertex 1 X-coordinate
    11.79,                                  !- Vertex 1 Y-coordinate
    -1.96,                                  !- Vertex 1 Z-coordinate
    7.8,                                    !- Vertex 2 X-coordinate
    11.79,                                  !- Vertex 2 Y-coordinate
    -1.96,                                  !- Vertex 2 Z-coordinate
    7.8,                                    !- Vertex 3 X-coordinate
    1.23,                                   !- Vertex 3 Y-coordinate
    -1.96,                                  !- Vertex 3 Z-coordinate
    4.38,                                   !- Vertex 4 X-coordinate
    1.23,                                   !- Vertex 4 Y-coordinate
    -1.96,                                  !- Vertex 4 Z-coordinate
    4.38,                                   !- Vertex 5 X-coordinate
    0,                                      !- Vertex 5 Y-coordinate
    -1.96,                                  !- Vertex 5 Z-coordinate
    0,                                      !- Vertex 6 X-coordinate
    0,                                      !- Vertex 6 Y-coordinate
    -1.96;                                  !- Vertex 6 Z-coordinate

  BuildingSurface:Detailed,
    East garage int wall,                   !- Name
    Wall,                                   !- Surface Type
    interior_garage_wall,                   !- Construction Name
    Garage_Zone,                            !- Zone Name
    Surface,                                !- Outside Boundary Condition
    West garage int wall,                   !- Outside Boundary Condition Object
    NoSun,                                  !- Sun Exposure
    NoWind,                                 !- Wind Exposure
    autocalculate,                          !- View Factor to Ground
    4,                                      !- Number of Vertices
    7.8,                                    !- Vertex 1 X-coordinate
    1.23,                                   !- Vertex 1 Y-coordinate
    0.64,                                   !- Vertex 1 Z-coordinate
    7.8,                                    !- Vertex 2 X-coordinate
    7.45,                                   !- Vertex 2 Y-coordinate
    0.64,                                   !- Vertex 2 Z-coordinate
    7.8,                                    !- Vertex 3 X-coordinate
```

```
    7.45,                                                    !- Vertex 3 Y-coordinate
    3.41,                                                    !- Vertex 3 Z-coordinate
    7.8,                                                     !- Vertex 4 X-coordinate
    1.23,                                                    !- Vertex 4 Y-coordinate
    3.41;                                                    !- Vertex 4 Z-coordinate

  BuildingSurface:Detailed,
    West garage int wall,                                    !- Name
    Wall,                                                    !- Surface Type
    interior_garage_wall,                                    !- Construction Name
    Zone 1,                                                  !- Zone Name
    Surface,                                                 !- Outside Boundary Condition
    East garage int wall,                                    !- Outside Boundary Condition Object
    NoSun,                                                   !- Sun Exposure
    NoWind,                                                  !- Wind Exposure
    autocalculate,                                           !- View Factor to Ground
    4,                                                       !- Number of Vertices
    7.8,                                                     !- Vertex 1 X-coordinate
    7.45,                                                    !- Vertex 1 Y-coordinate
    0.64,                                                    !- Vertex 1 Z-coordinate
    7.8,                                                     !- Vertex 2 X-coordinate
    1.23,                                                    !- Vertex 2 Y-coordinate
    0.64,                                                    !- Vertex 2 Z-coordinate
    7.8,                                                     !- Vertex 3 X-coordinate
    1.23,                                                    !- Vertex 3 Y-coordinate
    3.41,                                                    !- Vertex 3 Z-coordinate
    7.8,                                                     !- Vertex 4 X-coordinate
    7.45,                                                    !- Vertex 4 Y-coordinate
    3.41;                                                    !- Vertex 4 Z-coordinate

  BuildingSurface:Detailed,
    South garage int wall,                                   !- Name
    Wall,                                                    !- Surface Type
    interior_garage_wall,                                    !- Construction Name
    Garage_Zone,                                             !- Zone Name
    Surface,                                                 !- Outside Boundary Condition
    North garage int wall,                                   !- Outside Boundary Condition Object
    NoSun,                                                   !- Sun Exposure
    NoWind,                                                  !- Wind Exposure
    autocalculate,                                           !- View Factor to Ground
    4,                                                       !- Number of Vertices
    7.8,                                                     !- Vertex 1 X-coordinate
    7.45,                                                    !- Vertex 1 Y-coordinate
    0.64,                                                    !- Vertex 1 Z-coordinate
    12.2,                                                    !- Vertex 2 X-coordinate
    7.45,                                                    !- Vertex 2 Y-coordinate
    0.64,                                                    !- Vertex 2 Z-coordinate
    12.2,                                                    !- Vertex 3 X-coordinate
    7.45,                                                    !- Vertex 3 Y-coordinate
    3.41,                                                    !- Vertex 3 Z-coordinate
    7.8,                                                     !- Vertex 4 X-coordinate
    7.45,                                                    !- Vertex 4 Y-coordinate
    3.41;                                                    !- Vertex 4 Z-coordinate

  BuildingSurface:Detailed,
    North garage int wall,                                   !- Name
    Wall,                                                    !- Surface Type
    interior_garage_wall,                                    !- Construction Name
    Zone 1,                                                  !- Zone Name
    Surface,                                                 !- Outside Boundary Condition
    South garage int wall,                                   !- Outside Boundary Condition Object
    NoSun,                                                   !- Sun Exposure
    NoWind,                                                  !- Wind Exposure
    autocalculate,                                           !- View Factor to Ground
    4,                                                       !- Number of Vertices
    12.2,                                                    !- Vertex 1 X-coordinate
    7.45,                                                    !- Vertex 1 Y-coordinate
    0.64,                                                    !- Vertex 1 Z-coordinate
```

```
    7.8,                                    !- Vertex 2 X-coordinate
    7.45,                                   !- Vertex 2 Y-coordinate
    0.64,                                   !- Vertex 2 Z-coordinate
    7.8,                                    !- Vertex 3 X-coordinate
    7.45,                                   !- Vertex 3 Y-coordinate
    3.41,                                   !- Vertex 3 Z-coordinate
    12.2,                                   !- Vertex 4 X-coordinate
    7.45,                                   !- Vertex 4 Y-coordinate
    3.41;                                   !- Vertex 4 Z-coordinate

  BuildingSurface:Detailed,
    Garage floor,                           !- Name
    Floor,                                  !- Surface Type
    basement_floor,                         !- Construction Name
    Garage_Zone,                            !- Zone Name
    Adiabatic,                              !- Outside Boundary Condition
    ,                                       !- Outside Boundary Condition Object
    NoSun,                                  !- Sun Exposure
    NoWind,                                 !- Wind Exposure
    autocalculate,                          !- View Factor to Ground
    4,                                      !- Number of Vertices
    7.8,                                    !- Vertex 1 X-coordinate
    7.45,                                   !- Vertex 1 Y-coordinate
    0.64,                                   !- Vertex 1 Z-coordinate
    12.2,                                   !- Vertex 2 X-coordinate
    7.45,                                   !- Vertex 2 Y-coordinate
    0.64,                                   !- Vertex 2 Z-coordinate
    12.2,                                   !- Vertex 3 X-coordinate
    1.23,                                   !- Vertex 3 Y-coordinate
    0.64,                                   !- Vertex 3 Z-coordinate
    7.8,                                    !- Vertex 4 X-coordinate
    1.23,                                   !- Vertex 4 Y-coordinate
    0.64;                                   !- Vertex 4 Z-coordinate

  BuildingSurface:Detailed,
    Garage ceiling,                         !- Name
    Ceiling,                                !- Surface Type
    garage_ceiling,                         !- Construction Name
    Garage_Zone,                            !- Zone Name
    Surface,                                !- Outside Boundary Condition
    Garage ceiling reverse,                 !- Outside Boundary Condition Object
    NoSun,                                  !- Sun Exposure
    NoWind,                                 !- Wind Exposure
    autocalculate,                          !- View Factor to Ground
    4,                                      !- Number of Vertices
    12.2,                                   !- Vertex 1 X-coordinate
    7.45,                                   !- Vertex 1 Y-coordinate
    3.41,                                   !- Vertex 1 Z-coordinate
    7.8,                                    !- Vertex 2 X-coordinate
    7.45,                                   !- Vertex 2 Y-coordinate
    3.41,                                   !- Vertex 2 Z-coordinate
    7.8,                                    !- Vertex 3 X-coordinate
    1.23,                                   !- Vertex 3 Y-coordinate
    3.41,                                   !- Vertex 3 Z-coordinate
    12.2,                                   !- Vertex 4 X-coordinate
    1.23,                                   !- Vertex 4 Y-coordinate
    3.41;                                   !- Vertex 4 Z-coordinate

  BuildingSurface:Detailed,
    Garage ceiling reverse,                 !- Name
    Floor,                                  !- Surface Type
    garage_ceiling,                         !- Construction Name
    Zone 1,                                 !- Zone Name
    Surface,                                !- Outside Boundary Condition
    Garage ceiling,                         !- Outside Boundary Condition Object
    NoSun,                                  !- Sun Exposure
    NoWind,                                 !- Wind Exposure
    autocalculate,                          !- View Factor to Ground
```

```
  4,                                      !- Number of Vertices
  7.8,                                    !- Vertex 1 X-coordinate
  7.45,                                   !- Vertex 1 Y-coordinate
  3.41,                                   !- Vertex 1 Z-coordinate
  12.2,                                   !- Vertex 2 X-coordinate
  7.45,                                   !- Vertex 2 Y-coordinate
  3.41,                                   !- Vertex 2 Z-coordinate
  12.2,                                   !- Vertex 3 X-coordinate
  1.23,                                   !- Vertex 3 Y-coordinate
  3.41,                                   !- Vertex 3 Z-coordinate
  7.8,                                    !- Vertex 4 X-coordinate
  1.23,                                   !- Vertex 4 Y-coordinate
  3.41;                                   !- Vertex 4 Z-coordinate

BuildingSurface:Detailed,
  main floor 1,                           !- Name
  Floor,                                  !- Surface Type
  interior_floor,                         !- Construction Name
  Zone 1,                                 !- Zone Name
  Surface,                                !- Outside Boundary Condition
  basement ceiling 1,                     !- Outside Boundary Condition Object
  NoSun,                                  !- Sun Exposure
  NoWind,                                 !- Wind Exposure
  autocalculate,                          !- View Factor to Ground
  4,                                      !- Number of Vertices
  7.8,                                    !- Vertex 1 X-coordinate
  11.79,                                  !- Vertex 1 Y-coordinate
  0.64,                                   !- Vertex 1 Z-coordinate
  12.2,                                   !- Vertex 2 X-coordinate
  11.79,                                  !- Vertex 2 Y-coordinate
  0.64,                                   !- Vertex 2 Z-coordinate
  12.2,                                   !- Vertex 3 X-coordinate
  7.45,                                   !- Vertex 3 Y-coordinate
  0.64,                                   !- Vertex 3 Z-coordinate
  7.8,                                    !- Vertex 4 X-coordinate
  7.45,                                   !- Vertex 4 Y-coordinate
  0.64;                                   !- Vertex 4 Z-coordinate

BuildingSurface:Detailed,
  basement ceiling 1,                     !- Name
  Ceiling,                                !- Surface Type
  interior_floor_rev,                     !- Construction Name
  Basement_Zone,                          !- Zone Name
  Surface,                                !- Outside Boundary Condition
  main floor 1,                           !- Outside Boundary Condition Object
  NoSun,                                  !- Sun Exposure
  NoWind,                                 !- Wind Exposure
  autocalculate,                          !- View Factor to Ground
  4,                                      !- Number of Vertices
  7.8,                                    !- Vertex 1 X-coordinate
  7.45,                                   !- Vertex 1 Y-coordinate
  0.64,                                   !- Vertex 1 Z-coordinate
  12.2,                                   !- Vertex 2 X-coordinate
  7.45,                                   !- Vertex 2 Y-coordinate
  0.64,                                   !- Vertex 2 Z-coordinate
  12.2,                                   !- Vertex 3 X-coordinate
  11.79,                                  !- Vertex 3 Y-coordinate
  0.64,                                   !- Vertex 3 Z-coordinate
  7.8,                                    !- Vertex 4 X-coordinate
  11.79,                                  !- Vertex 4 Y-coordinate
  0.64;                                   !- Vertex 4 Z-coordinate

BuildingSurface:Detailed,
  main floor 2,                           !- Name
  Floor,                                  !- Surface Type
  interior_floor_tile,                    !- Construction Name
  Zone 1,                                 !- Zone Name
  Surface,                                !- Outside Boundary Condition
```

```
    basement ceiling 2,                                       !- Outside Boundary Condition Object
    NoSun,                                                    !- Sun Exposure
    NoWind,                                                   !- Wind Exposure
    autocalculate,                                            !- View Factor to Ground
    6,                                                        !- Number of Vertices
    0,                                                        !- Vertex 1 X-coordinate
    11.79,                                                    !- Vertex 1 Y-coordinate
    0.64,                                                     !- Vertex 1 Z-coordinate
    7.8,                                                      !- Vertex 2 X-coordinate
    11.79,                                                    !- Vertex 2 Y-coordinate
    0.64,                                                     !- Vertex 2 Z-coordinate
    7.8,                                                      !- Vertex 3 X-coordinate
    1.23,                                                     !- Vertex 3 Y-coordinate
    0.64,                                                     !- Vertex 3 Z-coordinate
    4.38,                                                     !- Vertex 4 X-coordinate
    1.23,                                                     !- Vertex 4 Y-coordinate
    0.64,                                                     !- Vertex 4 Z-coordinate
    4.38,                                                     !- Vertex 5 X-coordinate
    0,                                                        !- Vertex 5 Y-coordinate
    0.64,                                                     !- Vertex 5 Z-coordinate
    0,                                                        !- Vertex 6 X-coordinate
    0,                                                        !- Vertex 6 Y-coordinate
    0.64;                                                     !- Vertex 6 Z-coordinate

  BuildingSurface:Detailed,
    basement ceiling 2,                                       !- Name
    Ceiling,                                                  !- Surface Type
    interior_floor_tile_rev,                                  !- Construction Name
    Basement_Zone,                                            !- Zone Name
    Surface,                                                  !- Outside Boundary Condition
    main floor 2,                                             !- Outside Boundary Condition Object
    NoSun,                                                    !- Sun Exposure
    NoWind,                                                   !- Wind Exposure
    autocalculate,                                            !- View Factor to Ground
    6,                                                        !- Number of Vertices
    0,                                                        !- Vertex 1 X-coordinate
    0,                                                        !- Vertex 1 Y-coordinate
    0.64,                                                     !- Vertex 1 Z-coordinate
    4.38,                                                     !- Vertex 2 X-coordinate
    0,                                                        !- Vertex 2 Y-coordinate
    0.64,                                                     !- Vertex 2 Z-coordinate
    4.38,                                                     !- Vertex 3 X-coordinate
    1.23,                                                     !- Vertex 3 Y-coordinate
    0.64,                                                     !- Vertex 3 Z-coordinate
    7.8,                                                      !- Vertex 4 X-coordinate
    1.23,                                                     !- Vertex 4 Y-coordinate
    0.64,                                                     !- Vertex 4 Z-coordinate
    7.8,                                                      !- Vertex 5 X-coordinate
    11.79,                                                    !- Vertex 5 Y-coordinate
    0.64,                                                     !- Vertex 5 Z-coordinate
    0,                                                        !- Vertex 6 X-coordinate
    11.79,                                                    !- Vertex 6 Y-coordinate
    0.64;                                                     !- Vertex 6 Z-coordinate

  BuildingSurface:Detailed,
    attic floor,                                              !- Name
    Floor,                                                    !- Surface Type
    ceiling_insulated_reverse,                                !- Construction Name
    Attic_Zone,                                               !- Zone Name
    Surface,                                                  !- Outside Boundary Condition
    upstairs ceiling,                                         !- Outside Boundary Condition Object
    NoSun,                                                    !- Sun Exposure
    NoWind,                                                   !- Wind Exposure
    autocalculate,                                            !- View Factor to Ground
    10,                                                       !- Number of Vertices
    12.2,                                                     !- Vertex 1 X-coordinate
    3.662,                                                    !- Vertex 1 Y-coordinate
    6.64,                                                     !- Vertex 1 Z-coordinate
```

```
    9.411,                                                  !- Vertex 2 X-coordinate
    3.662,                                                  !- Vertex 2 Y-coordinate
    6.64,                                                   !- Vertex 2 Z-coordinate
    9.411,                                                  !- Vertex 3 X-coordinate
    1.23,                                                   !- Vertex 3 Y-coordinate
    6.64,                                                   !- Vertex 3 Z-coordinate
    4.38,                                                   !- Vertex 4 X-coordinate
    1.23,                                                   !- Vertex 4 Y-coordinate
    6.64,                                                   !- Vertex 4 Z-coordinate
    4.38,                                                   !- Vertex 5 X-coordinate
    0,                                                      !- Vertex 5 Y-coordinate
    6.64,                                                   !- Vertex 5 Z-coordinate
    0,                                                      !- Vertex 6 X-coordinate
    0,                                                      !- Vertex 6 Y-coordinate
    6.64,                                                   !- Vertex 6 Z-coordinate
    0,                                                      !- Vertex 7 X-coordinate
    11.79,                                                  !- Vertex 7 Y-coordinate
    6.64,                                                   !- Vertex 7 Z-coordinate
    9.4,                                                    !- Vertex 8 X-coordinate
    11.79,                                                  !- Vertex 8 Y-coordinate
    6.64,                                                   !- Vertex 8 Z-coordinate
    9.4,                                                    !- Vertex 9 X-coordinate
    9.427,                                                  !- Vertex 9 Y-coordinate
    6.64,                                                   !- Vertex 9 Z-coordinate
    12.2,                                                   !- Vertex 10 X-coordinate
    9.427,                                                  !- Vertex 10 Y-coordinate
    6.64;                                                   !- Vertex 10 Z-coordinate

  BuildingSurface:Detailed,
    upstairs ceiling,                                       !- Name
    Ceiling,                                                !- Surface Type
    ceiling_insulated,                                      !- Construction Name
    Zone 1,                                                 !- Zone Name
    Surface,                                                !- Outside Boundary Condition
    attic floor,                                            !- Outside Boundary Condition Object
    NoSun,                                                  !- Sun Exposure
    NoWind,                                                 !- Wind Exposure
    autocalculate,                                          !- View Factor to Ground
    10,                                                     !- Number of Vertices
    12.2,                                                   !- Vertex 1 X-coordinate
    9.427,                                                  !- Vertex 1 Y-coordinate
    6.64,                                                   !- Vertex 1 Z-coordinate
    9.4,                                                    !- Vertex 2 X-coordinate
    9.427,                                                  !- Vertex 2 Y-coordinate
    6.64,                                                   !- Vertex 2 Z-coordinate
    9.4,                                                    !- Vertex 3 X-coordinate
    11.79,                                                  !- Vertex 3 Y-coordinate
    6.64,                                                   !- Vertex 3 Z-coordinate
    0,                                                      !- Vertex 4 X-coordinate
    11.79,                                                  !- Vertex 4 Y-coordinate
    6.64,                                                   !- Vertex 4 Z-coordinate
    0,                                                      !- Vertex 5 X-coordinate
    0,                                                      !- Vertex 5 Y-coordinate
    6.64,                                                   !- Vertex 5 Z-coordinate
    4.38,                                                   !- Vertex 6 X-coordinate
    0,                                                      !- Vertex 6 Y-coordinate
    6.64,                                                   !- Vertex 6 Z-coordinate
    4.38,                                                   !- Vertex 7 X-coordinate
    1.23,                                                   !- Vertex 7 Y-coordinate
    6.64,                                                   !- Vertex 7 Z-coordinate
    9.411,                                                  !- Vertex 8 X-coordinate
    1.23,                                                   !- Vertex 8 Y-coordinate
    6.64,                                                   !- Vertex 8 Z-coordinate
    9.411,                                                  !- Vertex 9 X-coordinate
    3.662,                                                  !- Vertex 9 Y-coordinate
    6.64,                                                   !- Vertex 9 Z-coordinate
    12.2,                                                   !- Vertex 10 X-coordinate
    3.662,                                                  !- Vertex 10 Y-coordinate
```

```
  6.64;                                                 !- Vertex 10 Z-coordinate

 ! ========================================================================
 ! The following was created by the Basement preprocessor program.
 ! Weather File Location=Timmins ON CAN WYEC2-B-94831
 !

SurfaceProperty:OtherSideCoefficients,
  surfPropOthSdCoefBasementAvgWall,    !- Name
  0.0,                                 !- Combined Convective Radiative Film Coefficient
  1.0,                                 !- Constant Temperature
  1.0,                                 !- Constant Temperature Coefficient
  0.0,                                 !- External Dry-Bulb Temperature Coefficient
  0.0,                                 !- Ground Temperature Coefficient
  0.0,                                 !- Wind Speed Coefficient
  0.0,                                 !- Zone Air Temperature Coefficient
  scheduleOSCBasementWallSurfaceTemp,  !- Constant Temperature Schedule Name
  No,                                  !- Sinusoidal Variation of Constant Temperature
Coefficient
  24;                                  !- Period of Sinusoidal Variation

Schedule:Compact,
  scheduleOSCBasementWallSurfaceTemp,  !- Name
  Temperature,                         !- ScheduleType
  Through:   1/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  2.095,                               !- Field
  Through:   2/28,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  2.660,                               !- Field
  Through:   3/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  6.500,                               !- Field
  Through:   4/30,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  9.710,                               !- Field
  Through:   5/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  12.39,                               !- Field
  Through:   6/30,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  14.45,                               !- Field
  Through:   7/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  16.13,                               !- Field
  Through:   8/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  16.62,                               !- Field
  Through:   9/30,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  14.82,                               !- Field
  Through:  10/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  11.91,                               !- Field
  Through:  11/30,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  9.985,                               !- Field
```

```
  Through:  12/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  6.630;                               !- Field

SurfaceProperty:OtherSideCoefficients,
  surfPropOthSdCoefBasementAvgFloor,   !- Name
  0.0,                                 !- Combined Convective Radiative Film Coefficient
  1.0,                                 !- Constant Temperature
  1.0,                                 !- Constant Temperature Coefficient
  0.0,                                 !- External Dry-Bulb Temperature Coefficient
  0.0,                                 !- Ground Temperature Coefficient
  0.0,                                 !- Wind Speed Coefficient
  0.0,                                 !- Zone Air Temperature Coefficient
  scheduleOSCBasementFloorTemp,        !- Constant Temperature Schedule Name
  No,                                  !- Sinusoidal Variation of Constant Temperature
Coefficient
  24;                                  !- Period of Sinusoidal Variation

Schedule:Compact,
  scheduleOSCBasementFloorTemp,        !- Name
  Temperature,                         !- ScheduleType
  Through:   1/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  15.32,                               !- Field
  Through:   2/28,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  14.93,                               !- Field
  Through:   3/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  15.38,                               !- Field
  Through:   4/30,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  16.24,                               !- Field
  Through:   5/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  17.85,                               !- Field
  Through:   6/30,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  17.75,                               !- Field
  Through:   7/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  17.07,                               !- Field
  Through:   8/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  17.17,                               !- Field
  Through:   9/30,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  17.20,                               !- Field
  Through:  10/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  17.56,                               !- Field
  Through:  11/30,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  16.94,                               !- Field
  Through:  12/31,                     !- Field
  For:AllDays,                         !- Field
```

```
  Until:24:00,                         !- Field
  16.66;                               !- Field

SurfaceProperty:OtherSideCoefficients,
  surfPropOthSdCoefBasementUpperWall,  !- Name
  0.0,                                 !- Combined Convective Radiative Film Coefficient
  1.0,                                 !- Constant Temperature
  1.0,                                 !- Constant Temperature Coefficient
  0.0,                                 !- External Dry-Bulb Temperature Coefficient
  0.0,                                 !- Ground Temperature Coefficient
  0.0,                                 !- Wind Speed Coefficient
  0.0,                                 !- Zone Air Temperature Coefficient
  scheduleOSCBasementUpperWallTemp,    !- Constant Temperature Schedule Name
  No,                                  !- Sinusoidal Variation of Constant Temperature
Coefficient
  24;                                  !- Period of Sinusoidal Variation

Schedule:Compact,
  scheduleOSCBasementUpperWallTemp,    !- Name
  Temperature,                         !- ScheduleType
  Through:   1/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  -.4472,                               !- Field
  Through:   2/28,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  1.090,                               !- Field
  Through:   3/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  5.609,                               !- Field
  Through:   4/30,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  9.950,                               !- Field
  Through:   5/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  12.49,                               !- Field
  Through:   6/30,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  14.90,                               !- Field
  Through:   7/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  16.91,                               !- Field
  Through:   8/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  17.11,                               !- Field
  Through:   9/30,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  14.58,                               !- Field
  Through:  10/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  11.11,                               !- Field
  Through:  11/30,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  8.699,                               !- Field
  Through:  12/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  4.389;                               !- Field
```

```
SurfaceProperty:OtherSideCoefficients,
  surfPropOthSdCoefBasementLowerWall,  !- Name
  0.0,                                 !- Combined Convective Radiative Film Coefficient
  1.0,                                 !- Constant Temperature
  1.0,                                 !- Constant Temperature Coefficient
  0.0,                                 !- External Dry-Bulb Temperature Coefficient
  0.0,                                 !- Ground Temperature Coefficient
  0.0,                                 !- Wind Speed Coefficient
  0.0,                                 !- Zone Air Temperature Coefficient
  scheduleOSCBasementLowerWallTemp,    !- Constant Temperature Schedule Name
  No,                                  !- Sinusoidal Variation of Constant Temperature
Coefficient
  24;                                  !- Period of Sinusoidal Variation

Schedule:Compact,
  scheduleOSCBasementLowerWallTemp,    !- Name
  Temperature,                         !- ScheduleType
  Through:   1/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  4.743,                               !- Field
  Through:   2/28,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  4.295,                               !- Field
  Through:   3/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  7.428,                               !- Field
  Through:   4/30,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  9.460,                               !- Field
  Through:   5/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  12.29,                               !- Field
  Through:   6/30,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  13.97,                               !- Field
  Through:   7/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  15.32,                               !- Field
  Through:   8/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  16.11,                               !- Field
  Through:   9/30,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  15.06,                               !- Field
  Through:  10/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  12.75,                               !- Field
  Through:  11/30,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  11.32,                               !- Field
  Through:  12/31,                     !- Field
  For:AllDays,                         !- Field
  Until:24:00,                         !- Field
  8.964;                               !- Field
```

Appendix B - Modelled Assemblies – OBC & NBC

Table 1 - OBC 1997 Zone 1 Envelope Constructions (as simulated)

CONSTRUCTION	CODE REQUIREMENT	MATERIAL	MATERIAL RSI	THICKNESS	CONDUCTIVITY
Above Grade Wall		exterior airfilm	0.03		
		brick	0.14	0.1	0.72
		airspace	0.20		
		OSB	0.33	0.03	0.091
		fibreglass batt	2.75	0.14	0.043
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**3.65**		
Slab	**1.41**	XPS	1.69	0.0508	0.03
		Concrete 75	0.07	0.075	1.13
		TOTAL RSI	**1.76**		
Roof	**5.4**	exterior airfilm	0.03		
		asphalt singlies	0.79	0.03	0.038
		OSB	0.18	0.016	0.091
		airspace	0.2		
		blown cellulose	3.09	0.1216	0.039
		blown cellulose & trusses	2.19	0.089	0.039
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**6.67**		
Below Grade Wall	**1.41**	concrete 200	0.18	0.2	1.13
		airspace	0.20		
		Fiberglass batt	1.81	0.0890	0.043
		gypsum	0.08	0.0127	0.16
		TOTAL RSI	**2.27**		
Exposed Floor	**4.4**	blown cellulose	6.51	0.254	0.039
		TOTAL RSI	**4.4**		

Table 2 - OBC 1997 Zone 2 Envelope Constructions (as simulated)

CONSTRUCTION	CODE REQUIREMENT	MATERIAL	MATERIAL RSI	THICKNESS	CONDUCTIVITY
Above Grade Wall	**3.87**	exterior airfilm	0.03		
		brick	0.14	0.1	0.72
		airspace	0.20		
		OSB	0.33	0.03	0.091
		Mineral batt insulation	3.29	0.14	0.036
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**4.19**		
Slab	**1.41**	XPS	1.69	0.0508	0.03
		Concrete 75	0.07	0.075	1.13
		TOTAL RSI	**1.76**		
Roof	**6.7**	exterior airfilm	0.03		
		asphalt singlies	0.79	0.03	0.038
		OSB	0.18	0.016	0.091
		airspace	0.2		
		blown cellulose	4.37	0.1723	0.039
		blown cellulose & trusses	2.19	0.089	0.039
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**7.96**		
Below Grade Wall	**2.11**	concrete 200	0.18	0.2	1.13
		airspace	0.20		
		Mineral batt insulation	2.16	0.0890	0.036
		gypsum	0.08	0.0127	0.16
		TOTAL RSI	**2.62**		
Exposed Floor	**4.4**	blown cellulose	4.4	0.1716	0.039
		TOTAL RSI	**4.4**		

Table 3 - OBC 2006 Part 12 Zone 1 Envelope Constructions (as simulated)

CONSTRUCTION	CODE REQUIREMENT	MATERIAL	MATERIAL RSI	THICKNESS	CONDUCTIVITY
Above Grade Wall	**3.34**	exterior airfilm	0.03		
		brick	0.14	0.1	0.72
		airspace	0.20		
		OSB	0.33	0.03	0.091
		blown cellulose	3.04	0.14	0.039
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**3.93**		
Slab	**1.41**	XPS	1.69	0.0508	0.03
		Concrete 75	0.07	0.075	1.13
		TOTAL RSI	**1.76**		
Roof	**7**	exterior airfilm	0.03		
		asphalt singlies	0.79	0.03	0.038
		OSB	0.18	0.016	0.091
		airspace	0.2		
		blown cellulose	4.70	0.184	0.039
		blown cellulose & trusses	2.19	0.089	0.039
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**8.29**		
Below Grade Wall	**2.11**	concrete 200	0.18	0.2	1.13
		airspace	0.20		
		blown cellulose	2.00	0.0890	0.039
		gypsum	0.08	0.0127	0.16
		TOTAL RSI	**2.45**		
Exposed Floor	**4.4**	blown cellulose	4.4	0.1716	0.039
		TOTAL RSI	**4.4**		

Table 4 - OBC 2006 Part 12 Zone 2 Envelope Constructions (as simulated)

CONSTRUCTION	CODE REQUIREMENT	MATERIAL	MATERIAL RSI	THICKNESS	CONDUCTIVITY
Above Grade Wall	**3.87**	exterior airfilm	0.03		
		brick	0.14	0.1	0.72
		airspace	0.20		
		XPS	0.85	0.0254	0.03
		OSB	0.33	0.03	0.091
		Mineral batt insulation	3.29	0.14	0.036
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**3.93**		
Slab	**1.41**	XPS	1.69	0.0508	0.03
		Concrete 75	0.07	0.075	1.13
		TOTAL RSI	**1.76**		
Roof	**7**	exterior airfilm	0.03		
		asphalt singlies	0.79	0.03	0.038
		OSB	0.18	0.016	0.091
		airspace	0.2		
		blown cellulose	4.70	0.184	0.039
		blown cellulose & trusses	2.19	0.089	0.039
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**8.29**		
Below Grade Wall	**2.11**	concrete 200	0.18	0.2	1.13
		airspace	0.20		
		Mineral batt insulation	1.96	0.0890	0.036
		gypsum	0.08	0.0127	0.16
		TOTAL RSI	**2.42**		
Exposed Floor	**4.4**	blown cellulose	4.4	0.1716	0.039
		TOTAL RSI	**4.4**		

Table 5 - OBC 2009 Sb-12 Zone 1 Compliance Package A Envelope Constructions (as simulated)

CONSTRUCTION	CODE REQUIREMENT	MATERIAL	MATERIAL RSI	THICKNESS	CONDUCTIVITY
Above Grade Wall	**4.23**	exterior airfilm	0.03		
		brick	0.14	0.1	0.72
		airspace	0.20		
		XPS	0.85	0.0254	0.03
		OSB	0.33	0.03	0.091
		Mineral batt insulation	3.29	0.14	0.036
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**5.04**		
Slab	**0.88**	Concrete 75	0.07	0.075	1.13
		XPS	1.27	0.0381	0.03
		TOTAL RSI	**1.34**		
Roof	**8.81**	exterior airfilm	0.03		
		asphalt singlies	0.79	0.03	0.038
		OSB	0.18	0.016	0.091
		airspace	0.2		
		blown cellulose	6.49	0.2546	0.039
		blown cellulose & trusses	2.19	0.089	0.039
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**10.08**		
Below Grade Wall	**3.52**	concrete 200	0.18	0.2	1.13
		airspace	0.20		
		Mineral batt insulation	3.40	0.140	0.036
		gypsum	0.08	0.0127	0.16
		TOTAL RSI	**3.86**		
Exposed Floor	**5.46**	blown cellulose	5.46	0.2130	0.039
		TOTAL RSI	**5.46**		

Table 6 - OBC 2009 Sb-12 Zone 1 Compliance Package J Envelope Constructions (as simulated)

CONSTRUCTION	CODE REQUIREMENT	MATERIAL	MATERIAL RSI	THICKNESS	CONDUCTIVITY
Above Grade Wall	**3.87**	exterior airfilm	0.03		
		brick	0.14	0.1	0.72
		airspace	0.20		
		OSB	0.33	0.03	0.091
		Mineral batt insulation	3.29	0.14	0.036
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**4.19**		
Slab	**0.88**	Concrete 75	0.07	0.075	1.13
		TOTAL RSI	**1.34**		
Roof	**8.81**	exterior airfilm	0.03		
		asphalt singlies	0.79	0.03	0.038
		OSB	0.18	0.016	0.091
		airspace	0.2		
		blown cellulose	6.49	0.2546	0.039
		blown cellulose & trusses	2.19	0.089	0.039
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**10.08**		
Below Grade Wall	**2.11**	concrete 200	0.18	0.2	1.13
		airspace	0.20		
		Mineral batt insulation	2.16	0.0890	0.036
		gypsum	0.08	0.0127	0.16
		TOTAL RSI	**2.62**		
Exposed Floor	**5.46**	blown cellulose	5.46	0.2130	0.039
		TOTAL RSI	**5.46**		

Table 7 - OBC 2009 Sb-12 Zone 2 Compliance Package A Envelope Constructions (as simulated)

CONSTRUCTION	CODE REQUIREMENT	MATERIAL	MATERIAL RSI	THICKNESS	CONDUCTIVITY
Above Grade Wall	**5.11**	exterior airfilm	0.03		
		brick	0.14	0.1	0.72
		airspace	0.20		
		XPS	1.27	0.0381	0.03
		OSB	0.33	0.03	0.091
		Mineral batt insulation	3.29	0.14	0.036
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**5.46**		
Slab	**0.88**	XPS	1.27	0.0381	0.03
		Concrete 75	0.07	0.075	1.13
		TOTAL RSI	**1.34**		
Roof	**8.81**	exterior airfilm	0.03		
		asphalt singlies	0.79	0.03	0.038
		OSB	0.18	0.016	0.091
		airspace	0.2		
		blown cellulose	6.50	0.2546	0.039
		blown cellulose & trusses	2.19	0.089	0.039
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**10.09**		
Below Grade Wall	**3.52**	concrete 200	0.18	0.2	1.13
		airspace	0.20		
		Mineral batt insulation	3.40	0.1400	0.036
		gypsum	0.08	0.0127	0.16
		TOTAL RSI	**3.86**		
Exposed Floor	**5.46**	blown cellulose	5.46	0.2130	0.039
		TOTAL RSI	**5.46**		

Table 8 - OBC 2009 Sb-12 Zone 2 Compliance Package J Envelope Constructions (as simulated)

CONSTRUCTION	CODE REQUIREMENT	MATERIAL	MATERIAL RSI	THICKNESS	CONDUCTIVITY
Above Grade Wall	**4.23**	exterior airfilm	0.03		
		brick	0.14	0.1	0.72
		airspace	0.20		
		OSB	0.85	0.0254	0.03
		Blown Cellulose	0.33	0.03	0.091
		gypsum	3.04	0.14	0.039
		interior airfilm	0.08	0.0127	0.16
		TOTAL RSI	0.12		
Slab		Concrete 75	0.07	0.075	1.13

		TOTAL RSI	**1.34**		
Roof	**8.81**	exterior airfilm	0.03		
		asphalt singlies	0.79	0.03	0.038
		OSB	0.18	0.016	0.091
		airspace	0.2		
		blown cellulose	6.50	0.2546	0.039
		blown cellulose & trusses	2.19	0.089	0.039
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**10.09**		
Below Grade Wall	**2.11**	concrete 200	0.18	0.2	1.13
		airspace	0.20		
		blown cellulose	2.00	0.089	0.039
		gypsum	0.08	0.0127	0.16
		TOTAL RSI	**2.45**		
Exposed Floor	**5.46**	blown cellulose	5.46	0.2130	0.039
		TOTAL RSI	**5.46**		

Table 9 - OBC 2012 Sb-12 Zone 1 Compliance Package A Envelope Constructions (as simulated)

CONSTRUCTION	CODE REQUIREMENT	MATERIAL	MATERIAL RSI	THICKNESS	CONDUCTIVITY
Above Grade Wall	**4.23**	exterior airfilm	0.03		
		brick	0.14	0.1	0.72
		airspace	0.20		
		XPS	0.85	0.0254	0.03
		OSB	0.33	0.03	0.091
		Mineral batt insulation	3.29	0.14	0.036
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**5.04**		
Slab	**0.88**	XPS	1.27	0.0381	0.03
		Concrete 75	0.07	0.075	1.13
		TOTAL RSI	**1.34**		
Roof	**8.81**	exterior airfilm	0.03		
		asphalt singlies	0.79	0.03	0.038
		OSB	0.18	0.016	0.091
		airspace	0.2		
		blown cellulose	6.49	0.2546	0.039
		blown cellulose & trusses	2.19	0.089	0.039
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**10.08**		
Below Grade Wall	**3.52**	concrete 200	0.18	0.2	1.13
		airspace	0.20		
		Mineral batt insulation	3.40	0.140	0.036
		gypsum	0.08	0.0127	0.16
		TOTAL RSI	**3.86**		
Exposed Floor	**5.46**	blown cellulose	5.46	0.2130	0.039
		TOTAL RSI	**5.46**		

Table 10 - OBC 2012 Sb-12 Zone 1 Compliance Package J Envelope Constructions (as simulated)

CONSTRUCTION	CODE REQUIREMENT	MATERIAL	MATERIAL RSI	THICKNESS	CONDUCTIVITY
Above Grade Wall	**3.87**	exterior airfilm	0.03		
		brick	0.14	0.1	0.72
		airspace	0.20		
		OSB	0.33	0.03	0.091
		Mineral batt insulation	3.29	0.14	0.036
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**4.19**		
Slab	**0.88**	XPS	1.27	0.0381	0.03
		Concrete 75	0.07	0.075	1.13
		TOTAL RSI	**1.34**		
Roof	**8.81**	exterior airfilm	0.03		
		asphalt singlies	0.79	0.03	0.038
		OSB	0.18	0.016	0.091
		airspace	0.2		
		blown cellulose	6.49	0.2546	0.039
		blown cellulose & trusses	2.19	0.089	0.039
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**10.08**		
Below Grade Wall	**2.11**	concrete 200	0.18	0.2	1.13
		airspace	0.20		
		Mineral batt insulation	2.16	0.0890	0.036
		gypsum	0.08	0.0127	0.16
		TOTAL RSI	**2.62**		
Exposed Floor	**5.46**	blown cellulose	5.46	0.2130	0.039
		TOTAL RSI	**5.46**		

Table 11 - OBC 2012 Sb-12 Zone 2 Compliance Package A Envelope Constructions (as simulated)

CONSTRUCTION	CODE REQUIREMENT	MATERIAL	MATERIAL RSI	THICKNESS	CONDUCTIVITY
Above Grade Wall	**5.11**	exterior airfilm	0.03		
		brick	0.14	0.1	0.72
		airspace	0.20		
		XPS	1.27	0.0381	0.03
		OSB	0.33	0.03	0.091
		Mineral batt insulation	3.29	0.14	0.036
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**5.46**		
Slab	**0.88**	XPS	1.27	0.0381	0.03
		Concrete 75	0.07	0.075	1.13
		TOTAL RSI	**1.34**		
Roof	**8.81**	exterior airfilm	0.03		
		asphalt singlies	0.79	0.03	0.038
		OSB	0.18	0.016	0.091
		airspace	0.2		
		blown cellulose	6.50	0.2546	0.039
		blown cellulose & trusses	2.19	0.089	0.039
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**10.09**		
Below Grade Wall	**3.52**	concrete 200	0.18	0.2	1.13
		airspace	0.20		
		Mineral batt insulation	3.40	0.1400	0.036
		gypsum	0.08	0.0127	0.16
		TOTAL RSI	**3.86**		
Exposed Floor	**5.46**	blown cellulose	5.46	0.2130	0.039
		TOTAL RSI	**5.46**		

Table 12 - OBC 2012 Sb-12 Zone 2 Compliance Package J Envelope Constructions (as simulated)

CONSTRUCTION	CODE REQUIREMENT	MATERIAL	MATERIAL RSI	THICKNESS	CONDUCTIVITY
Above Grade Wall	**4.23**	exterior airfilm	0.03		
		brick	0.14	0.1	0.72
		airspace	0.20		
		OSB	0.85	0.0254	0.03
		Blown Cellulose	0.33	0.03	0.091
		gypsum	3.04	0.14	0.039
		interior airfilm	0.08	0.0127	0.16
		TOTAL RSI	0.12		
Slab		Concrete 75	0.07	0.075	1.13
		TOTAL RSI	**1.34**		
Roof	**8.81**	exterior airfilm	0.03		
		asphalt singlies	0.79	0.03	0.038
		OSB	0.18	0.016	0.091
		airspace	0.2		
		blown cellulose	6.50	0.2546	0.039
		blown cellulose & trusses	2.19	0.089	0.039
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**10.09**		
Below Grade Wall	**2.11**	concrete 200	0.18	0.2	1.13
		airspace	0.20		
		blown cellulose	2.00	0.089	0.039
		gypsum	0.08	0.0127	0.16
		TOTAL RSI	**2.45**		
Exposed Floor	**5.46**	blown cellulose	5.46	0.2130	0.039
		TOTAL RSI	**5.46**		

Table 13 - OBC SB-12 Proposed 15% Increase Zone 1 Compliance Package A Envelope Constructions (as simulated)

CONSTRUCTION	CODE REQUIREMENT	MATERIAL	MATERIAL RSI	THICKNESS	CONDUCTIVITY
Above Grade Wall	**3.34**	exterior airfilm	0.03		
	1.32 (exterior)	brick	0.14	0.1	0.72
		airspace	0.20		
		XPS	1.69	0.0508	0.03
		OSB	0.33	0.03	0.091
		Mineral batt insulation	3.29	0.14	0.036
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**5.88**		
Slab		Concrete 75	0.07	0.075	1.13
		TOTAL RSI	**1.34**		
Roof	**10.56**	exterior airfilm	0.03		
		asphalt singlies	0.79	0.03	0.038
		OSB	0.18	0.016	0.091
		airspace	0.2		
		blown cellulose	8.27	0.3228	0.039
		blown cellulose & trusses	2.19	0.089	0.039
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**11.85**		
Below Grade Wall	**3.52**	XPS	1.69	0.0508	0.03
	1.4 (exterior)	concrete 200	0.18	0.2	1.13
		airspace	0.20		
		insulation	3.40	0.1400	0.036
		gypsum	0.08	0.0127	0.16
		TOTAL RSI	**3.86**		
Exposed Floor	**5.46**	blown cellulose	5.46	0.2130	0.039
		TOTAL RSI	**5.46**		

Table 14 – NBC 2010 Zone 1 Envelope Constructions (as simulated)

CONSTRUCTION	CODE REQUIREMENT (Ratio)	MATERIAL	MATERIAL RSI	THICKNESS	CONDUCTIVITY
Above Grade Wall	**0.2**	exterior airfilm	0.03		
		brick	0.14	0.1	0.72
		airspace	0.20		
		OSB	0.33	0.03	0.091
		Fireglass batt insulation	2.75	0.14	0.043
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**3.65**		
Slab		Concrete 75	0.07	0.075	1.13
		TOTAL RSI	**1.34**		
Roof	**0.2**	exterior airfilm	0.03		
		asphalt singlies	0.79	0.03	0.038
		OSB	0.18	0.016	0.091
		airspace	0.2		
		blown cellulose	2.29	0.09009	0.039
		blown cellulose & trusses	2.19	0.089	0.039
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**6.87**		
Below Grade Wall	**0.2**	concrete 200	0.18	0.2	1.13
		airspace	0.20		
		gypsum	1.81	0.0890	0.043
		gypsum	0.08	0.0127	0.16
		TOTAL RSI	**2.27**		
Exposed Floor	**0.2**	blown cellulose	4.40	0.1716	0.039
		TOTAL RSI	**4.40**		

Table 15 – NBC 2010 Zone 2 Envelope Constructions (as simulated)

CONSTRUCTION	CODE REQUIREMENT	MATERIAL	MATERIAL RSI	THICKNESS	CONDUCTIVITY
Above Grade Wall	**0.2**	exterior airfilm	0.03		
		brick	0.14	0.1	0.72
		airspace	0.20		
		XPS	0.85	0.0254	0.03
		OSB	0.33	0.03	0.091
		Fireglass batt insulation	2.75	0.14	0.043
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**4.50**		
Slab		Concrete 75	0.07	0.075	1.13
		TOTAL RSI	**1.34**		
Roof	**0.2**	exterior airfilm	0.03		
		asphalt singlies	0.79	0.03	0.038
		OSB	0.18	0.016	0.091
		airspace	0.2		
		blown cellulose	3.28	0.129	0.039
		blown cellulose & trusses	2.19	0.089	0.039
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**6.87**		
Below Grade Wall	**0.2**	concrete 200	0.18	0.2	1.13
		airspace	0.20		
		gypsum	1.64	0.0890	0.043
		gypsum	0.08	0.0127	0.16
		TOTAL RSI	**2.10**		
Exposed Floor	**0.2**	blown cellulose	4.40	0.1716	0.039
		TOTAL RSI	**4.40**		

Table 16 – NBC 2012 Proposed - No HRV Zone 1 Envelope Constructions (as simulated)

CONSTRUCTION	CODE REQUIREMENT	MATERIAL	MATERIAL RSI	THICKNESS	CONDUCTIVITY
Above Grade Wall	**3.27**	exterior airfilm	0.03		
		brick	0.14	0.1	0.72
		airspace	0.20		
		OSB	0.33	0.03	0.091
		Mineral batt insulation	3.29	0.14	0.036
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**4.19**		
Slab	**1.96**	XPS	2.12	0.0635	0.03
		Concrete 75	0.07	0.075	1.13
		TOTAL RSI	**1.34**		
Roof	**8.66**	exterior airfilm	0.03		
		asphalt singlies	0.79	0.03	0.038
		OSB	0.18	0.016	0.091
		airspace	0.2		
		blown cellulose	6.50	0.2550	0.039
		blown cellulose & trusses	2.19	0.089	0.039
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**6.87**		
Below Grade Wall	**3.17**	concrete 200	0.18	0.2	1.13
		airspace	0.20		
		Mineral batt insulation	3.40	0.140	0.036
		gypsum	0.08	0.0127	0.16
		TOTAL RSI	**3.86**		
Exposed Floor	**4.75**	blown cellulose	4.75	0.1853	0.039
		TOTAL RSI	**4.75**		

Table 17 – NBC 2012 Proposed - HRV Zone 1 Envelope Constructions (as simulated)

CONSTRUCTION	CODE REQUIREMENT	MATERIAL	MATERIAL RSI	THICKNESS	CONDUCTIVITY
Above Grade Wall	**3.16**	exterior airfilm	0.03		
		brick	0.14	0.1	0.72
		airspace	0.20		
		OSB	0.33	0.03	0.091
		Mineral batt insulation	3.29	0.14	0.036
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**4.50**		
Slab	**1.96**	XPS	2.12	0.0635	0.03
		Concrete 75	0.07	0.075	1.13
		TOTAL RSI	**2.19**		
Roof	**8.66**	exterior airfilm	0.03		
		asphalt singlies	0.79	0.03	0.038
		OSB	0.18	0.016	0.091
		airspace	0.2		
		blown cellulose	6.50	0.2550	0.039
		blown cellulose & trusses	2.19	0.089	0.039
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**10.09**		
Below Grade Wall	**3.17**	concrete 200	0.18	0.2	1.13
		airspace	0.20		
		Mineral batt insulation	3.09	0.140	0.036
		gypsum	0.08	0.0127	0.16
		TOTAL RSI	**3.54**		
Exposed Floor	**4.75**	blown cellulose	4.75	0.1853	0.039
		TOTAL RSI	**4.75**		

Table 18 – NBC 2012 Proposed – No HRV Zone 2 Envelope Constructions (as simulated)

CONSTRUCTION	CODE REQUIREMENT	MATERIAL	MATERIAL RSI	THICKNESS	CONDUCTIVITY
Above Grade Wall	**3.27**	exterior airfilm	0.03		
		brick	0.14	0.1	0.72
		airspace	0.20		
		OSB	0.33	0.03	0.091
		Mineral batt insulation	3.29	0.14	0.036
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**4.19**		
Slab	**2.83**	XPS	2.96	0.0889	0.03
		Concrete 75	0.07	0.075	1.13
		TOTAL RSI	**3.88**		
Roof	**10.43**	exterior airfilm	0.03		
		asphalt singlies	0.79	0.03	0.038
		OSB	0.18	0.016	0.091
		airspace	0.2		
		blown cellulose	8.27	0.3250	0.039
		blown cellulose & trusses	2.19	0.089	0.039
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**11.86**		
Below Grade Wall	**3.17**	concrete 200	0.18	0.2	1.13
		airspace	0.20		
		Mineral batt insulation	3.40	0.140	0.036
		gypsum	0.08	0.0127	0.16
		TOTAL RSI	**4.15**		
Exposed Floor	**5.07**	blown cellulose	5.07	0.1977	0.039
		TOTAL RSI	**5.07**		

Table 19 – NBC 2012 Proposed – HRV Zone 2 Envelope Constructions (as simulated)

CONSTRUCTION	CODE REQUIREMENT	MATERIAL	MATERIAL RSI	THICKNESS	CONDUCTIVITY
Above Grade Wall	**4.13**	exterior airfilm	0.03		
		brick	0.14	0.1	0.72
		airspace	0.20		
		XPS	0.85	0.85	0.0254
		OSB	0.33	0.03	0.091
		Fibreglass batt insulation	2.75	0.14	0.043
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**4.50**		
Slab	**3.72**	XPS	3.81	0.1143	0.03
		Concrete 75	0.07	0.075	1.13
		TOTAL RSI	**3.88**		
Roof	**10.43**	exterior airfilm	0.03		
		asphalt singlies	0.79	0.03	0.038
		OSB	0.18	0.016	0.091
		airspace	0.2		
		blown cellulose	8.27	0.3250	0.039
		blown cellulose & trusses	2.19	0.089	0.039
		gypsum	0.08	0.0127	0.16
		interior airfilm	0.12		
		TOTAL RSI	**11.86**		
Below Grade Wall	**3.17**	XPS	0.85	0.0254	0.03
		concrete 200	0.18	0.2	1.13
		airspace	0.20		
		Fibreglass batt insulation	2.85	0.140	0.043
		gypsum	0.08	0.0127	0.16
		TOTAL RSI	**4.15**		
Exposed Floor	**5.07**	blown cellulose	5.07	0.1977	0.039
		TOTAL RSI	**5.07**		

Table 20 – Passive House Standard Levels – Zone 1 & 2 Envelope Constructions (as simulated)

	MATERIAL	MATERIAL RSI	THICKNESS	CONDUCTIVITY
Above Grade Wall	exterior airfilm	0.03		
	brick	0.14	0.1	0.72
	airspace	0.20		
	OSB	0.18	0.016	0.091
	Mineral batt insulation	4.26	0.184	0.036
	Mineral batt insulation (cavity)	5.61	0.202	0.036
	Mineral batt insulation	3.24	0.14	0.036
	gypsum	0.08	0.0127	0.16
	interior airfilm	0.12		
	TOTAL RSI	**13.86**		
Slab	XPS	10.16	0.3048	0.03
	Concrete 75	0.08	0.089	1.13
	TOTAL RSI	**10.24**		
Roof	exterior airfilm	0.03		
	asphalt singlies	0.79	0.03	0.038
	OSB	0.18	0.016	0.091
	airspace	0.2		
	blown cellulose	22.43	0.9000	0.039
	blown cellulose & trusses	2.19	0.089	0.039
	gypsum	0.08	0.0127	0.16
	interior airfilm	0.12		
	TOTAL RSI	**26.01**		
Below Grade Wall	concrete 200	0.18	0.2	1.13
	airspace	0.20	0.20	
	Mineral batt insulation	6.31	0.292	0.036
	Mineral batt insulation (structural)	1.96	0.089	0.036
	gypsum	0.08	0.0127	0.16
	TOTAL RSI	**4.15**		
Exposed Floor	blown cellulose	6.81	0.2450	0.036
	TOTAL RSI	**6.81**		

Appendix C - Framing Percentages Calculations

Walls without Windows

For framing percentages without windows, a composite RSI-value was calculated to account thermal bridging's impact on the thermal resistance of the insulation, using the following Parallel Path Method:

Equation 1 – Composite RSI value

$$RSI_{COMP} = (RSI_F * (A_F/A_{TOTAL})) + (RSI_{INS} * (A_{INS}/A_{TOTAL})+\ldots)$$

Where : RSI_F – framing RSI-value (top and bottom plates, studs)

A_F – total area of framing (top and bottom plates, studs)

RSI_{INS} – insulation RSI-value

A_{INS} – total insulation area

A_{TOTAL} – total area of wall section (stud to stud)

Based on the Parallel Path Heat Flow Calculation Eq. 5.43 in [1]

Areas for the framing (including the top plate, bottom plate, and studs), and insulation were calculated based on measurements from the CCHT house drawings. Thermal resistance values were determined for the top and bottom plates, studs, and insulation based on material properties in Chapter 26 of ASHRAE Fundamentals (2009).

To find the average RSI value of the insulation for the wall (which accounts for the impact of the framing on the RSI value of the insulation), the composite RSI value was divided by the insulation RSI value.

Equation 2 – Average RSI -value

$$RSI_{AVG} = RSI_{COMP} / R_{INS}]$$

Where RSI_{COMP} – framing RSI-value

R_{INS} – insulation RSI-value

The framing percentage was then calculated by finding the difference between the composite RSI-value and insulation RSI-value (Equation 3).

Equation 3 – Framing Percentage for Walls

Framing Percentage = 1 - RSI_{AVG}

Where RSI_{AVG} - average RSI value based on RSI_{INS} and RSI_{COMP}

Example Calculation – Above Grade Wall

Table 1 - Example Calculation - Average RSI -value

Component	Area (m^2)					Dimensions (m)				Conductivity (W/(m-K)			Thermal Resistance (W/(m^2-K)			
	Area 1 (Top Plate) – m^2	Area 2 (wall)	Area 3 (studs)	Area 3 (bottom plate)	Total Area	Length	Wall Height	O.C.	Thickness	k_{PLATE}	k_{STUD}	k_{INS}	R_{PLATE}	R_{STUD}	R_{INS}	R_{COMP}
Above grade wall	0.46	29.09	3.24	0.46	33.24	12.00	2.77	0.41	0.04	0.12	0.12	0.04	0.32	0.32	0.88	0.72

Equation 1 $RSI_{COMP} = (0.32 * (0.46/33.24)) + (29.09 * (0.88/33.24)) + (3.24* (0.32/33.24)) + (0.46 * (0.46/33.24))$

$RSI_{COMP} = 0.72$

Equation 2 $RSI_{AVG} = (0.72 / 0.88)$

$= 0.82$

Equation 3 Framing Percentage $= 1 – 0.82$

$= 0.183$

Table 2 – Wall Framing Percentage Calculations(no windows)

			Area 1 (Top Plate)	Area 2 (wall)	Area 3 (studs)	Area 3 (btm plate)	Total Area	Length (m)	R_{PLATE}	k_{PLATE}	R_{STUD}	k_{STUD}	R_{INS}	k_{INS}	R_{COMP}
Above grade	First Floor	North	0.46	29.09	3.24	0.46	33.24	12.00	0.32	0.12	0.32	0.12	0.88	0.04	0.72
		East	0.45	28.82	3.21	0.45	32.94	11.89	0.32	0.12	0.32	0.12	0.88	0.04	0.72
		South	0.46	29.09	3.24	0.46	33.24	12.00	0.32	0.12	0.32	0.12	0.88	0.04	0.72
		West	0.45	28.82	3.21	0.45	32.94	11.89	0.32	0.12	0.32	0.12	0.88	0.04	0.72
	Second Floor	North	0.46	25.98	2.69	0.46	29.58	12.00	0.32	0.12	0.32	0.12	0.88	0.04	0.73
		East	0.45	25.74	2.67	0.45	29.31	11.89	0.32	0.12	0.32	0.12	0.88	0.04	0.73
		South	0.46	25.98	2.69	0.46	29.58	12.00	0.32	0.12	0.32	0.12	0.88	0.04	0.73
		West	0.45	25.74	2.67	0.45	29.31	11.89	0.32	0.12	0.32	0.12	0.88	0.04	0.73
Below Grade	Basement	North	0.46	25.59	1.70	0.46	28.20	12.00	0.32	0.12	0.32	0.12	0.88	0.04	0.76
		East	0.45	25.35	1.68	0.45	27.94	11.89	0.32	0.12	0.32	0.12	0.88	0.04	0.76
		South	0.46	25.59	1.70	0.46	28.20	12.00	0.32	0.12	0.32	0.12	0.88	0.04	0.76
		West	0.45	25.35	1.68	0.45	27.94	11.89	0.32	0.12	0.32	0.12	0.88	0.04	0.76

	Adjusted RSI	% Difference	Framing percentage
R_{AG}	0.72	0.82	0.183
R_{BG}	0.76	0.86	0.142

Walls with Windows

For walls with windows, the total areas of the walls and windows were determined, taking measurements from the geometry used in the EnergyPlus idf file. Total areas of the window framing were then calculated and a percentage of stud area (Equation 4) and percentage of insulation was determined (Equation 5). The percentages were used to adjust the conductivities for the studs and insulation.

Equation 4 – Stud Area Percentage for Walls with Windows

$$\text{Stud Percentage} = (A_F / (A_W - A_{WIN}))$$

Where A_F – total area of framing (top and bottom plates, studs, jack and cripple studs, and lintels)

A_W – total wall area (stud to stud)

A_{WIN} – total window area

Equation 5 - Insulation Area Percentage for Walls with Windows

$$\text{Insulation Percentage} = 1 - \text{Window Percentage}$$

Equation 2 was then used to calculate the adjusted RSI value of the studs with the window percentage used to adjust the k value for the wall insulation and calculate the composite RSI value for the insulation. The framing percentage was calculated using Equation 3. Adjusted RSI values were calculated for studs and insulations using Equation 6 and Equation 7.

Equation 6 - Adjusted RSI Value – Stud

$$\text{Adjusted } RSI_{STUD} = \text{Stud Percentage} / RSI_{STUD}$$

Equation 7 - Adjusted RSI Value - Insulation

$$\text{Adjusted } RSI_{INS} = \text{Stud Percentage} / RSI_{INS}$$

A composite RSI value for the studs and insulation was then calculated using Equation 8, adding both adjusted RSI values in parallel [2].

Equation 8 - Composite RSI (Studs and Insulation)

$$RSI_{COMPWIN} = \text{Adjusted } RSI_{STUD} + \text{Adjusted } RSI_{INS}\text{Equation 3}$$

The inverse of $RSI_{COMPWIN}$ was used to calculate the final framing percentag

Example Calculation – Above Grade Wall – South Wall 1 A

Equation 4	Stud Percentage	**= (**6.82/(26.82-2.70))
		= 0.14
Equation 6	Adjusted R_{STUD}	= 0.14 / 1.17
		= 0.12
Equation 5	Insulation Percentage	= 1 - 0.14
		= 0.86
Equation 7	Adjusted R_{INS}	= 0.86/3.26
		= 0.26
Equation 8	$RSI_{COMPWIN}$	= 0.12 + 0.26
		= 0.38
Equation 2	RSI_{AVG}	= ((1/0.38) / 3.26)
		= 0.80
Equation 3	Framing Percentage	= 1 – 0.801
		= 0.199

Table 3 - Wall Framing Percentages (with windows)

Wall	Window	Width	Height	Area	Total Area	Lintil	Jack stud	Cripple	Stud area	Total Wood Area	% Stud (Total Wood Area/(Total Area-Total Window Area)	% Batt	R_{STUD} (k/l, where k=0.12)	R_{BATT}(k/l, where k=0.043)	Adjusted R_{STUD} (% Stud/R_{STUD})	Adjusted R_{BATT} (% Batt/R_{BATT})	$R_{STUDBATT}$(Adjusted R_{BATT} + Adjusted R_{STUD})	Adjusted R_{BATT}	% Difference	Framing percentage
south wall 1a		4.38	6.00	26.28																
	south XX6	1.43	2.23	3.19		0.77	0.46	0.13												
	south XX7	1.63	2.23	3.63		0.89	0.46	0.13												
					6.82	1.66	0.91	0.26	0.77	2.70	0.14	0.86	1.17	3.26	0.12	0.26	0.38	2.61	0.80	**0.199**
south wall 3a		5.03	3.23	16.25																
	south WW 4	2.03	1.03	2.08		1.11	0.25	0.07												
	south L3	1.43	0.83	1.18		0.77	0.25	0.08												
					3.25	1.89	0.49	0.16	0.43	2.48	0.19	0.81	1.17	3.26	0.16	0.25	0.41	2.43	0.75	**0.254**
east wall 1b		4.34	2.77	12.02																
	East E7A	0.43	1.63	0.69		0.20	0.21	0.04												
	East E7B	0.43	1.63	0.69		0.20	0.21	0.04												
					1.38	0.40	0.42	0.09	0.87	1.35	0.13	0.87	1.17	3.26	0.11	0.27	0.38	2.65	0.81	**0.185**
north wall 1	a	12.20	6.00	73.20																
	b	9.40	2.05	19.27	92.47															
	North H7a	0.83	1.63	1.34		0.43	0.46	0.24	21.60											

	North H7b	0.83	1.63	1.34		0.43	0.46	0.24	8.66											
	North A1b	1.20	0.21	0.25		0.64	0.46	0.29	0.61											
	North C3	1.33	2.22	2.94		0.71	0.46	0.21	12.34											
	North L7	1.43	1.63	2.32		0.77	0.46	0.24												
	North U4	1.02	1.03	1.04		0.54	0.46	0.26												
	North E3	0.43	0.53	0.22		0.20	0.46	0.28												
	North X4	1.62	0.85	1.36		0.88	0.46	0.26												
					10.81	4.60	3.65	2.01	9.32	15.93	0.20	0.80	1.17	3.26	0.17	0.25	0.41	2.41	0.74	**0.259**
north bsmt wall 1a		12.20	0.64	19.06																
	North A1a	1.20	0.21	0.25		0.64	0.02	0.01												
	North A1b	1.20	0.21	0.25		0.64	0.02	0.01												
					0.49	1.29	0.05	0.01	0.14	1.44	0.08	0.92	1.17	3.26	0.07	0.28	0.35	2.86	0.88	**0.122**
west wall 1		11.79	6.00	70.74																
	West JJ4	1.03	1.03	1.05		0.54	0.23	0.18												
					1.05	0.54	0.23	0.18	2.07	0.72	0.01	0.99	1.17	3.26	0.01	0.30	0.31	3.20	0.98	**0.018**

Roof

Two separate framing percentages were calculated for roofs: one for the bottom cord and the second for the truss to account for changing insulation thicknesses per building code requirements. The bottom cord framing percentage was calculated using the same method as for walls without windows (Equation 1, Equation 2, and Equation 3). The second framing factor was calculated for the web bracing and top cord portions of each truss. As the height of insulation changed depending on the thermal resistance requirement of the building code and the type of insulation used, separate framing percentage calculations were performed for each building code. Table shows the calculation for this percentage. A composite U-value was determined based on a 38 x 89 mm joist and insulation.

The roof of the CCHT house consists of a number of different truss shapes and constructions. A total of six raised heel trusses were selected based on their size on complexity of construction to be representative of the all trusses in the roof. Cords in the trusses were assumed to measure 38 x 89 mm based on project documentation for the CCHT houses. An area–weighted U-value was calculated with the required insulation levels and an estimation of the total cord area.

Table 4 - Example of Composite RSI Value Calculation for Trusses - Truss R6

Trusses	**Shape**	**Height (m)**	**Width (m)**	**Depth (m)**	**Length (m)**	**O.C. (m)**	A_{INS}	A_{W1}	A_{W2}	A_{W3}	R_{TRUSS}
Bottom Cord		0.089	0.038	1.000	1.000	0.610	0.085	0.005			0.86
Trusses	**Shape**	**Height(m)**	**Width (m)**	**Depth (m)**	**Length (m)**	**O.C. (m)**	A_{INS}	A_{Wood}	R_{INS}	R_{ood3}	R_{Comp}
R6	1	0.2036	0.089	0.038	1.37	0.610	0.276	0.001	5.22	0.74	
	2	0.2036	0.089	0.038	1.21	0.610	0.245	0.001	5.22	0.74	
	3	0.2036	0.089	0.038	1.52	0.610	0.307	0.002	5.22	0.74	
	4	0.2036	0.089	0.038	1.57	0.610	0.317	0.003	5.22	0.74	
Total Truss							0.286	0.007	5.22	0.74	5.11

For each shape: $A_{INS} = L_S * O.C.$

Where, A_{INS} = area of the insulation

L_S = length of shape

O.C. – off centre

A_{W1} = Length of top cord * Width of top cord

A_{W2} = Length of web bracing * Width of web bracing

A_{W2} = Length of web bracing * Width of web bracing

$U_{wood} = (k/l)$

Where, k = conductance of pine [3]

L= length of web bracing

$U_{wood} = (k/l)$

Where, k = conductance of insulation (type changes per building code [3]

L= length of web bracing

$U_{COMP} = (((A_{W1} + A_{W1} + A_{W1} \ldots) * U_{wood}) + (A_{INS} * U_{INS})) / A_{TOTAL}$

Where, $A_{TOTAL} = A_{W1} + A_{W1} + A_{W1} \ldots + A_{INS}$

$R_{TRUSS} = 1 / U_{COMP}$

The total cord area of each of the representative trusses was calculated using the drawing scale and estimated insulation height. To calculate, each truss was divided into sections and cord area calculated for each section. An area-weighted U-value was calculated for each section of the truss. An average for the each whole truss was then calculated, and then using the six representative trusses an average truss U-value was determined for the roof and converted to RSI.

Top cord framing percentages were calculated for the Zone 1 baseline, Zone 2 Tier 2, and Tier 4 levels. Framing percentages for all other compliance packages were calculated using a linear interpolation calculation. The following equation was used:

Equation 9 – Interpolation of Roof Insulation Thickness [4]

$$y = y_0 + (x - x_0)\frac{y_1 - y_0}{x_1 - x_0} = y_0 + \frac{(x - x_0)y_1 - (x - x_0)y_0}{x_1 - x_0}$$

Where y = Insulation Thickness,

y_0 = Lowest Insulation Thickness,

y_1 = Greatest Insulation Thickness,

x = Required Composite RSI,

x_0= Lowest Composite RSI, and

x_1 = Greatest Composite RSI.

Required composite RSI values were determined by subtracting the composite RSI value for the bottom cord for the RSI requirement stated by the building code. Once a composite RSI value was calculated for the trusses for all building codes iterations, framing percentages were calculated for each code and insulation height modelled. Values are listed in **Error! Reference source not found.**Error! Reference source not found..

The roof insulation was input into EnergyPlus as two different materials, CeilingInsulation-TC (truss) and CeilingInsulation-BC (bottom cord). The calculated framing percentages for each were used to adjust the conductivity of the roof insulation material for each simulation.

Roof Trusses

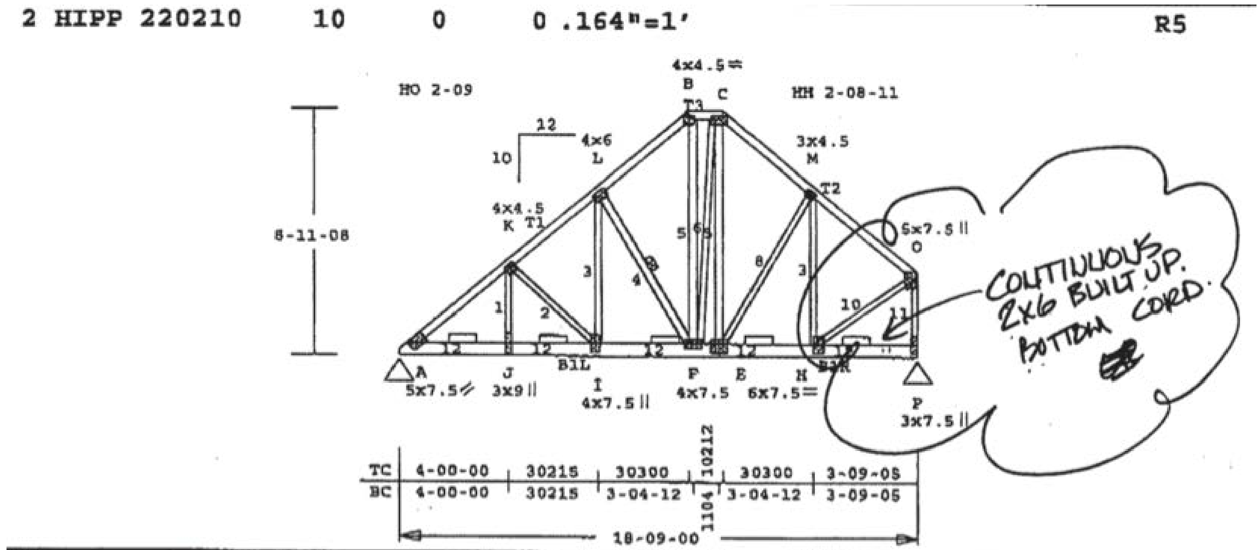


Figure 1 - Truss R5[5]

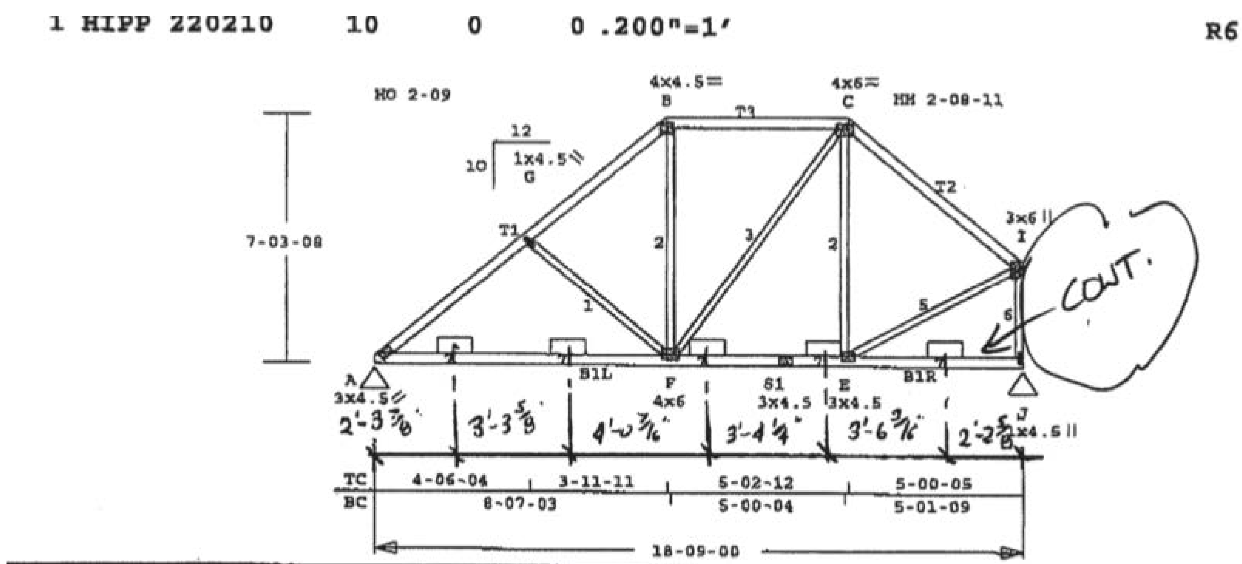


Figure 2- Truss R6 [5]

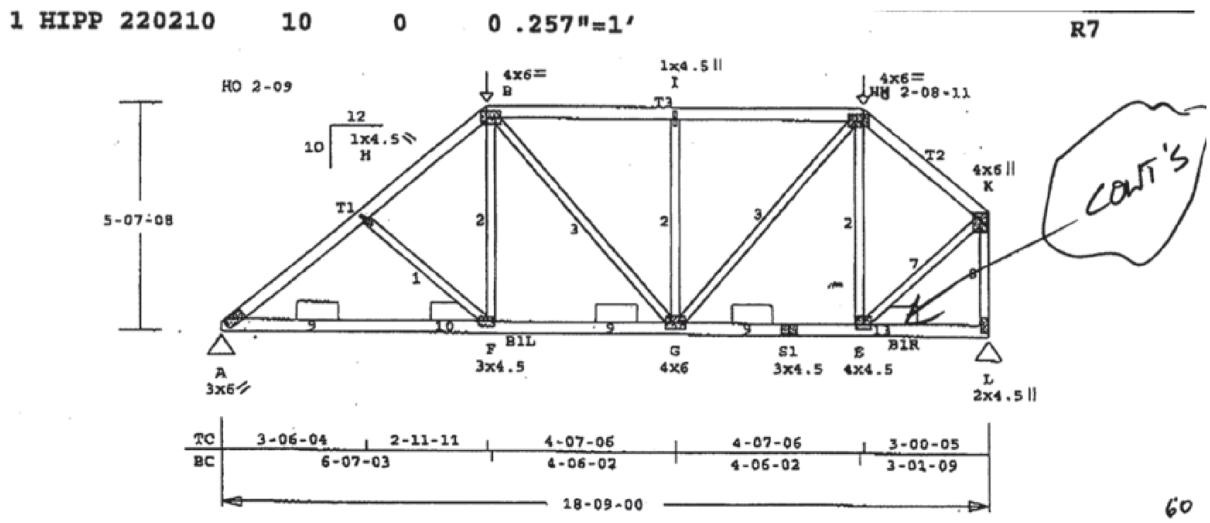


Figure 3 - Truss R7[5]

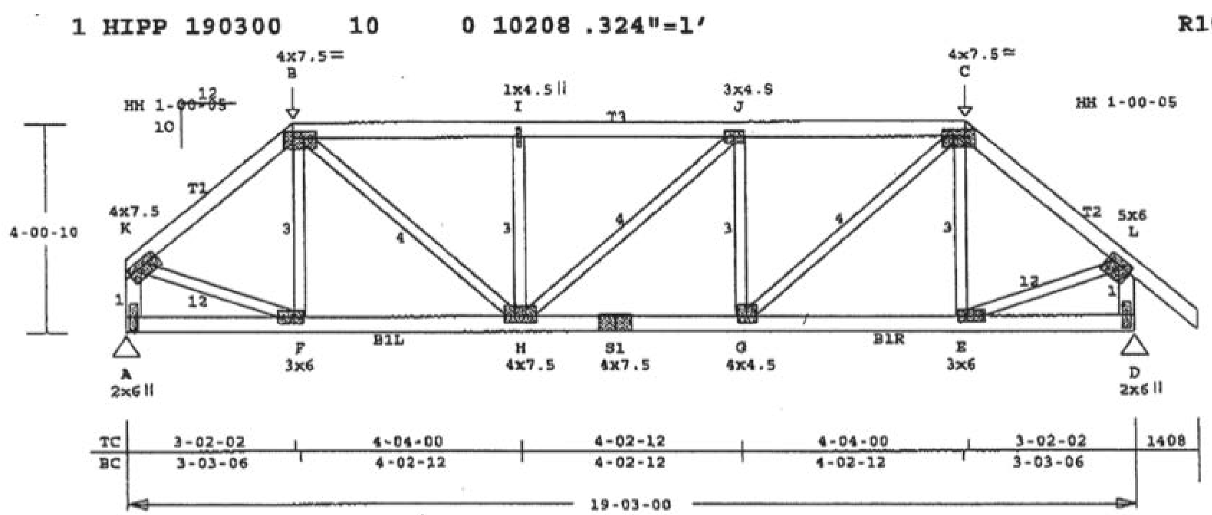


Figure 4 - Truss R10 [5]

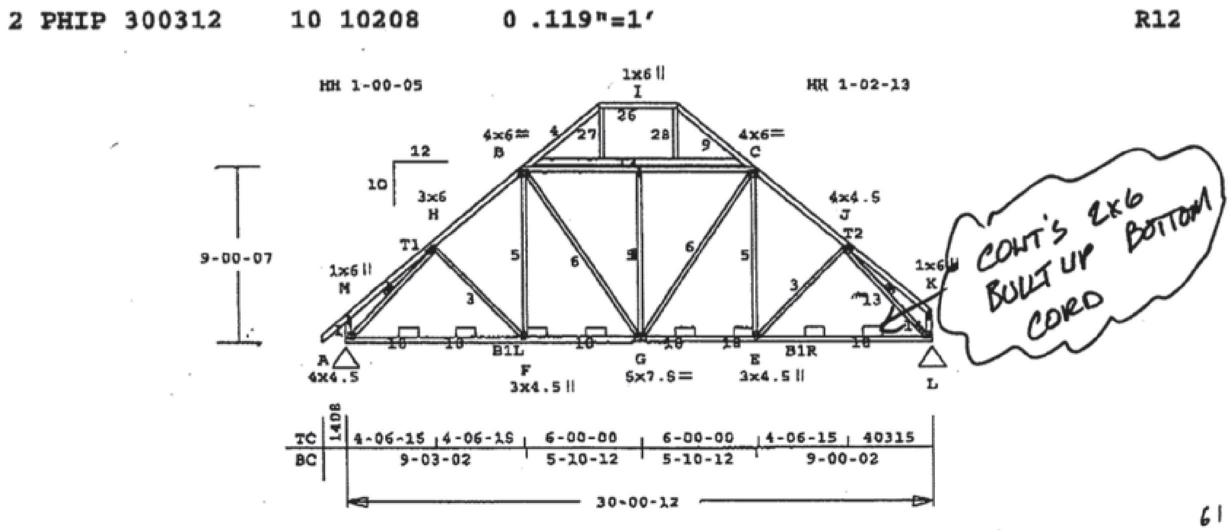


Figure 5 - Truss R12 - [5]

Roof Framing Percentages

Table 5 – OBC, NBC, and Passive House Levels Roof Framing Percentages

Code	Insulation Height	Framing Percentage
OBC 1997 Zone 1	0.1216	0.01
OBC 1997 Zone 2	0.1716	0.01
OBc 2006	0.184	0.01
OBC 2009 SB-12	0.2546	0.01
OBC 2012 SB-12	0.2546	0.01
OBC Proposed 15% Increase	0.3328	0.01
NBC 2010 Zone 1	0.090	0.01
NBC 2010 Zone 2	0.1290	0.01
NBC 2012 Amendment Zone 1	0.2550	0.01
NBC 2012 Amendment Zone 2	0.3250	0.01
Passive House Levels	0.8900	0.03

Framing Percentage Calculations for Double Stud Assemblies

Table 6 Framing Percentage Calculations for Double Stud Assemblies

			Area 1 (Top Plate)	Area 2 (wall)	Area 3 (btm plate)	Total Area	Length (m)	R_{PLATE}	kP_{LATE}	R_{INS}	k_{INS}	R_{COMP}
Above grade	First Floor	North	0.46	32.33	0.46	33.24	12.00	0.32	0.12	0.88	0.04	0.84
		East	0.45	32.03	0.45	32.94	11.89	0.32	0.12	0.88	0.04	0.84
		South	0.46	32.33	0.46	33.24	12.00	0.32	0.12	0.88	0.04	0.84
		West	0.45	32.03	0.45	32.94	11.89	0.32	0.12	0.88	0.04	0.84
	Second Floor	North	0.46	28.67	0.46	29.58	12.00	0.32	0.12	0.88	0.04	0.84
		East	0.45	28.41	0.45	29.31	11.89	0.32	0.12	0.88	0.04	0.84
		South	0.46	28.67	0.46	29.58	12.00	0.32	0.12	0.88	0.04	0.84
		West	0.45	28.41	0.45	29.31	11.89	0.32	0.12	0.88	0.04	0.84
Below Grade	Basement	North	0.46	27.29	0.46	28.20	12.00	0.32	0.12	0.88	0.04	0.84
		East	0.45	27.04	0.45	27.94	11.89	0.32	0.12	0.88	0.04	0.84
		South	0.46	27.29	0.46	28.20	12.00	0.32	0.12	0.88	0.04	0.84
		West	0.45	27.04	0.45	27.94	11.89	0.32	0.12	0.88	0.04	0.84

	Adjusted RSI	% Difference	Framing percentage
R_{AG}	0.84	0.95	0.047
R_{BG}	0.84	0.95	0.055

Table 7 - Framing Percentages for Walls (with Windows)

Wall	Window	Width	Height	Area	Total Area	Lintil	Jack stud	Cripple	Total Wood Area	% Stud (Total Wood Area/(Total Area-Total Window Area)	% Batt	R_{STUD} (k/l, where k=0.12)	R_{BATT}(k/l, where k=0.043)	Adjusted R_{STUD} (% Stud/R_{STUD})	Adjusted R_{BATT} (% Batt/R_{BATT})	$R_{STUDBATT}$(Adjusted R_{BATT} + Adjusted R_{STUD})	Adjusted R_{BATT}	% Difference	Framing percentage
south wall 1a		4.38	6.00	26.28															
	south XX6	1.43	2.23	3.19		0.77	0.46	0.13											
	south XX7	1.63	2.23	3.63		0.89	0.46	0.13											
					6.82	1.66	0.91	0.26	1.93	0.10	0.90	1.17	3.26	0.08	0.28	0.36	2.77	0.85	**0.151**
south wall 3a		5.03	3.23	16.25															
	south WW4	2.03	1.03	2.08		1.11	0.25	0.07											
	south L3	1.43	0.83	1.18		0.77	0.25	0.08											
					3.25	1.89	0.49	0.16	2.04	0.16	0.84	1.17	3.26	0.13	0.26	0.39	2.54	0.78	**0.220**
east wall 1b		4.34	2.77	12.02															
	East E7A	0.43	1.63	0.69		0.20	0.21	0.04											
	East E7B	0.43	1.63	0.69		0.20	0.21	0.04											
					1.38	0.40	0.42	0.09	0.48	0.05	0.95	1.17	3.26	0.04	0.29	0.33	3.01	0.92	**0.075**
north wall 1	a	12.20	6.00	73.20															
	b	9.40	2.05	19.27	92.47														
	North H7a	0.83	1.63	1.34		0.43	0.46	0.24											
	North H7b	0.83	1.63	1.34		0.43	0.46	0.24											
	North A1b	1.20	0.21	0.25		0.64	0.46	0.29											
	North C3	1.33	2.22	2.94		0.71	0.46	0.21											
	North L7	1.43	1.63	2.32		0.77	0.46	0.24											
	North U4	1.02	1.03	1.04		0.54	0.46	0.26											
	North E3	0.43	0.53	0.22		0.20	0.46	0.28											
	North X4	1.62	0.85	1.36		0.88	0.46	0.26											
					10.81	4.60	3.65	2.01	6.61	0.08	0.92	1.17	3.26	0.07	0.28	0.35	2.84	0.87	**0.127**
h bsmt wall		12.20	0.64	19.06															
	North A1a	1.20	0.21	0.25		0.64	0.02	0.01											

	North A1b	1.20	0.21	0.25		0.64	0.02	0.01										
					0.49	1.29	0.05	0.01	1.30	0.18	0.82	1.17	3.26	0.15	0.25	0.40	2.47	0.76	**0.242**
west wall 1		11.79	6.00	70.74															
	West JJ4	1.03	1.03	1.05		0.54	0.23	0.18											
					1.05	0.54	0.23	0.18	0.72	0.01	0.99	1.17	3.26	0.01	0.30	0.31	3.20	0.98	**0.018**

Tier Roof Framing Percentages

Table 8 – Tier Roof Linear Interpolation Values

Code	Insulation Height	Framing Percentage
Tier 1	0.3000	0.01
Tier 2	0.4500	0.01
Tier 3 Zone 1	0.5500	0.01
Tier 3 Zone 2	0.7500	0.01
Tier 4	0.9000	0.03

Appendix D - Treated Floor Area Definition

In the context of this research treated floor area (TFA) is defined as the interior floor area, measured from interior walls, including the basement at 60% of its area and excluding interior partition walls and stairwells. This definition was developed based on the Passive House and Hot2000 definitions of treated floor area, and takes into consideration that basements are commonly used as living space in North America. In PHPP [37], TFA is defined as the floor area inside the building envelope, determined by the clear width between building envelope and excluding interior partition walls greater than 1.5m in height and 0.1m2 in area among other elements. Basements with ceiling heights greater than 2m are included in TFA at 60 % of their area. Hot2000 calculates TFA based on interior measurements only [87].

Treated Floor Area Calculations

Table 1 - Conditioned Area

Floor	Room	Length	Width	Area (m²)
Ground Floor	Living Room Pt. A	3.89	3.01	11.71
	Living Room Pt. b	1.34	2.18	2.92
	Entry	2.01	2.64	5.31
	Hallway	1.71	1.34	2.29
	Bathroom	1.53	1.64	2.51
	Hallway Pt. 2	2.28	1.71	3.84
	Dining Room	3.23	3.83	12.37
	Kitchen	4.08	4.8	19.58
	Kitchen (Counter Area) Pt. 1	1.73	0.95	1.64
	Family Room	4.8	4.41	21.17
	Family Room (bay window area) Pt.1	0.47	0.5	0.24
	Family Room (bay window area) Pt.2	1.83	0.5	0.92
Total Ground Floor				**84.50**
Second Floor	Bedroom 2	3.89	4.12	14.21
	Ensuite Bathroom	3.99	2.19	8.74
	Master Bedroom Pt.1	2.52	1.98	4.99
	Master Bedroom Pt.2	3.34	2.76	9.22
	Master Bedroom Pt.3	2.6	5.3	13.78
	Master Bedroom Pt.4 closet	2.76	1.82	5.02
	Hallway	2.28	1.24	2.83
	Hallway	0.66	1.05	0.69
	Laundry	2.1	2.12	4.45
	Hallway	1.29	3.43	4.42
	Bedroom 3 Pt. 1	2.51	3.83	9.61
	Bedroom 3 Pt. 2	0.87	2.3	2.00
	Bathroom	1.74	3.55	6.18
	Bedroom 4 Pt. 1	3.71	2.83	10.50
	Bedroom 4 Pt. 2	2.88	0.66	1.90
Total Second Floor				**98.55**
Basement		3.5	3.91	13.69
		2.08	2.57	5.35
		1.91	2.4	4.58
		3.08	3.78	11.64
		1.91	1.28	1.22
		8.54	4.79	40.91
		1.12	0.39	0.44
		0.281	0.39	0.11
Total Basement Area				**77.93**
Total Basement Area at 60%				**31.17**
Total Treated Floor Area				**214.22**

Appendix E - Tier Compliance Package Assemblies

Table 1 - Tier Compliance Packages Zone 1

Assembly Type	Description Baseline	Tier 1	Tier 2	Tier 3	Tier 4
Above Grade Walls	100mm brick	100mm brick	100mm brick	100mm brick	100mm brick,
	20mm airspace	20mm airspace	20mm airspace	20mm airspace	20mm airspace
	16mm OSB	50.8mm XPS	50.8mm XPS	16mm OSB	16mm OSB
	38 x 140 x 405mm O.C. with Mineral Wool Insulation (mid-density)	16mm OSB	16mm OSB	38 x 89 x 405mm O.C. with Mineral Wool Insulation (mid-density)	38 x 140 x 405mm O.C. with Mineral Wool Insulation (mid-density)
	6 mil poly	38 x 140 x 405mm O.C. with Mineral Wool Insulation (mid-density)	38 x 140 x 405mm O.C. with Mineral Wool Insulation (mid-density)	140mm Mineral Wool insulation (mid-density) Cavity	292 mm Mineral Wool insulation (mid-density) Cavity (89mm + 203mm Batt)
		6 mil poly	6 mil poly	38 x 89 x 610mm O.C. with Mineral Wool Insulation (mid-density)	38 x 89 x 610mm O.C. with Mineral Wool Insulation (mid-density)
	12.7mm Gypsum	12.7mm Gypsum	12.7mm Gypsum	6 mil poly	6 mil poly
				12.7mm Gypsum	12.7mm Gypsum
	200mm Concrete	50.8mm XPS	50.8mm XPS	200mm Concrete	200mm Concrete
	20mm Airspace	200mm Concrete	200mm Concrete	20mm Airspace	20mm Airspace
	38 x 89 x 405mm O.C. with Mineral Wool Insulation (mid-density)	20mm Airspace	20mm Airspace	140mm Mineral Batt Insulation (mid-density) Cavity	292mm Mineral Wool insulation (mid-density) Cavity (89mm + 203mm Batt)
Below Grade Walls	6 mil poly	38 X 140 x 405mm O.C. with Mineral Wool Insulation (mid-density)	38 x 140 x 405mm O.C. with Mineral Wool Insulation (mid-density)	38 x 89 x 405mm O.C. with Mineral Wool Insulation (mid-density)	38 x 89 x 405mm O.C. with Mineral Wool Insulation (mid-density)

		6 mil poly	6 mil poly	6 mil poly	6 mil poly
	12.7mm Gypsum	12.7mm Gypsum	12.7mm Gypsum	12.7mm Gypsum	12.7mm Gypsum
Roof	3mm Asphalt Shingles	3mm Asphalt Shingles	3mm Asphalt Shingles	3mm Asphalt Shingles	3mm Asphalt Shingles
	16mm OSB	16mm OSB	16mm OSB	16mm OSB	16mm OSB
	300 mm Blown Cellulose Insulation	450 mm Blown Cellulose Insulation	450 mm Blown Cellulose Insulation	550 mm Blown Cellulose Insulation	900 mm Blown Cellulose Insulation
	38 x 89mm x 610 O.C. Joists with Blown Cellulose	38 x 89 x 610mm O.C. Joists with Blown Cellulose	38 x 89 x 610mm O.C. Joists with Blown Cellulose	38 x 89 x 610mm O.C. Joists with Blown Cellulose	38 x 89 x 610mm O.C. Joists with Blown Cellulose
	12.7mm Gypsum	12.7mm Gypsum	12.7mm Gypsum	12.7mm Gypsum	12.7mm Gypsum
Slab	75mm Concrete	10mil Poly Soil Gas Barrier	10mil Poly Soil Gas Barrier	10mil Poly Soil Gas Barrier	10mil Poly Soil Gas Barrier
		76.2mm XPS	76.2mm XPS	76.2mm XPS	304.8mm XPS
		75mm Concrete	75mm Concrete	75mm Concrete	75mm Concrete
Exposed Floor	213mm Blown Cellulose	213mm Blown Cellulose	245mm Blown Cellulose	245mm Blown Cellulose	245mm Blown Cellulose

Table 2 - Tier Compliance Packages Zone 2

Assembly Type	**Description**				
	Baseline	**Tier 1**	**Tier 2**	**Tier 3**	**Tier 4**
Above Grade Walls	100mm brick	100mm brick	100mm brick	100mm brick,	100mm brick,
	20mm airspace	20mm airspace	20mm airspace	20mm airspace	20mm airspace
	25.4mm XPS	50.8mm XPS	50.8mm XPS	50.8mm XPS	16mm OSB
	16mm OSB	16mm OSB	16mm OSB	16mm OSB	38 x 140 x 405mm O.C. with Mineral Wool Insulation (mid-density)
	38 x 140 x 405mm O.C. with Mineral Wool Insulation (mid-density)	38 x 140 x 405mm O.C. with Mineral Wool Insulation (mid-density)	38 x 140 x 405mm O.C. with Mineral Wool Insulation (mid-density)	38 x 140 x 405mm O.C. with Mineral Wool Insulation (mid-density)	292 mm Mineral Wool insulation (mid-density) Cavity (89mm + 203mm Batt)
	6 mil poly	6 mil poly	140mm Mineral Wool insulation (mid-density) Cavity	140mm Mineral Wool insulation (mid-density) Cavity	38 x 89 x 610mm O.C. with Mineral Batt (mid-density)
	12.7mm Gypsum	12.7mm Gypsum	38 x 89 x 610mm O.C. with Mineral Wool Insulation (mid-density)	38 x 89 x 610mm O.C. with Mineral Wool Insulation (mid-density)	6 mil poly
			6 mil poly	6 mil poly	12.7mm Gypsum
			12.7mm Gypsum	12.7mm Gypsum	
Below Grade Walls	200mm Concrete	50.8mm XPS	200mm Concrete	200mm Concrete	200mm Concrete
	20mm Airspace	200mm Concrete	20mm Airspace	20mm Airspace	20mm Airspace

	38 x 89 x 405mm O.C. with Mineral Wool Insulation (mid-density)	20mm Airspace	229mm Mineral Batt Insulation (mid-density) Cavity (89mm + 140mm batt)	203mm Mineral Batt Insulation (mid-density) Cavity	292 mm Mineral Wool insulation (mid-density) Cavity (89mm + 203mm Batt)
	6 mil poly	38 X 140 x 405mm O.C. with Mineral Wool Insulation (mid-density)	38 x 89 x 405mm O.C. with Mineral Wool Insulation (mid-density)	38 x 89 x 405mm O.C. with Mineral Wool Insulation (mid-density)	38 x 89 x 405mm O.C. with Mineral Wool Insulation (mid-density)
		6 mil poly	6 mil poly	6 mil poly	6 mil poly
	12.7mm Gypsum	12.7mm Gypsum	12.7mm Gypsum	12.7mm Gypsum	12.7mm Gypsum
Roof	3mm Asphalt Shingles	3mm Asphalt Shingles	3mm Asphalt Shingles	3mm Asphalt Shingles	3mm Asphalt Shingles
	16mm OSB	16mm OSB	16mm OSB	16mm OSB	16mm OSB
	300 mm Blown Cellulose Insulation	450 mm Blown Cellulose Insulation	450 mm Blown Cellulose Insulation	750mm Blown Cellulose Insulation	900 mm Blown Cellulose Insulation
	38 x 89 x 610mm O.C. Joists with Blown Cellulose	38 x 89 x 610mm O.C. Joists with Blown Cellulose	38 x 89 x 610mm O.C. Joists with Blown Cellulose	38 x 89 x 610mm O.C. Joists with Blown Cellulose	38 x 89 x 610mm O.C. Joists with Blown Cellulose
	12.7mm Gypsum	12.7mm Gypsum	12.7mm Gypsum	12.7mm Gypsum	12.7mm Gypsum
Slab	75mm Concrete	10mil Poly Soil Gas Barrier	10mil Poly Soil Gas Barrier	10mil Poly Soil Gas Barrier	10mil Poly Soil Gas Barrier
		76.2mm XPS	101.6mm XPS	266.7mm XPS	304.8mm XPS
		75mm Concrete	75mm Concrete	75mm Concrete	75mm Concrete
Exposed Floor	213mm Blown Cellulose	213mm Blown Cellulose	245mm Blown Cellulose	245mm Blown Cellulose	245mm Blown Cellulose

Appendix F – Cost Calculations

Window Costs

Table 3 - Window Area Calculations

Wall	Window	Width	Height	Area
south wall 1a	south XX6	1.43	2.23	3.19
	south XX7	1.63	2.23	3.63
south wall 3a	south WW4	2.03	1.03	2.08
	south L3	1.43	0.83	1.18
east wall 1b	East E7A	0.43	1.63	0.69
	East E7B	0.43	1.63	0.69
north wall 1	North H7a	0.83	1.63	1.34
	North H7b	0.83	1.63	1.34
	North A1b	1.20	0.21	0.25
	North C3	1.33	2.22	2.94
	North L7	1.43	1.63	2.32
	North U4	1.02	1.03	1.04
	North E3	0.43	0.53	0.22
	North X4	1.62	0.85	1.36
north bsmt wall 1a	North A1a	1.20	0.21	0.25
	North A1b	1.20	0.21	0.25
west wall 1	West JJ4	1.03	1.03	1.05
			Average	**1.40**
			Median	**1.19**
			Max	**3.63**
			Min	**0.27**

Cost Estimates using Average, Median, Maximum, and Minimum areas of CCHT windows

- Pella
    - Double pane – Baseline (OBC SB-12 2012 Compliance Package 'J')
    - Triple pane – Tier 1
- Zola
    - Classic Clad – Tier 2
    - Thermo Clad – Tier 3
    - Thermo Plus – Tier 4

Contract - Detailed

,
Phone: Fax:

Sales Rep Name:
Sales Rep Phone:
Sales Rep Fax:
Sales Rep E-Mail:

Customer Information	Project/Delivery Address	Order Information
	Amanda Yip-Dual Glaze	Quote Name: Amanda Yip
	Lot #	Order Number: 786
,	,	**Quote Number: TBD**
Day Phone:	County:	Order Type: Installed Sales
Mobile Phone:	Owner Name:	Wall Depth:
Fax Number:		Payment Terms:
E-Mail:	Owner Phone:	Tax Code: HST
Contact Name:		Cust Delivery Date: None
		Quoted Date: 12/10/2012
Great Plains #:		Contracted Date:
Customer Number:		Booked Date:
Customer Account:		Customer PO #:

Line #	Location:	Attributes	Qty
10	CASEMENT 0.28	**Pella 350 Series, Casement Right, 33 X 56, White**	1

Viewed From Exterior

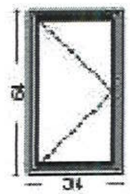
PK #
541

1: Non-Standard SizeNon-Standard Size Right Casement
Frame Size: 33 X 56
General Information: Yes, Standard, Vinyl, Block, Foam Insulated, 3 1/4", 3 1/4", Sill Adapter Included, No Head Expander
Exterior Color / Finish: White
Interior Color / Finish: White
Glass: Insulated Dual Low E NaturalSun Argon Non High Altitude
Hardware Options: Standard Roto Operator, No Limited Opening Hardware, White, Steel
Screen: Full Screen, Conventional Fiberglass
Grille: No Grille,
Wrapping Information: No Interior Trim, Pella Recommended Clearance, Perimeter Length = 178", Glazing Pressure = 60.

$669.03

Rough Opening: 33 - 1/2" X 56 - 1/2"

Line #	Location:	Attributes	
15	CASEMENT 0.28	**Pella 350 Series, Casement Right, 34 X 64, White**	**Qty** 1



Viewed From Exterior

PK # 541

1: Non-Standard SizeNon-Standard Size Right Casement
Frame Size: 34 X 64
General Information: Yes, Standard, Vinyl, Block, Foam Insulated, 3 1/4", 3 1/4", Sill Adapter Included, No Head Expander
Exterior Color / Finish: White
Interior Color / Finish: White
Glass: Insulated Dual Low E NaturalSun Argon Non High Altitude
Hardware Options: Standard Roto Operator, No Limited Opening Hardware, White, Steel
Screen: Full Screen, Conventional Fiberglass
Grille: No Grille,
Wrapping Information: No Interior Trim, Pella Recommended Clearance, Perimeter Length = 196", Glazing Pressure = 75.

$722.92

Rough Opening: 34 - 1/2" X 64 - 1/2"

Line #	Location:	Attributes	
20	CASEMENT 0.28	**Pella 350 Series, Direct Set Fixed Frame, 88 X 64, White**	**Qty** 1

Viewed From Exterior

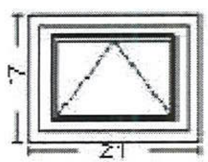
PK # 541

1: 8864 Fixed Frame Direct Set
Frame Size: 88 X 64
General Information: No, Standard, Vinyl, Block, 3 1/4", 3 1/4", Sill Adapter Included, No Head Expander
Exterior Color / Finish: White
Interior Color / Finish: White
Glass: Insulated Dual Tempered Low E NaturalSun Argon Non High Altitude
Grille: No Grille,
Wrapping Information: No Interior Trim, Pella Recommended Clearance, Perimeter Length = 304", Glazing Pressure = 170.

$970.69

Rough Opening: 88 - 1/2" X 64 - 1/2"

Line #	Location:	Attributes	
25	CASEMENT 0.28	**Pella 350 Series, Awning Top Hinge, 21 X 17, White**	**Qty** 1



Viewed From Exterior

PK # 541

1: Non-Standard SizeNon-Standard Size Top Hinge Awning
Frame Size: 21 X 17
General Information: Yes, Standard, Vinyl, Block, Foam Insulated, 3 1/4", 3 1/4", Sill Adapter Included, No Head Expander
Exterior Color / Finish: White
Interior Color / Finish: White
Glass: Insulated Dual Low E NaturalSun Argon Non High Altitude
Hardware Options: Standard Roto Operator, No Limited Opening Hardware, White, Steel
Screen: Full Screen, Conventional Fiberglass
Grille: No Grille,
Wrapping Information: No Interior Trim, Pella Recommended Clearance, Perimeter Length = 76", Glazing Pressure = 155.

$363.63

Rough Opening: 21 - 1/2" X 17 - 1/2"

Line #	Location:	Attributes	Qty
30	FIXED 0.28	**Pella 350 Series, Direct Set Fixed Frame, 33 X 56, White**	1

Viewed From Exterior

PK # 541

1: Non-Standard SizeNon-Standard Size Fixed Frame Direct Set
Frame Size: 33 X 56
General Information: No, Standard, Vinyl, Block, 3 1/4", 3 1/4", Sill Adapter Included, No Head Expander
Exterior Color / Finish: White
Interior Color / Finish: White
Glass: Insulated Dual Low E NaturalSun Argon Non High Altitude
Grille: No Grille,
Wrapping Information: No Interior Trim, Pella Recommended Clearance, Perimeter Length = 178", Glazing Pressure = 60.

$593.42

Rough Opening: 33 - 1/2" X 56 - 1/2"

Line #	Location:	Attributes	Qty
35	FIXED- 0.28	**Pella 350 Series, Direct Set Fixed Frame, 34 X 64, White**	1

Viewed From Exterior

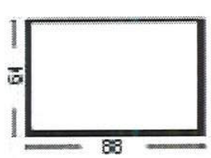
PK # 541

1: Non-Standard SizeNon-Standard Size Fixed Frame Direct Set
Frame Size: 34 X 64
General Information: No, Standard, Vinyl, Block, 3 1/4", 3 1/4", Sill Adapter Included, No Head Expander
Exterior Color / Finish: White
Interior Color / Finish: White
Glass: Insulated Dual Low E NaturalSun Argon Non High Altitude
Grille: No Grille,
Wrapping Information: No Interior Trim, Pella Recommended Clearance, Perimeter Length = 196", Glazing Pressure = 75.

$647.32

Rough Opening: 34 - 1/2" X 64 - 1/2"

Line #	Location:	Attributes	Qty
40	FIXED-0.28	**Pella 350 Series, Direct Set Fixed Frame, 88 X 64, White**	1



Viewed From Exterior

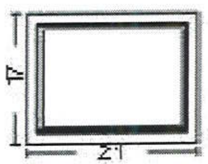
PK # 541

1: 8864 Fixed Frame Direct Set
Frame Size: 88 X 64
General Information: No, Standard, Vinyl, Block, 3 1/4", 3 1/4", Sill Adapter Included, No Head Expander
Exterior Color / Finish: White
Interior Color / Finish: White
Glass: Insulated Dual Tempered Low E NaturalSun Argon Non High Altitude
Grille: No Grille,
Wrapping Information: No Interior Trim, Pella Recommended Clearance, Perimeter Length = 304", Glazing Pressure = 170.

$970.69

Rough Opening: 88 - 1/2" X 64 - 1/2"

Line #	Location:	Attributes	Qty
45	FIXED- 0.28	**Pella 350 Series, Direct Set Fixed Frame, 21 X 17, White**	1



Viewed From Exterior

PK #
541

1: Non-Standard SizeNon-Standard Size Fixed Frame Direct Set
Frame Size: 21 X 17
General Information: No, Standard, Vinyl, Block, 3 1/4", 3 1/4", Sill Adapter Included, No Head Expander
Exterior Color / Finish: White
Interior Color / Finish: White
Glass: Insulated Dual Low E NaturalSun Argon Non High Altitude
Grille: No Grille,
Wrapping Information: No Interior Trim, Pella Recommended Clearance, Perimeter Length = 76", Glazing Pressure = 155.

$287.99

Rough Opening: 21 - 1/2" X 17 - 1/2"

Thank You For Purchasing Pella® Products

PELLA WARRANTY:

Pella products are covered by Pella's limited warranties in effect at the time of sale. All applicable product warranties are incorporated into and become a part of this contract. Please see the warranties for complete details, taking special note of the two important notice sections regarding installation of Pella products and proper management of moisture within the wall system. Neither Pella Corporation nor Pella Window & Doors Ontario will be bound by any other warranty unless specifically set out in this contract. However, Pella Corporation will not be liable for branch warranties which create obligations in addition to or obligations which are inconsistent with Pella written warranties.

Clear opening (egress) information does not take into consideration the addition of a Rolscreen [or any other accessory] to the product. You should consult your local building code to ensure your Pella products meet local egress requirements.

Per the manufacturer's limited warranty, unfinished mahogany exterior windows and doors must be finished upon receipt prior to installing and refinished annually, thereafter. Variations in wood grain, color, texture or natural characteristics are not covered under the limited warranty.

Quote prices are valid for 30 days. All product is made exclusively for your project and cannot be canceled or changed once this quote is signed by you. Pella will contact you prior to delivery. Every attempt will be made to meet your requested need date, but cannot be guaranteed. Pella Windows & Doors of Ontario shall not be liable for any direct, indirect or consequential damage or loss caused by delay in shipment. Pella is not responsible for compliance with local building ordinances. Payment terms are noted at the top of this proposal. Past due accounts will be subject to the maximum allowed interest charges. I have read and agree to the terms of this proposal.

☐ **Project Checklist has been reviewed**

Customer Name (Please print)

Customer Signature

Date

Credit Card Approval Signature

Pella Sales Rep Name (Please print)

Pella Sales Rep Signature

Date

Order Totals	
Taxable Subtotal	$5,225.69
Sales Tax @ 13%	$679.34
Non-taxable Subtotal	$0.00
Total	$5,905.03
Deposit Received	
Amount Due	**$5,905.03**

Contract - Detailed

,
Phone: Fax:

Sales Rep Name:
Sales Rep Phone:
Sales Rep Fax:
Sales Rep E-Mail:

Customer Information	Project/Delivery Address	Order Information
	Amanda Yip- Triple Glaze	Quote Name: Amanda Yip
	Lot #	Order Number: 786
,	,	**Quote Number: TBD**
Day Phone:	County:	Order Type: Installed Sales
Mobile Phone:	Owner Name:	Wall Depth:
Fax Number:		Payment Terms:
E-Mail:	Owner Phone:	Tax Code: HST
Contact Name:		Cust Delivery Date: None
		Quoted Date: 12/10/2012
Great Plains #:		Contracted Date:
Customer Number:		Booked Date:
Customer Account:		Customer PO #:

Line #	Location:	Attributes	Qty
10	CASEMENT 0.24	**Pella 350 Series, Casement Right, 33 X 56, White**	1

Viewed From Exterior

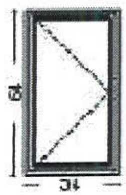
PK #
541

$836.87

1: Non-Standard SizeNon-Standard Size Right Casement
Frame Size: 33 X 56
General Information: Yes, Standard, Vinyl, Block, Foam Insulated, 3 1/4", 3 1/4", Sill Adapter Included, No Head Expander
Exterior Color / Finish: White
Interior Color / Finish: White
Glass: Insulated Triple Low E NaturalSun Argon Non High Altitude
Hardware Options: Standard Roto Operator, No Limited Opening Hardware, White, Steel
Screen: Full Screen, Conventional Fiberglass
Grille: No Grille,
Wrapping Information: No Interior Trim, Pella Recommended Clearance, Perimeter Length = 178", Glazing Pressure = 60.

Rough Opening: 33 - 1/2" X 56 - 1/2"

Line #	Location:	Attributes	Qty
15	CASEMENT 0.24	**Pella 350 Series, Casement Right, 34 X 64, White**	1



Viewed From Exterior

PK # 541

1: Non-Standard SizeNon-Standard Size Right Casement
Frame Size: 34 X 64
General Information: Yes, Standard, Vinyl, Block, Foam Insulated, 3 1/4", 3 1/4", Sill Adapter Included, No Head Expander
Exterior Color / Finish: White
Interior Color / Finish: White
Glass: Insulated Triple Low E NaturalSun Argon Non High Altitude
Hardware Options: Standard Roto Operator, No Limited Opening Hardware, White, Steel
Screen: Full Screen, Conventional Fiberglass
Grille: No Grille,
Wrapping Information: No Interior Trim, Pella Recommended Clearance, Perimeter Length = 196", Glazing Pressure = 75.

$907.74

Rough Opening: 34 - 1/2" X 64 - 1/2"

Line #	Location:	Attributes	Qty
20	CASEMENT 0.24	**Pella 350 Series, Direct Set Fixed Frame, 88 X 64, White**	1

Viewed From Exterior

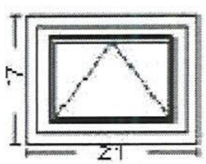
PK # 541

1: 8864 Fixed Frame Direct Set
Frame Size: 88 X 64
General Information: No, Standard, Vinyl, Block, 3 1/4", 3 1/4", Sill Adapter Included, No Head Expander
Exterior Color / Finish: White
Interior Color / Finish: White
Glass: Insulated Triple Tempered Low E NaturalSun Argon Non High Altitude
Grille: No Grille,
Wrapping Information: No Interior Trim, Pella Recommended Clearance, Perimeter Length = 304", Glazing Pressure = 170.

$1,257.35

Rough Opening: 88 - 1/2" X 64 - 1/2"

Line #	Location:	Attributes	Qty
25	CASEMENT 0.24	**Pella 350 Series, Awning Top Hinge, 21 X 17, White**	1



Viewed From Exterior

PK # 541

1: Non-Standard SizeNon-Standard Size Top Hinge Awning
Frame Size: 21 X 17
General Information: Yes, Standard, Vinyl, Block, Foam Insulated, 3 1/4", 3 1/4", Sill Adapter Included, No Head Expander
Exterior Color / Finish: White
Interior Color / Finish: White
Glass: Insulated Triple Low E NaturalSun Argon Non High Altitude
Hardware Options: Standard Roto Operator, No Limited Opening Hardware, White, Steel
Screen: Full Screen, Conventional Fiberglass
Grille: No Grille,
Wrapping Information: No Interior Trim, Pella Recommended Clearance, Perimeter Length = 76", Glazing Pressure = 155.

$435.29

Rough Opening: 21 - 1/2" X 17 - 1/2"

Line #	Location:	Attributes	
30	FIXED 0.24	**Pella 350 Series, Direct Set Fixed Frame, 33 X 56, White**	**Qty**

Viewed From Exterior

PK # 541

1: Non-Standard SizeNon-Standard Size Fixed Frame Direct Set
Frame Size: 33 X 56
General Information: No, Standard, Vinyl, Block, 3 1/4", 3 1/4", Sill Adapter Included, No Head Expander
Exterior Color / Finish: White
Interior Color / Finish: White
Glass: Insulated Triple Low E NaturalSun Argon Non High Altitude
Grille: No Grille,
Wrapping Information: No Interior Trim, Pella Recommended Clearance, Perimeter Length = 178", Glazing Pressure = 60.

Qty: 1

$761.28

Rough Opening: 33 - 1/2" X 56 - 1/2"

Line #	Location:	Attributes	
35	FIXED- 0.24	**Pella 350 Series, Direct Set Fixed Frame, 34 X 64, White**	**Qty**

Viewed From Exterior

PK # 541

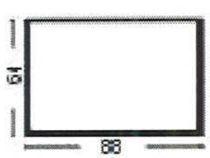
1: Non-Standard SizeNon-Standard Size Fixed Frame Direct Set
Frame Size: 34 X 64
General Information: No, Standard, Vinyl, Block, 3 1/4", 3 1/4", Sill Adapter Included, No Head Expander
Exterior Color / Finish: White
Interior Color / Finish: White
Glass: Insulated Triple Low E NaturalSun Argon Non High Altitude
Grille: No Grille,
Wrapping Information: No Interior Trim, Pella Recommended Clearance, Perimeter Length = 196", Glazing Pressure = 75.

Qty: 1

$832.15

Rough Opening: 34 - 1/2" X 64 - 1/2"

Line #	Location:	Attributes	
40	FIXED 0.24	**Pella 350 Series, Direct Set Fixed Frame, 88 X 64, White**	**Qty**



Viewed From Exterior

PK # 541

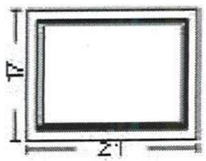
1: 8864 Fixed Frame Direct Set
Frame Size: 88 X 64
General Information: No, Standard, Vinyl, Block, 3 1/4", 3 1/4", Sill Adapter Included, No Head Expander
Exterior Color / Finish: White
Interior Color / Finish: White
Glass: Insulated Triple Tempered Low E NaturalSun Argon Non High Altitude
Grille: No Grille,
Wrapping Information: No Interior Trim, Pella Recommended Clearance, Perimeter Length = 304", Glazing Pressure = 170.

Qty: 1

$1,257.35

Rough Opening: 88 - 1/2" X 64 - 1/2"

Line #	Location:	Attributes	Qty
45	FIXED- 0.24	**Pella 350 Series, Direct Set Fixed Frame, 21 X 17, White**	1



Viewed From Exterior

PK #
541

1: Non-Standard SizeNon-Standard Size Fixed Frame Direct Set
Frame Size: 21 X 17
General Information: No, Standard, Vinyl, Block, 3 1/4", 3 1/4", Sill Adapter Included, No Head Expander
Exterior Color / Finish: White
Interior Color / Finish: White
Glass: Insulated Triple Low E NaturalSun Argon Non High Altitude
Grille: No Grille,
Wrapping Information: No Interior Trim, Pella Recommended Clearance, Perimeter Length = 76", Glazing Pressure = 155.

$359.69

Rough Opening: 21 - 1/2" X 17 - 1/2"

Thank You For Purchasing Pella® Products

PELLA WARRANTY:
Pella products are covered by Pella's limited warranties in effect at the time of sale. All applicable product warranties are incorporated into and become a part of this contract. Please see the warranties for complete details, taking special note of the two important notice sections regarding installation of Pella products and proper management of moisture within the wall system. Neither Pella Corporation nor Pella Window & Doors Ontario will be bound by any other warranty unless specifically set out in this contract. However, Pella Corporation will not be liable for branch warranties which create obligations in addition to or obligations which are inconsistent with Pella written warranties.

Clear opening (egress) information does not take into consideration the addition of a Rolscreen [or any other accessory] to the product. You should consult your local building code to ensure your Pella products meet local egress requirements.

Per the manufacturer's limited warranty, unfinished mahogany exterior windows and doors must be finished upon receipt prior to installing and refinished annually, thereafter. Variations in wood grain, color, texture or natural characteristics are not covered under the limited warranty.

Quote prices are valid for 30 days. All product is made exclusively for your project and cannot be canceled or changed once this quote is signed by you. Pella will contact you prior to delivery. Every attempt will be made to meet your requested need date, but cannot be guaranteed. Pella Windows & Doors of Ontario shall not be liable for any direct, indirect or consequential damage or loss caused by delay in shipment. Pella is not responsible for compliance with local building ordinances. Payment terms are noted at the top of this proposal. Past due accounts will be subject to the maximum allowed interest charges. I have read and agree to the terms of this proposal.

☐ **Project Checklist has been reviewed**

Customer Name (Please print)

Customer Signature

Date

Credit Card Approval Signature

Pella Sales Rep Name (Please print)

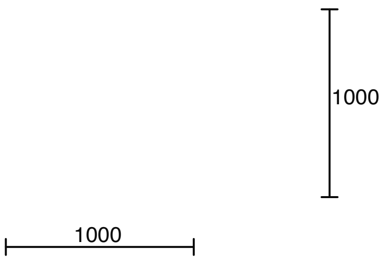
Pella Sales Rep Signature

Date

Order Totals	
Taxable Subtotal	$6,647.72
Sales Tax @ 13%	$864.20
Non-taxable Subtotal	$0.00
Total	$7,511.92
Deposit Received	
Amount Due	**$7,511.92**

Zola European Windows
a dba of Zeitgeist Products LLC
1104 Garfield Ave
Louisville, CO 80027
(303) 578-0001

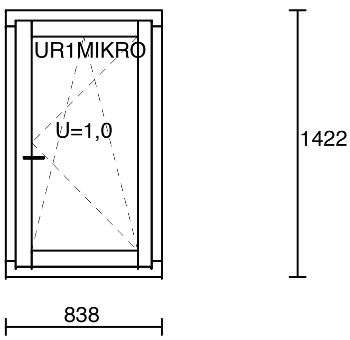
Order number J-1191B date12/12/15 Amanda Yip classic clad
page 1



Pos.no 1: window screens
size (W x H): 1000 x 1000

quantity	price	value
70 x	12.32 =	862.40

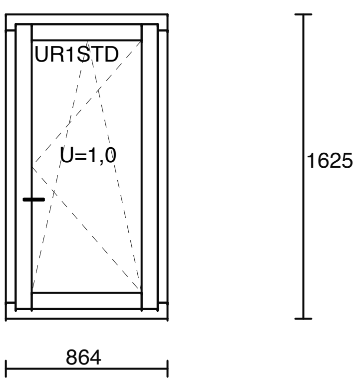
70 square feet of operable windows



Pos.no 2: 33"x56"
size (W x H): 838 x 1422

quantity	price	value
1 x	841.80 =	841.80

System: Classic Clad pine finger-jointed
colour: PINE TRANS
glass: U=1,0
window U (W/m2K)= 1.26
Frame: 68x80mm
Sash: 68x80mm
Fitting: tilt&turn
hinge caps: R01.2 new silver
Handle: Hoppe Secustik F1



Pos.no 3: 34"x64"
size (W x H): 864 x 1625

quantity	price	value
1 x	894.01 =	894.01

System: Classic Clad pine finger-jointed
colour: PINE TRANS
glass: U=1,0
window U (W/m2K)= 1.25
Frame: 68x80mm
Sash: 68x80mm
hinge caps: R01.2 new silver
Handle: Hoppe Secustik F1

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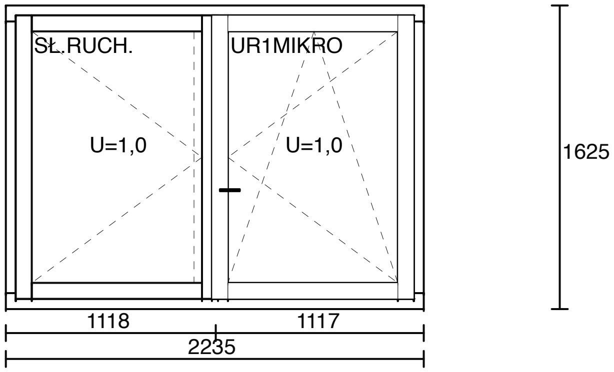
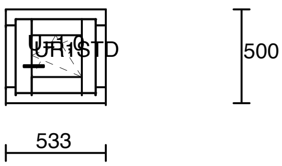
see next page



Pos.no 4: 88" x 64"
size (W x H): 2235 x 1625

quantity	price	value
1 x	1750.49 =	1750.49

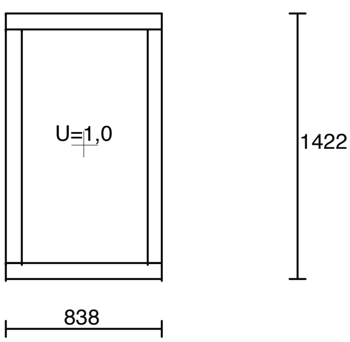
System: Classic Clad pine finger-jointed
colour: PINE TRANS
glass: U=1,0
window U (W/m2K)= 1.21
Frame: 68x80mm
Sash: 68x80mm
hinge caps: R01.2 new silver
Handle: Hoppe Secustik F1



Pos.no 5: 21"x 19-11/16"
size (W x H): 533 x 500

quantity	price	value
1 x	509.85 =	509.85

System: Classic Clad pine finger-jointed
colour: PINE TRANS
glass: U=1,0
window U (W/m2K)= 1.39
500-mm minimum for operable
windows, so window could
not be 17 inches
Frame: 68x80mm
Sash: 68x80mm
hinge caps: R01.2 new silver
Handle: Hoppe Secustik F1



Pos.no 6: 33" x 56" fixed
size (W x H): 838 x 1422

quantity	price	value
1 x	591.10 =	591.10

System: Classic Clad pine finger-jointed
colour: PINE TRANS
glass: U=1,0
window U (W/m2K)= 1.25
Frame: 68x80mm
hinge caps: R01.2 new silver
Handle: Hoppe Secustik F1

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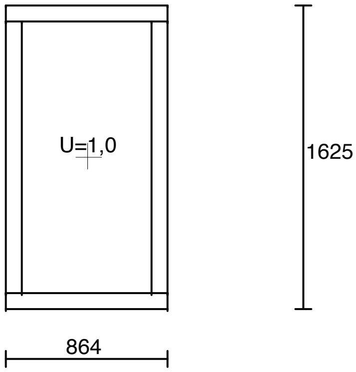
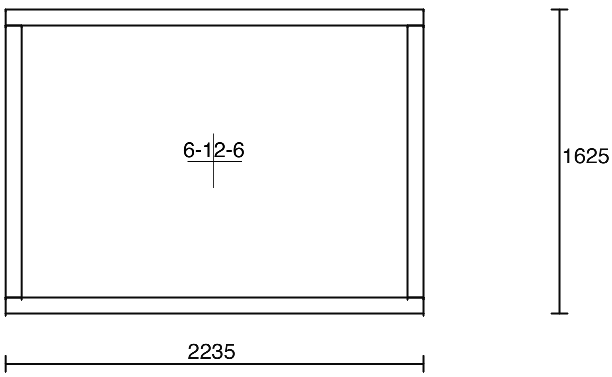
see next page



Pos.no 7: 34" x 64" fixed
size (W x H): 864 x 1625

quantity	price	value
1 x	638.18 =	638.18

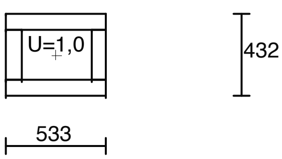
System: Classic Clad pine finger-jointed
colour: PINE TRANS
glass: U=1,0
window U (W/m2K)= 1.24
Frame: 68x80mm
hinge caps: R01.2 new silver
Handle: Hoppe Secustik F1



Pos.no 8: 88" x 64"
size (W x H): 2235 x 1625

quantity	price	value
1 x	1192.91 =	1192.91

System: Classic Clad pine finger-jointed
colour: PINE TRANS
glass: 6-12-6
window U (W/m2K)= 1.39
Frame: 68x80mm
hinge caps: R01.2 new silver
Handle: Hoppe Secustik F1



Pos.no 9: 21" x 17" fixed
size (W x H): 533 x 432

quantity	price	value
1 x	369.13 =	369.13

System: Classic Clad pine finger-jointed
colour: PINE TRANS
glass: U=1,0
window U (W/m2K)= 1.43
Verify size
Frame: 68x80mm
hinge caps: R01.2 new silver
Handle: Hoppe Secustik F1
Verify size. I had to increase the size of the small operable window, so it is no longer the same size as this fixed window.
400-mm minimum for fixed windows.
500-mm minimum for operable windows.

---

surface = 12.953 m2 Total excluding tax/shipping = $7649.87 USD

Florian Speier <florian@zolawindows.com> 7 February, 2013 4:23 PM
To: Amanda Yip
Re: Zola Pricing

Amanda,

Actually, that makes things easy- you can just use the ThermoPlus Clad quote we provided and subtract 10%. The only difference between those two lines is that the ThermPlus Clad is thermally broken with a layer of Purenit, and this add 10%. Is that sufficient for your needs?

Florian

On Thu, Feb 7, 2013 at 1:38 PM, Amanda Yip <amanda.yip@ryerson.ca> wrote:

> Hi Florian,
>
> Yes, if you can, I'd like a quote for that list for the ThermoClad windows. That list is the same as the list I had sent you for the previous quotes. And a week sounds great!
>
> Thank you,
>
> -Amanda
>
> Amanda Yip
> MASc Candidate, Building Science
> Dept. of Architectural Science
> Ryerson University
> amanda.yip@ryerson.ca
>
> On 2013-02-07, at 2:29 PM, Florian Speier <florian@zolawindows.com> wrote:
>
>> Amanda,
>>
>> So to confirm you would like us to put tougher a quote in ThermoClad for the new list you provide? We can do that, but we will probably need about one week.
>>
>> Florian
>>
>> On Wed, Feb 6, 2013 at 9:35 AM, Amanda Yip <amanda.yip@ryerson.ca> wrote:
>>
>>> Hi Florian,
>>>
>>> I had planned to use the quote you did for the the ThermoClad windows for the Gemini House, but the sizes and types are too different. Would it be possible to get some additional prices from you for the ThermoClad windows for the following windows?
>>>
>>>> Casement - 1 Qty- 33w x 56h
>>>> 1 Qty- 34w x 64h
>>>> 1 Qty- 88w x 64h
>>>> 1 Qty- 21w x 17w
>>>>
>>>> Fixed- 1 Qty- 33w x 56h
>>>> 1 Qty- 34w x 64h
>>>> 1 Qty- 88w x 64h
>>>> 1 Qty- 21w x 17w
>>>
>>> Thank you,
>>>
>>> -Amanda
>>>
>>> Amanda Yip
>>> MASc Candidate, Building Science
>>> Dept. of Architectural Science
>>> Ryerson University
>>> amanda.yip@ryerson.ca

On 2012-12-24, at 2:38 PM, Amanda Yip <amanda.yip@ryerson.ca> wrote:

> Thanks, Florian.
>
> Happy holidays!
>
> Amanda Yip
> MASc Candidate, Building Science
> Dept. of Architectural Science
> Ryerson University
> amanda.yip@ryerson.ca
>
> On 2012-12-20, at 1:15 PM, Florian Speier wrote:
>
>> Hi Amanda,
>>
>> Attached out the quotes we put together for you in Thermo and Classic Wood for your research project. Best of luck finishing up the paper, and let me know if you have any questions.
>>
>> --
>> Florian Speier
>> Swiss Architect, CPHC
>> vice-president, Zola Windows
>>
>> <J-1191-0214-1 thermoplus clad.pdf><J-1191B-0214-1 classic clad.pdf><features thermo plus clad.pages><zola_classic_clad.pdf><zola_thermoplus_clad.pdf>

--
Florian Speier
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--
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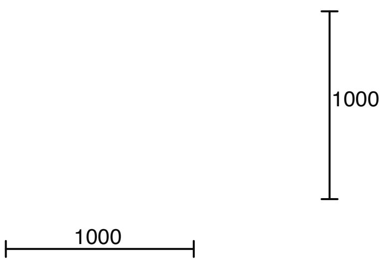
Zola European Windows
a dba of Zeitgeist Products LLC
1104 Garfield Ave
Louisville, CO 80027
(303) 578-0001

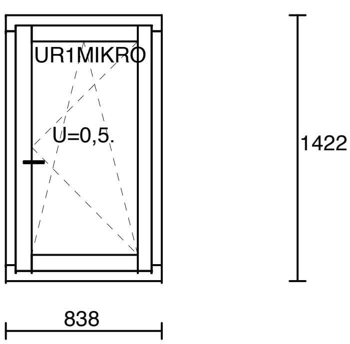
Order number J-1191 date12/12/15 Amanda Yip thermo plus clad
page 1



Pos.no 1: window screens
size (W x H): 1000 x 1000

quantity	price	value
70 x	12.32 =	862.40

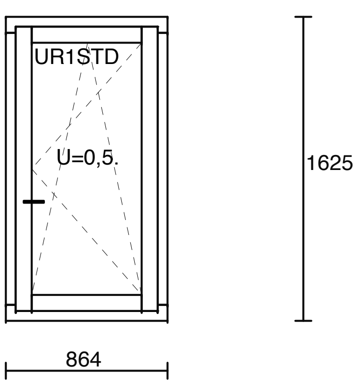
70 square feet of operable windows



Pos.no 2: 33"x56"
size (W x H): 838 x 1422

quantity	price	value
1 x	1051.95 =	1051.95

System: ThermoPlus Clad pine finger-jointed
colour: PINE TRANS
glass: U=0,5.
window U (W/m2K)= 0.84
Frame: 88x80mm
Sash: 88x80mm
Fitting: tilt&turn
hinge caps: R01.2 new silver
Handle: Hoppe Secustik F1



Pos.no 3: 34"x64"
size (W x H): 864 x 1625

quantity	price	value
1 x	1131.30 =	1131.30

System: ThermoPlus Clad pine finger-jointed
colour: PINE TRANS
glass: U=0,5.
window U (W/m2K)= 0.82
Frame: 88x80mm
Sash: 88x80mm
hinge caps: R01.2 new silver
Handle: Hoppe Secustik F1

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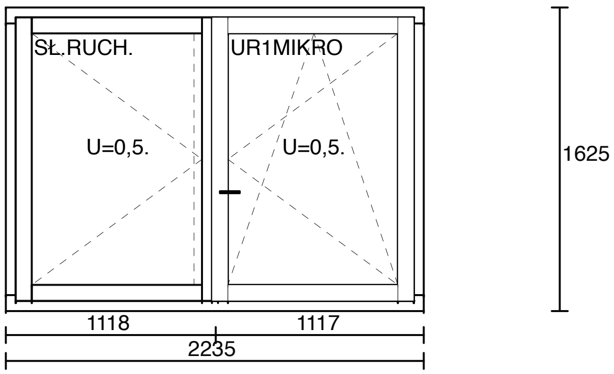
see next page

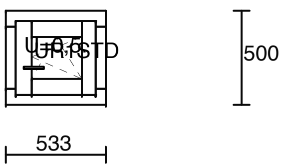
Order number J-1191 date12/12/15 Amanda Yip thermo plus clad
page 2



Pos.no 4: 88" x 64"
size (W x H): 2235 x 1625

quantity	price	value
1 x	2267.99 =	2267.99

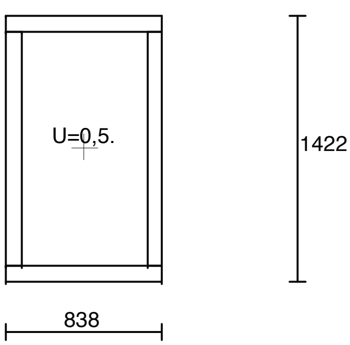
System: ThermoPlus Clad pine finger-jointed
glass: U=0,5.
window U (W/m2K)= 0.76
Frame: 88x80mm
Sash: 88x80mm
hinge caps: R01.2 new silver
Handle: Hoppe Secustik F1



Pos.no 5: 21"x 19-11/16"
size (W x H): 533 x 500

quantity	price	value
1 x	601.29 =	601.29

System: ThermoPlus Clad pine finger-jointed
colour: PINE TRANS
glass: U=0,5.
window U (W/m2K)= 1.03
500-mm minimum for operable
windows, so window could
not be 17 inches
Frame: 88x80mm
Sash: 88x80mm
hinge caps: R01.2 new silver
Handle: Hoppe Secustik F1



Pos.no 6: 33" x 56" fixed
size (W x H): 838 x 1422

quantity	price	value
1 x	708.04 =	708.04

System: ThermoPlus Clad pine finger-jointed
colour: PINE TRANS
glass: U=0,5.
window U (W/m2K)= 0.81
Frame: 88x80mm
hinge caps: R01.2 new silver
Handle: Hoppe Secustik F1

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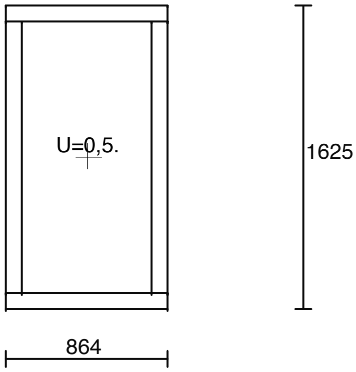
see next page

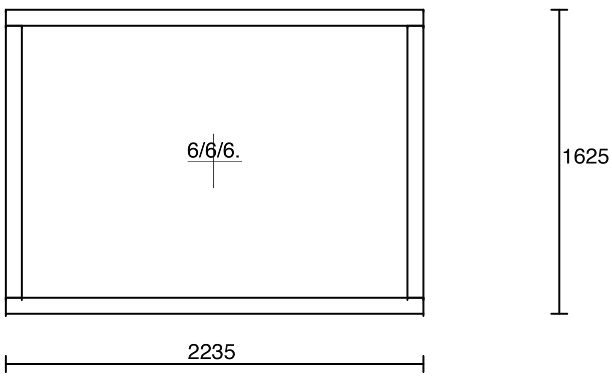
Order number J-1191 date12/12/15 Amanda Yip thermo plus clad
page 3



Pos.no 7: 34" x 64" fixed
size (W x H): 864 x 1625

quantity	price	value
1 x	776.77 =	776.77

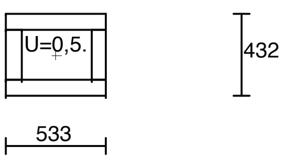
System: ThermoPlus Clad pine finger-jointed
colour: PINE TRANS
glass: U=0,5.
window U (W/m2K)= 0.79
Frame: 88x80mm
hinge caps: R01.2 new silver
Handle: Hoppe Secustik F1



Pos.no 8: 88" x 64"
size (W x H): 2235 x 1625

quantity	price	value
1 x	1649.96 =	1649.96

System: ThermoPlus Clad pine finger-jointed
colour: PINE TRANS
glass: 6/6/6.
window U (W/m2K)= 0.68
Frame: 88x80mm
hinge caps: R01.2 new silver
Handle: Hoppe Secustik F1



Pos.no 9: 21" x 17" fixed
size (W x H): 533 x 432

quantity	price	value
1 x	397.34 =	397.34

System: ThermoPlus Clad pine finger-jointed
colour: PINE TRANS
glass: U=0,5.
window U (W/m2K)= 1.05
Verify size
Frame: 88x80mm
hinge caps: R01.2 new silver
Handle: Hoppe Secustik F1
Verify size. I had to increase the size of the small operable window, so it is no longer the same size as this fixed window.
400-mm minimum for fixed windows.
500-mm minimum for operable windows.

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surface = 12.953 m2 Total excluding tax/shipping = $9447.04 USD

Table 4 - Window Prices Per Size

Size (m^2)		Baseline	Tier 1	Tier 2	Tier 3	Tier 4
Average	**1.4**	$450.66	$570.49	$546.95	$613.01	$681.13
Max	**3.63**	$267.05	$345.91	$404.88	$485.04	$538.94
Min	**0.22**	$1,460.21	$1,781.47	$1,969.70	$2,014.04	$2,237.83
Median	**1.18**	$582.77	$739.99	$609.42	$673.68	$748.53

Table 1 – Total Window Costs Per Tier

Wall	Window	Area (m^2)	Baseline	Tier 1	Tier 2	Tier 3	Tier 4
south wall 1a	south XX6	3.19	$851.59	$1,103.07	$1,291.12	$1,546.75	$1,718.61
	south XX7	3.63	$970.69	$1,257.35	$1,471.70	$1,763.08	$1,958.98
south wall 3a	south WW4	2.08	$554.29	$717.98	$840.38	$1,006.76	$1,118.63
	south L3	1.18	$685.12	$869.95	$716.45	$792.00	$880.00
east wall 1b	East E7A	0.69	$402.48	$511.05	$420.88	$465.26	$516.96
	East E7B	0.69	$402.48	$511.05	$420.88	$465.26	$516.96
north wall 1	North H7a	1.34	$358.01	$463.74	$542.79	$650.26	$722.51
	North H7b	1.34	$358.01	$463.74	$542.79	$650.26	$722.51
	North A1b	0.25	$359.21	$438.24	$484.55	$495.45	$550.51
	North C3	2.94	$785.52	$1,017.50	$1,190.96	$1,426.75	$1,585.28
	North L7	2.32	$618.38	$801.00	$937.55	$1,123.17	$1,247.97
	North U4	1.04	$606.30	$769.86	$634.03	$700.88	$778.76
	North E3	0.22	$325.81	$397.49	$439.49	$449.38	$499.32
	North X4	1.36	$364.43	$472.06	$552.53	$661.92	$735.47
north bsmt wall 1a	North A1a	0.25	$359.21	$438.24	$484.55	$495.45	$550.51
	North A1b	0.25	$359.21	$438.24	$484.55	$495.45	$550.51
west wall 1	West JJ4	1.05	$612.27	$777.45	$640.27	$707.79	$786.43
		Total Cost	**$8,973.01**	**$11,448.00**	**$12,095.47**	**$13,895.89**	**$15,439.87**
		Average $/m^2	**$450.66**	**$570.49**	**$546.95**	**$613.01**	**$681.13**

Building Envelope Costs

Table 5 – Building Envelope Component Surface Areas

Surface Areas - From EnergyPlus Annual Performance Summary	
Above Grade Wall - Insulated	218.06
Below Grade Wall	23.00
Roof - Insulated	17.66
Ceiling	132.36
Slab	106.85
Exposed Floor	27.37

Table 6 - Baseline Building Envelope Costs – Zone 1

Component	Baseline	Cost

Above Grade Wall	100mm brick	$7.500
	20mm airspace	
	16mm OSB	$0.42
	38 X 140 mm x 405mm O.C	$11.060
	Mineral Wool Insulation (mid-density)	$1.000
	6 mil poly	$0.250
	Mudding & tapping	$0.600
	12.7mm Gypsum	$1.300
	Total Cost Per Square Foot	**$22.125**
	Total Cost Per Square Metre	**$238.152**
Below Grade Wall	200mm Concrete	$43.00
	20mm Airspace	
	38 x 89 mm x 405mm O.C. with Mineral Wool Insulation (mid-density)	$11.63
	6 mil poly	$0.66
	Mudding & tapping	$0.600
	12.7mm Gypsum	$1.30
	Total Cost Per Square Foot	**$57.19**
	Total Cost Per Square Metre	**$615.588**
Roof	3mm Asphalt Shingles Limited lifetime Warranty	$2.10
	16mm OSB	$0.42
	Total Cost Per Square Foot	$2.52
	Total Cost Per Square Metre	$27.071
	200 mm Blown Cellulose Insulation	$0.50
	38 x 89mm x 610 O.C. Joists with Blown Cellulose	$11.63
	Mudding & tapping	$0.600
	12.7mm Gypsum	$1.30
	Total Cost Per Square Foot	$16.55
	Total Cost Per Square Metre	$178.089
Slab	75mm Concrete	$7.00
	Total Cost Per Square Foot	**$7.00**
	Total Cost Per Square Metre	**$75.347**
Exposed Floor	213mm Blown Cellulose	$0.60
	Total Cost Per Square Foot	**$0.60**
	Total Cost Per Square Metre	**$6.458**
Total Construction Cost Per Square Foot		**$116.82**
Total Construction Cost Per Square Metre		**$1,257.44**

Table 7 - Tier 1 Building Envelope Costs – Zone 1

Component	Tier 1	Costs
Above Grade Wall	100mm brick	$7.500
	20mm airspace	
	50.8mm XPS	$2.480
	16mm OSB	$0.42
	38 X 140 mm x 405mm O.C	$10.860
	Mineral Wool Insulation (mid-density)	$1.000
	Mudding & tapping	$0.600
	6 mil poly	$0.660
	12.7mm Gypsum	$1.300
	Total Cost Per Square Foot	**$24.82**
	Total Cost Per Square Metre	**$267.106**
Below Grade Wall	200mm Concrete	$43.00
	20mm Airspace	
	38 X 140 mm x 405mm O.C. with Mineral Wool Insulation (mid-density)	$10.86
	6 mil poly	$0.66
	Mudding & tapping	$0.600
	12.7mm Gypsum	$1.30
	Total Cost Per Square Foot	**$56.42**
	Total Cost Per Square Metre	**$607.300**
Roof	3mm Asphalt Shingles Limited lifetime Warranty	$2.10
	16mm OSB	$0.42
	300 mm Blown Cellulose Insulation	$0.80
	38 x 89mm x 610 O.C. Joists with Blown Cellulose	$11.63
	Mudding & tapping	$0.600
	12.7mm Gypsum	$1.30
	Total Cost Per Square Foot	**$16.85**
	Total Cost Per Square Metre	**$181.32**
Slab	10mil Poly Soil Gas Barrier	$0.09
	76.2mm XPS	$3.72
	75mm Concrete	$7.00
	Total Cost Per Square Foot	**$10.81**
	Total Cost Per Square Metre	**$116.385**
Exposed Floor	213mm Blown Cellulose	$0.60
	Total Cost Per Square Foot	**$0.60**
	Total Cost Per Square Metre	**$6.458**
Total Construction Cost Per Square Foot		**$122.85**
Total Construction Cost Per Square Metre		**$1,322.37**

Table 8 - Tier 2 Building Envelope Costs - Zone 1

Component	Tier 2	Costs
Above Grade Wall	100mm brick	$7.500
	20mm airspace	
	76.2mm XPS	$3.720
	16mm OSB	$0.42
	38 x 140mm x 405 O.C.	$10.860
	Mineral Wool Insulation (mid-density)	$1.000
	Mudding & tapping	$0.600
	6 mil poly	$0.660
	12.7mm Gypsum	$1.300
	Total Cost Per Square Foot	**$26.06**
	Total Cost Per Square Metre	**$280.454**
Below Grade Wall	50.8mm XPS	$2.48
	200mm Concrete	$43.00
	20mm Airspace	
	38 x 140 mm x 405mm O.C. with Mineral Wool Insulation (mid-density)	$10.86
	Mudding & tapping	$0.600
	6 mil poly	$0.66
	12.7mm Gypsum	$1.30
	Total Cost Per Square Foot	**$58.90**
	Total Cost Per Square Metre	**$633.994**
Roof	3mm Asphalt Shingles Limited lifetime Warranty	$2.10
	16mm OSB	$0.42
	450 mm Blown Cellulose Insulation	$1.35
	38 x 89mm x 610 O.C. Joists with Blown Cellulose	$11.63
	Mudding & tapping	$0.600
	12.7mm Gypsum	$1.30
	Total Cost Per Square Foot	**$17.40**
	Total Cost Per Square Metre	**$187.24**
Slab	10mil Poly Soil Gas Barrier	$0.09
	76.2mm XPS	$3.72
	75mm Concrete	$7.00
	Total Cost Per Square Foot	**$10.81**
	Total Cost Per Square Metre	**$116.385**
Exposed Floor	245mm Blown Cellulose	$0.75
	Total Cost Per Square Foot	**$0.75**
	Total Cost Per Square Metre	**$8.073**
Total Construction Cost Per Square Foot		**$127.27**
Total Construction Cost Per Square Metre		**$1,369.95**

Table 9 - Tier 3 Building Envelope Costs - Zone 1

Component	Tier 3	Cost
Above Grade Wall	100mm brick	$7.500
	20mm airspace	
	16mm OSB	$0.42
	38 x 89mm x 405 O.C. with Mineral Wool Insulation (mid-density)	$11.660
	140mm Mineral Wool insulation (mid-density) Cavity	$1.000
	38 x 89mm x 610mm O.C. with Mineral Wool Insulation (mid-density)	$11.660
	Mudding & tapping	$0.600
	6 mil poly	$0.660
	12.7mm Gypsum	$1.300
	Total Cost Per Square Foot	**$34.80**
	Total Cost Per Square Metre	**$374.530**
Below Grade Wall	200mm Concrete	$43.00
	20mm Airspace	
	140mm Mineral Batt Insulation (mid-density) Cavity	$1.00
	38 x 89mm x 405mm O.C. with Mineral Wool Insulation (mid-density)	$11.63
	Mudding & tapping	$0.600
	6 mil poly	$0.66
	12.7mm Gypsum	$1.30
	Total Cost Per Square Foot	**$58.19**
	Total Cost Per Square Metre	**$626.352**
Roof	3mm Asphalt Shingles Limited lifetime Warranty	$2.10
	16mm OSB	$0.42
	550 mm Blown Cellulose Insulation	$1.65
	38 x 89mm x 610 O.C. Joists with Blown Cellulose	$11.63
	Mudding & tapping	$0.600
	12.7mm Gypsum	$1.30
	Total Cost Per Square Foot	**$17.70**
	Total Cost Per Square Metre	**$190.47**
Slab	10mil Poly Soil Gas Barrier	$0.09
	76.2mm XPS	$3.72
	75mm Concrete	$7.00
	Total Cost Per Square Foot	**$10.81**
	Total Cost Per Square Metre	**$116.39**
Exposed Floor	245mm Blown Cellulose	$0.75
	Total Cost Per Square Foot	**$0.75**
	Total Cost Per Square Metre	**$8.07**
Total Construction Cost Per Square Foot		**$135.60**
Total Construction Cost Per Square Metre		**$1,459.61**

Table 10 - Tier 4 Building Envelope Costs - Zone 1

Component	Tier 4	Costs

Above Grade Wall	100mm brick	$7.500
	20mm airspace	
	16mm OSB	$0.42
	38 x 140mm x 405 O.C. with Mineral Wool Insulation (mid-density)	$12.630
	292 mm Mineral Wool insulation (mid-density) Cavity (89mm + 203mm Batt)	$2.000
	38 x 89mm x 610mm O.C. with Mineral Batt (mid-density)	$11.660
	Mudding & tapping	$0.600
	6 mil poly	$0.660
	12.7mm Gypsum	$1.300
	Total Cost Per Square Foot	**$36.77**
	Total Cost Per Square Metre	**$395.735**
Below Grade Wall	200mm Concrete	$43.00
	20mm Airspace	
	292 mm Mineral Wool insulation (mid-density) Cavity (89mm + 203mm Batt)	$2.00
	38 x 89mm x 405mm O.C. with Mineral Wool Insulation (mid-density)	$11.63
	Mudding & tapping	$0.600
	6 mil poly	$0.66
	12.7mm Gypsum	$1.30
	Total Cost Per Square Foot	**$59.19**
	Total Cost Per Square Metre	**$637.116**
Roof	3mm Asphalt Shingles Limited lifetime Warranty	$2.10
	16mm OSB	$0.42
	900 mm Blown Cellulose Insulation	$2.80
	38 x 89mm x 610 O.C. Joists with Blown Cellulose	$11.63
	Mudding & tapping	$0.600
	12.7mm Gypsum	$1.30
	Total Cost Per Square Foot	**$18.85**
	Total Cost Per Square Metre	**$202.85**
Slab	10mil Poly Soil Gas Barrier	$0.09
	304.8mm XPS	$14.88
	75mm Concrete	$7.00
	Total Cost Per Square Foot	**$21.97**
	Total Cost Per Square Metre	**$236.510**
Exposed Floor	245mm Blown Cellulose	$0.75
	Total Cost Per Square Foot	**$0.75**
	Total Cost Per Square Metre	**$8.073**
Total Construction Cost Per Square Foot		**$142.55**
Total Construction Cost Per Square Metre		**$1,534.42**

Energy Calculations

Heating Energy Consumption

Table 11 - Heating Energy Consumption

	Use (MJ)	Use (m^3)
Baseline	637,830	17,009
Tier 1	419,209	11,179
Tier 2	300,016	8,000
Tier 3	223,398	5,957
Tier 4	75,132	2,004

1 m^3 = 37.5 MJ [88]

Joules to m3: 1 Joule = 0.000001 MJ

Ontario Energy Prices

Table 12 - Ontario Natural Gas Prices - Climate Zone 1 [70]

Charge	Cost ($/m3)
Gas Supply Charge	**0.128548**
Transportation	0.055359
First 30	0.082998
Next 55	0.078377
Next 85	0.074755
Over 170	0.072058
Cost Adjustment	-0.020258
Total Annual Charge	65
Total Annual Adjustment	-6

Table 13 - Ontario Electricity Prices [71]

	Cost	Time Frame	Total Hours	Weight
On-Peak	$0.118	7-11a; 5-7p	6	0.1775
Mid-Peak	$0.990	11a-5p	6	0.1775
Off-Peak	$0.063	7p-7a; weekends & holidays	12	0.645
Weighted Average Price*	$0.105			

*Weighted Average Price = (On-Peak Cost * Weight)+(Mid-Peak Cost * Weight) + (Off-Peak * Weight)

Projected Energy Costs with Fuel Escalation Rates

Table 14 - Baseline Projected Energy Costs with Fuel Escalation Rates and 2% Inflation

Year	Additional Mortgage Payment Over Baseline	Low Rate - 1.5%	Moderate Rate - 3.50%	High Rate - 5.5%
1	$0.00	$2,228.68	$2,228.68	$2,228.68
2	$0.00	$2,306.68	$2,351.26	$2,395.83
3	$0.00	$2,387.42	$2,480.58	$2,575.52
4	$0.00	$2,470.98	$2,617.01	$2,768.68
5	$0.00	$2,557.46	$2,760.94	$2,976.33
6	$0.00	$2,646.97	$2,912.80	$3,199.56
7	$0.00	$2,739.62	$3,073.00	$3,439.53
8	$0.00	$2,835.50	$3,242.01	$3,697.49
9	$0.00	$2,934.75	$3,420.32	$3,974.80
10	$0.00	$3,037.46	$3,608.44	$4,272.91
11	$0.00	$3,143.77	$3,806.91	$4,593.38
12	$0.00	$3,253.81	$4,016.29	$4,937.88
13	$0.00	$3,367.69	$4,237.18	$5,308.22
14	$0.00	$3,485.56	$4,470.23	$5,706.34
15	$0.00	$3,607.55	$4,716.09	$6,134.32
16	$0.00	$3,733.82	$4,975.48	$6,594.39
17	$0.00	$3,864.50	$5,249.13	$7,088.97
18	$0.00	$3,999.76	$5,537.83	$7,620.64
19	$0.00	$4,139.75	$5,842.41	$8,192.19
20	$0.00	$4,284.64	$6,163.74	$8,806.61
21	$0.00	$4,434.60	$6,502.75	$9,467.10
22	$0.00	$4,589.81	$6,860.40	$10,177.13
23	$0.00	$4,750.46	$7,237.72	$10,940.42
24	$0.00	$4,916.72	$7,635.80	$11,760.95
25	$0.00	$5,088.81	$8,055.76	$12,643.02
26		$5,266.92	$8,498.83	$13,591.25
27		$5,451.26	$8,966.27	$14,610.59
28		$5,642.05	$9,459.41	$15,706.38
29		$5,839.52	$9,979.68	$16,884.36
30		$6,043.91	$10,528.56	$18,150.69
31		$6,255.44	$11,107.63	$19,511.99
32		$6,474.39	$11,718.55	$20,975.39
33		$6,700.99	$12,363.07	$22,548.55
34		$6,935.52	$13,043.04	$24,239.69
35		$7,178.27	$13,760.41	$26,057.66
36		$7,429.51	$14,517.23	$28,011.99
37		$7,689.54	$15,315.68	$30,112.89
38		$7,958.67	$16,158.04	$32,371.35
39		$8,237.23	$17,046.73	$34,799.21
40		$8,525.53	$17,984.30	$37,409.15
TOTAL		$188,435.50	$304,450.19	$506,482.04

Table 15 - Tier 1 Projected Energy Cost Savings with Fuel Escalation Rates and 2% Inflation

Year	Additional Mortgage Payment Over Baseline	Low Rate - 1.5%	Moderate Rate - 3.50%	High Rate - 5.5%
1	$1,155.17	$775.57	$775.57	$775.57
2	$1,177.35	$802.71	$818.22	$833.73
3	$1,199.96	$830.81	$863.23	$896.27
4	$1,223.00	$859.89	$910.70	$963.48
5	$1,246.48	$889.98	$960.79	$1,035.75
6	$1,270.41	$921.13	$1,013.64	$1,113.43
7	$1,294.80	$953.37	$1,069.39	$1,196.93
8	$1,319.66	$986.74	$1,128.20	$1,286.70
9	$1,345.00	$1,021.27	$1,190.25	$1,383.21
10	$1,370.82	$1,057.02	$1,255.72	$1,486.95
11	$1,397.14	$1,094.01	$1,324.78	$1,598.47
12	$1,423.97	$1,132.30	$1,397.64	$1,718.35
13	$1,451.31	$1,171.94	$1,474.51	$1,847.23
14	$1,479.17	$1,212.95	$1,555.61	$1,985.77
15	$1,507.57	$1,255.41	$1,641.17	$2,134.71
16	$1,536.52	$1,299.35	$1,731.44	$2,294.81
17	$1,566.02	$1,344.82	$1,826.66	$2,466.92
18	$1,596.09	$1,391.89	$1,927.13	$2,651.94
19	$1,626.73	$1,440.61	$2,033.12	$2,850.83
20	$1,657.97	$1,491.03	$2,144.95	$3,064.65
21	$1,689.80	$1,543.22	$2,262.92	$3,294.49
22	$1,722.24	$1,597.23	$2,387.38	$3,541.58
23	$1,755.31	$1,653.13	$2,518.68	$3,807.20
24	$1,789.01	$1,710.99	$2,657.21	$4,092.74
25	$1,823.36	$1,770.88	$2,803.36	$4,399.70
26		$1,832.86	$2,957.54	$4,729.67
27		$1,897.01	$3,120.21	$5,084.40
28		$1,963.40	$3,291.82	$5,465.73
29		$2,032.12	$3,472.87	$5,875.66
30		$2,103.24	$3,663.88	$6,316.33
31		$2,176.86	$3,865.39	$6,790.06
32		$2,253.05	$4,077.99	$7,299.31
33		$2,331.90	$4,302.28	$7,846.76
34		$2,413.52	$4,538.90	$8,435.27
35		$2,497.99	$4,788.54	$9,067.91
36		$2,585.42	$5,051.91	$9,748.01
37		$2,675.91	$5,329.77	$10,479.11
38		$2,769.57	$5,622.90	$11,265.04
39		$2,866.51	$5,932.16	$12,109.92
40		$2,966.83	$6,258.43	$13,018.16
TOTAL	$36,624.90	$65,574.44	$105,946.86	$176,252.75

Table 16 - Tier 2 Projected Energy Cost Savings with Fuel Escalation Rates and 2% Inflation

Year	Additional Mortgage Payment Over Baseline	Low Rate - 1.5%	Moderate Rate - 3.50%	High Rate - 5.5%
1	$1,478.41	$1,198.55	$1,198.55	$1,198.55
2	$1,506.80	$1,240.50	$1,264.47	$1,288.44
3	$1,535.73	$1,283.91	$1,334.01	$1,385.07
4	$1,565.21	$1,328.85	$1,407.38	$1,488.95
5	$1,595.27	$1,375.36	$1,484.79	$1,600.62
6	$1,625.90	$1,423.50	$1,566.45	$1,720.67
7	$1,657.11	$1,473.32	$1,652.61	$1,849.72
8	$1,688.93	$1,524.89	$1,743.50	$1,988.45
9	$1,721.36	$1,578.26	$1,839.39	$2,137.58
10	$1,754.41	$1,633.50	$1,940.56	$2,297.90
11	$1,788.09	$1,690.67	$2,047.29	$2,470.24
12	$1,822.42	$1,749.84	$2,159.89	$2,655.51
13	$1,857.41	$1,811.09	$2,278.69	$2,854.68
14	$1,893.08	$1,874.48	$2,404.02	$3,068.78
15	$1,929.42	$1,940.08	$2,536.24	$3,298.93
16	$1,966.47	$2,007.99	$2,675.73	$3,546.36
17	$2,004.22	$2,078.26	$2,822.89	$3,812.33
18	$2,042.70	$2,151.00	$2,978.15	$4,098.26
19	$2,081.92	$2,226.29	$3,141.95	$4,405.63
20	$2,121.90	$2,304.21	$3,314.76	$4,736.05
21	$2,162.64	$2,384.86	$3,497.07	$5,091.25
22	$2,204.16	$2,468.33	$3,689.41	$5,473.10
23	$2,246.48	$2,554.72	$3,892.33	$5,883.58
24	$2,289.61	$2,644.13	$4,106.41	$6,324.85
25	$2,333.57	$2,736.68	$4,332.26	$6,799.21
26		$2,832.46	$4,570.53	$7,309.15
27		$2,931.60	$4,821.91	$7,857.34
28		$3,034.20	$5,087.12	$8,446.64
29		$3,140.40	$5,366.91	$9,080.13
30		$3,250.31	$5,662.09	$9,761.14
31		$3,364.08	$5,973.50	$10,493.23
32		$3,481.82	$6,302.05	$11,280.22
33		$3,603.68	$6,648.66	$12,126.24
34		$3,729.81	$7,014.33	$13,035.71
35		$3,860.35	$7,400.12	$14,013.38
36		$3,995.47	$7,807.13	$15,064.39
37		$4,135.31	$8,236.52	$16,194.22
38		$4,280.04	$8,689.53	$17,408.78
39		$4,429.85	$9,167.45	$18,714.44
40		$4,584.89	$9,671.66	$20,118.03
TOTAL	$46,873.22	$101,337.53	$163,728.32	$272,377.74

Table 17 - Tier 3 Projected Energy Cost Savings with Fuel Escalation Rates and 2% Inflation

Year	Additional Mortgage Payment Over Baseline	Low Rate - 1.5%	Moderate Rate - 3.50%	High Rate - 5.5%
1	$3,070.47	$1,470.44	$1,470.44	$1,470.44
2	$3,129.42	$1,521.91	$1,551.32	$1,580.73
3	$3,189.51	$1,575.18	$1,636.64	$1,699.28
4	$3,250.75	$1,630.31	$1,726.66	$1,826.73
5	$3,313.16	$1,687.37	$1,821.62	$1,963.73
6	$3,376.78	$1,746.43	$1,921.81	$2,111.01
7	$3,441.61	$1,807.55	$2,027.51	$2,269.34
8	$3,507.69	$1,870.82	$2,139.02	$2,439.54
9	$3,575.04	$1,936.29	$2,256.67	$2,622.50
10	$3,643.68	$2,004.06	$2,380.79	$2,819.19
11	$3,713.63	$2,074.21	$2,511.73	$3,030.63
12	$3,784.94	$2,146.80	$2,649.88	$3,257.93
13	$3,857.61	$2,221.94	$2,795.62	$3,502.27
14	$3,931.67	$2,299.71	$2,949.38	$3,764.94
15	$4,007.16	$2,380.20	$3,111.59	$4,047.32
16	$4,084.10	$2,463.51	$3,282.73	$4,350.86
17	$4,162.51	$2,549.73	$3,463.28	$4,677.18
18	$4,242.43	$2,638.97	$3,653.76	$5,027.97
19	$4,323.89	$2,731.33	$3,854.72	$5,405.06
20	$4,406.91	$2,826.93	$4,066.73	$5,810.44
21	$4,491.52	$2,925.87	$4,290.40	$6,246.23
22	$4,577.76	$3,028.28	$4,526.37	$6,714.69
23	$4,665.65	$3,134.27	$4,775.32	$7,218.30
24	$4,755.23	$3,243.97	$5,037.96	$7,759.67
25	$4,846.53	$3,357.51	$5,315.05	$8,341.64
26		$3,475.02	$5,607.38	$8,967.27
27		$3,596.65	$5,915.79	$9,639.81
28		$3,722.53	$6,241.15	$10,362.80
29		$3,852.82	$6,584.42	$11,140.01
30		$3,987.66	$6,946.56	$11,975.51
31		$4,127.23	$7,328.62	$12,873.67
32		$4,271.69	$7,731.70	$13,839.20
33		$4,421.20	$8,156.94	$14,877.14
34		$4,575.94	$8,605.57	$15,992.92
35		$4,736.09	$9,078.88	$17,192.39
36		$4,901.86	$9,578.22	$18,481.82
37		$5,073.42	$10,105.02	$19,867.96
38		$5,250.99	$10,660.79	$21,358.05
39		$5,434.78	$11,247.14	$22,959.91
40		$5,625.00	$11,865.73	$24,681.90
TOTAL	$97,349.65	$124,326.45	$200,870.91	$334,168.00

Table 18 - Tier 4 Projected Energy Cost Savings with Fuel Escalation Rates and 2% Inflation

Year	Additional Mortgage Payment Over Baseline	Low Rate - 1.5%	Moderate Rate - 3.50%	High Rate - 5.5%
1	$4,538.57	$1,996.59	$1,996.59	$1,996.59
2	$4,625.71	$2,066.47	$2,106.40	$2,146.34
3	$4,714.52	$2,138.80	$2,222.26	$2,307.31
4	$4,805.04	$2,213.66	$2,344.48	$2,480.36
5	$4,897.29	$2,291.14	$2,473.43	$2,666.39
6	$4,991.32	$2,371.33	$2,609.47	$2,866.37
7	$5,087.16	$2,454.32	$2,752.99	$3,081.34
8	$5,184.83	$2,540.22	$2,904.40	$3,312.44
9	$5,284.38	$2,629.13	$3,064.14	$3,560.88
10	$5,385.84	$2,721.15	$3,232.67	$3,827.94
11	$5,489.25	$2,816.39	$3,410.47	$4,115.04
12	$5,594.64	$2,914.96	$3,598.04	$4,423.67
13	$5,702.06	$3,016.99	$3,795.94	$4,755.44
14	$5,811.54	$3,122.58	$4,004.71	$5,112.10
15	$5,923.12	$3,231.87	$4,224.97	$5,495.51
16	$6,036.84	$3,344.99	$4,457.35	$5,907.67
17	$6,152.75	$3,462.06	$4,702.50	$6,350.75
18	$6,270.88	$3,583.24	$4,961.14	$6,827.05
19	$6,391.28	$3,708.65	$5,234.00	$7,339.08
20	$6,514.00	$3,838.45	$5,521.87	$7,889.51
21	$6,639.06	$3,972.80	$5,825.57	$8,481.23
22	$6,766.53	$4,111.84	$6,145.98	$9,117.32
23	$6,896.45	$4,255.76	$6,484.01	$9,801.12
24	$7,028.86	$4,404.71	$6,840.63	$10,536.20
25	$7,163.82	$4,558.88	$7,216.86	$11,326.42
26		$4,718.44	$7,613.79	$12,175.90
27		$4,883.58	$8,032.55	$13,089.09
28		$5,054.51	$8,474.34	$14,070.77
29		$5,231.41	$8,940.43	$15,126.08
30		$5,414.51	$9,432.15	$16,260.54
31		$5,604.02	$9,950.92	$17,480.08
32		$5,800.16	$10,498.22	$18,791.08
33		$6,003.17	$11,075.62	$20,200.41
34		$6,213.28	$11,684.78	$21,715.44
35		$6,430.74	$12,327.44	$23,344.10
36		$6,655.82	$13,005.45	$25,094.91
37		$6,888.77	$13,720.75	$26,977.03
38		$7,129.88	$14,475.39	$29,000.30
39		$7,379.43	$15,271.54	$31,175.33
40		$7,637.71	$16,111.47	$33,513.48
TOTAL	$143,895.73	$168,812.43	$272,745.71	$453,738.60