TOWARDS DEVELOPMENT OF A 1980'S GREATER HAMILTON AREA SINGLE DETACHED RESIDENTIAL HOUSING ARCHETYPE: RETROFITTING TO THE PERFORMANCE LEVELS OF NET ZERO ENERGY READY

By

Tyler William Simpson

Bachelor of Technology (Civil Engineering), McMaster University, 2011

Diploma of Architectural Technology, Mohawk College, 2007

A Major Research Project

presented to Ryerson University

in partial fulfillment of the

requirements for the degree of

Master of Building Science

in the program of

Building Science

Toronto, Ontario, Canada, 2021

© Tyler William Simpson, 2021

Author's Declaration

I hereby declare that I am the sole author of this Major Research Project (MRP). This is a true copy of the MRP, including any required final revisions.

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

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

I understand that my MRP may be made electronically available to the public.

Tyler William Simpson

TOWARDS DEVELOPMENT OF A 1980'S GREATER HAMILTON AREA
SINGLE DETACHED RESIDENTIAL HOUSING ARCHETYPE:
RETROFITTING TO THE PERFORMANCE LEVELS OF NET ZERO ENERGY READY

Tyler William Simpson
Master of Building Science, 2021
Ryerson University

Abstract

This research defined attributes of existing residential housing in the Greater Hamilton Area for the development of an archetype model that would represent a two-storey single detached house to investigate the potential of the existing housing stock to achieve Net Zero Energy Ready performance. Energy modelling displayed significant alteration of the building enclosure was required to accomplish Net Zero Energy Ready performance. A hygrothermal analysis of the above grade wall assemblies concluded caution should be applied when implementing a double stud wall assembly and consideration should be given to the permeability of the exterior insulation when a low permeance interior membrane is present. The findings of this research supported the development of the first archetype model to represent the Greater Hamilton Area that identified retrofit strategies that can reduce the energy consumption of the existing single detached housing stock, while acknowledging solutions that ensured durability was preserved.

Acknowledgment

Thank you to the faculty in the Master of Building Science program at Ryerson University. The support I have received has significantly increased my knowledge and confidence in building science and matters related to it. Especially to my supervisor Dr. Russell Richman (Professor and Chair Graduate Department of Building Science, Ryerson University) and the second reader Dr. Mark Gorgolewski (Professor and Chair, Department of Architectural Science, Ryerson University) for their detailed analysis in the development of my major research project. I would also like to an extend a loving thank you to my wife Grace Elizabeth Simpson, as her support with our two young boys has provided the time to allow the completion of my research.

Table of Contents

Abstract.....iii

List of Tables.....ix

List of Figures.....xi

Abbreviations.....xvi

1 INTRODUCTION.....1

1.1 Research Objective and Questions.....3

1.2 Research Methodology.....4

2 LITERATURE REVIEW.....5

2.1 Energy Consumption of 1980's Residential Housing in Ontario, Canada.....5

2.2 Defining an Accurate Archetype Model.....6

2.3 Data Collection for the Development of a Baseline Energy Model.....8

2.4 Calibration Process for an Energy Model.....11

2.5 Limitations of Energy Models Developed in HOT2000 v11.....15

2.5.1 Lack of Scheduling for Lighting, Appliance, and Mechanical System Operation.....15

2.5.2 Limited Selection of Building Materials and Mechanical Equipment.....15

2.5.3 Ground heat loss in Foundations.....15

2.5.4 Inadequate Accuracy due to the Utilization of the Bin Method.....16

2.5.5 Inability to Precisely Model Solar Gains.....16

2.5.6 Predicated Energy Usage Comparing HOT2000 to EnergyPlus and a Measured Model.....17

2.5.7 Effect of HOT2000 Energy Model Inaccuracy on National Building Code Step Development.....18

2.6 Strategies to Reduce Energy Consumption in Existing Residential Houses Through Building Enclosure Retrofits....18

2.6.1 Attic and Roof Retrofits 19

2.6.2 Above Grade Wall Retrofits 20

2.6.3 Below Grade Wall and Slab Retrofits....21

2.6.4 Attributes of Windows for Low Energy Residential Houses 23

2.7 Potential Moisture Issues with Highly Insulated Building Enclosures....24

2.7.1 Dense-Packed Cellulose Roof Assemblies....24

2.7.2 Double-Stud Above Grade Wall Assemblies 26

2.7.3 Failure Mechanisms of Below Grade Wall Assemblies 26

2.8 Mechanical Systems for Net Zero Energy Ready Houses 27

2.8.1 Implementing Mechanical Systems that Achieve Occupant Comfort 28

2.9 Canadian Home Builders Association Net Zero Energy Ready Renovation Pilot Program 32

3 PHASE ONE: FIELD INVESTIGATION FOR DEFINITION OF ARCHTYPE PARAMETERS 34

3.1 Archetype Development Limitations....34

3.2 Data Collection 36

4 PHASE TWO: ARCHETYPE ENERGY MODEL DEVELOPMENT 42

4.1 HOT2000 Input Parameters 42

4.1.1 General House Information 43

4.1.2 Building Enclosure Assemblies....44

4.1.3 Temperatures 48
4.1.4 Occupant Base Loads 48
4.1.5 Natural Air Infiltration 49
4.1.6 Ventilation 50
4.1.7 Heating and Cooling System 50
4.1.8 Domestic Hot Water 51
4.1.9 Baseline Energy Model 51
4.2 Calibrated Baseline Energy Model 54
5 PHASE THREE: APPLICATION OF BUILDING ENCLOSURE AND MECHNICAL SYSTEM RETROFIT STRATEGIES 59
5.1 Calculation of an Energy Budget 59
5.2 Application of Retrofit Strategies 60
5.2.1 Airtightness 62
5.2.2 Building Enclosure: Above Grade Walls 63
5.2.3 Windows 64
5.2.4 Ventilation System 66
5.2.5 Heating and Cooling Mechanical Equipment 67
5.2.6 Domestic Hot Water 69
5.2.7 Increased Insulation Levels: Below Grade Walls, Ceiling, and Basement Slab 71
6 PHASE FOUR: EVALUATION OF COMFORT AND DURABILITY 74
6.1 Assessing the Comfort of the Below Grade Slab 74

6.2 Hygrothermal Modelling: Retrofitted Above Grade Wall Assemblies 75

6.2.1 Normal Operating Conditions 77

6.2.2 Exposure to a Driving Rain Leak 80

7 CONCLUSIONS AND FUTURE WORK 83

7.1 Conclusion 83

7.2 Future Research 87

Appendices 89

A1 Definition of the Plateau neighborhood of East Stoney Creek, a community within the City of Hamilton 89

A2 Window Inspection Data: 1980's Plateau Neighborhood 89

A3 Exterior Door Inspection Data: 1980's Plateau Neighborhood 90

A4 ACH Values for the GHA Archetype Based on the Preconstruction ACH Estimate Equations *(Khemet, 2019)* 90

A5 Collected Utility Bill Data: 1980's Plateau Neighborhood 91

A6 HOT2000 Baseline Energy Model Run 93

A7 Calculations of Weather Normalized Energy Consumption Data: Natural Gas and Electricity ... 114

A8 HOT2000 Calibrated Energy Model Run 116

A9 NRCan Solar Photovoltaic Ready Checklist 137

A10 Composition of Above Grade Wall Assemblies for WUFI Hygrothermal Modelling 139

Reference List 146

List of Tables

Table 1: Fenestration and Door Efficiency Requirements (Canadian Home Builders Association, 2020b).. 33

Table 2: Total and Percentage of Various Housing Types Visually Observed in the Plateau Neighbourhood of East Stoney Creek a Community within the City of Hamilton 35

Table 3: Parameters Selected for Data Collection (Zirnhelt, 2013) 36

Table 4: Common Features of a Single Detached Residential House in the Plateau Neighborhood of East Stoney Creek 37

Table 5: Summary Description of the GHA Archetype vs. Clarington and Toronto, Ontario Archetypes 41

Table 6: Ceiling Measurements for Length of Eave or Base and Area of the Baseline Energy Model in HOT2000 44

Table 7: Calendarized Natural Gas Utility Bill Data of the Baseline Energy Model 51

Table 8: Calendarized Electricity Utility Bill Data of the Baseline Energy Model 52

Table 9: Calibration Parameters of the Baseline Energy Model to the Calendarized Utility Bill Consumption for Natural Gas 56

Table 10: Calibration Parameters of the Baseline Energy Model to the Calendarized Utility Bill Consumption for Electricity 57

Table 11: Final Calibrated Baseline Energy Model Consumption Value vs. Reference Cases 58

Table 12: Reduction in Energy Consumption with Improved Airtightness 63

Table 13: Impact on Energy Consumption When Increasing the Effective Thermal Resistance of the Above Grade Wall Assembly..... 64

Table 14: Impact on Energy Consumption When Decreasing the U-value of the Windows in the Calibrated Baseline Energy Model 65

Table 15: Impact on Energy Consumption with the Integration of a Whole House Ventilation System 66

Table 16: Impact on Energy Consumption with Integration of Air Source Heat Pump..... 68

Table 17: All Electric Heating and Cooling Equipment Pathway 69

Table 18: Impact on Energy Consumption with Integration of an Instantaneous Hot Water Unit..... 70

Table 19: All Electrical Heating and Cooling Equipment with Instantaneous Electric Hot Water Unit 71

Table 20: Impact on Energy Consumption When Increasing the Effective Thermal Resistance of the Below Grade Wall Assembly..... 72

Table 21: Impact on Energy Consumption When Increasing the Effective Thermal Resistance of the Ceiling Assembly 72

Table 22: Impact on the Energy Consumption with the Inclusion of Insulation in the Below Grade Slab ... 73

Table 23: Final Housing Packages to Achieve NZER for a House in the Plateau Neighborhood of East Stoney Creek 85

Table 24: Durability Analysis of the Retrofitted Above Grade Wall Assemblies 87

List of Figures

Figure 1: Sequential Methodology for Research 4

Figure 2: Energy Consumption for Single Detached Housing in Clarington, Ontario (Natural Resources Canada_CanmetENERGY, 2006) 6

Figure 3: Timeline of Graduate Research at Ryerson University into Archetype Model Development for Deep Energy Retrofits of Existing Residential Houses (Vimal, 2021) 6

Figure 4: Overarching Methodology for Multi-Scale Housing Archetype Development (Ali et al., 2019) 7

Figure 5: Energy Audit Checklist (Hubler et al., 2010) 9

Figure 6: Key Features of the CCHT Twin House (Zirnhelt, 2013) 10

Figure 7: Process for Energy Model Calibration (Hubler et al., 2010) 11

Figure 8: Data Source Hierarchy of Reliability for Model Calibration (Raftery et al., 2011) 13

Figure 9: Calibration Process (Zirnhelt, 2013) 14

Figure 10: Statistical Methods to Quantify Error Between Predicted and Measured Energy Use (ASHRAE Guideline 14 – Measurement of Energy, Demand, and Water Savings) 14

Figure 11: Ground Heat Loss Calculation for BASESIMP (Beausoleil-Morrison, 2021) 16

Figure 12: Energy Modelling Comparison of HOT2000 vs. EnergyPlus (Li et al., 2020) 17

Figure 13: Energy Modelling Comparison of Monitored Building to HOT2000 vs. EnergyPlus (Li et al., 2020) 17

Figure 14: TEDI and Qloss Formulas (Foroushani, 2021) 18

Figure 15: Flash and Batt and Exterior Roof Insulation Retrofit Applications (Finch & Hanam, 2013) 20

Figure 16: Above Grade Wall Retrofits: Interior and Exterior Approaches (Finch & Hanam, 2013) 21

Figure 17: Below Grade Wall Retrofits: Interior and Exterior Approaches (Finch & Hanam, 2013) .. 22Figure 18: Floor Slab Retrofit (Finch & Hanam, 2013) 23

Figure 19: High-performance Window Retrofit Installation Procedure (Finch & Hanam, 2013) 24

Figure 20: Example of Common Practice for Dense-Packed Cellulose Roof Insulation (Schumacher & Lepage, 2012) 25

Figure 21: Heating System Runtime Duration Curves (NRCan Local Energy Efficiency Partnerships (LEEP) Team, 2017) 29

Figure 22: CAN/CSA-F280-12 Design Cooling Loads, A/C Sizing Options, and Cooling Airflows with Different Window Selections (NRCan Local Energy Efficiency Partnerships (LEEP) Team, 2017) 30

Figure 23: Minimum Effective Thermal Resistance of Opaque Assemblies (Canadian Home Builders Association, 2020b) 33

Figure 24: Urban Single Detached Development of Houses Constructed in the 1980's in the City of Hamilton (Planning and Economic Development Department GIS Planning and Analysis City of Hamilton, 2020) 36

Figure 25: Representation of a Typical House in the Plateau Neighbourhood of East Stoney Creek a Community in the City of Hamilton 38

Figure 26: Typical Basement Floor Plan of the Archetype Model for the Plateau Neighborhood (Information Collected from Owner) 39

Figure 27: First Floor Plan of the Archetype Model for the Plateau Neighborhood (Information Collected from Owner) 39

Figure 28: Second Floor Plan of the Archetype Model for the Plateau Neighborhood (Information Collected from Owner) 40

Figure 29: General Archetype Information Entered into HOT2000 Baseline Energy Model 43

Figure 30: Ceiling Information in the Development of the Baseline Energy Model in HOT2000 44

Figure 31: Detailed Information of Materials Used in Development of a Above Grade Wall Assembly in the Baseline HOT2000 Energy Model 45

Figure 32: Detailed Information of Window Parameters Defined in HOT2000 for the Development of the Baseline Energy Model 46

Figure 33: Detailed Information of Foundation Parameters Defined in HOT2000 for the Development of the Baseline Energy Model 47

Figure 34: Equations for the Determination of the Preconstruction ACH in Existing Low-Rise Residential Buildings in Canada (Khemet, 2019) 49

Figure 35: Calendarized Utility Bill Data (Natural Gas) vs. Baseline HOT2000 Energy Model 53

Figure 36: Calendarized Utility Bill Data (Electricity) vs Baseline HOT2000 Energy Model 54

Figure 37: Calendarized Utility Bill Data vs. Normalized Calculated Utility Bill Data (Natural Gas) 55

Figure 38: Calendarized Utility Bill Data vs. Normalized Calculated Utility Bill Data (Electricity) 55

Figure 39: Calendarized Utility Bill Data (Natural Gas) vs. Calibrated HOT2000 Baseline Energy Model 57

Figure 40: Calendarized Utility Bill Data (Electricity) vs. Calibrated HOT2000 Baseline Energy Model 58

Figure 41: Passive Strategies First to Achieve NZER 61

Figure 42: Hierarchy for the Steps in the Passive Strategies First Approach to Achieve NZER 61

Figure 43: Percentage Estimated Energy Consumption by Device of Calibrated HOT2000 Baseline Energy Model 62

Figure 44: Percentage of Annual Heat Loss by Building Enclosure Assembly 62

Figure 45: Temperature Analysis to Determine Comfort and Durability of an Uninsulated vs. Insulated Below Grade Slab Assembly 75

Figure 46: Base Case Above Grade Wall Assembly 76

Figure 47: Interior Retrofitted Above Grade Wall Assembly 76

Figure 48: Exterior Retrofitted Above Grade Wall Assembly 77

Figure 49: Normal Operating Conditions: Percentage of Moisture Content for Interior Face of Exterior OSB Sheathing in the Base Case and Interior Retrofitted (Double Stud) Above Grade Wall Assembly (North Orientation) 78

Figure 50: Normal Operating Conditions: Percentage of Moisture Content for Interior Face of Exterior OSB Sheathing in the Base Case and Interior Retrofitted (Double Stud) Above Grade Wall Assembly (South Orientation) 78

Figure 51: Normal Operating Conditions: Percentage of Moisture Content for Interior Face of Exterior OSB Sheathing in the Base Case and Exterior Retrofitted (Foam Board and Mineral Wool Insulation) Above Grade Wall Assembly (North Orientation) 79

Figure 52: Normal Operating Conditions: Percentage of Moisture Content for Interior Face of Exterior OSB Sheathing in the Base Case and Exterior Retrofitted (Foam Board and Mineral Wool Insulation) Above Grade Wall Assembly (South Orientation) 80

Figure 53: Exposure to a Driving Rain Leak: Percentage of Moisture Content of the Interior Face of the Exterior OSB Sheathing in the Base Case and Interior Retrofitted Above Grade Wall Assembly (East Orientation) 81

Figure 54: Exposure to a Driving Rain Leak: Percentage of Moisture Content of the Interior Face of the Exterior OSB Sheathing in the Base Case and Interior Retrofitted Above Grade Wall Assembly (Southeast Orientation) 81

Figure 55: Exposure to a Driving Rain Leak: Percentage of Moisture Content of the Interior Face of the Exterior OSB Sheathing in the Base Case and Interior Retrofitted Above Grade Wall Assembly (East Orientation) 82

Figure 56: Exposure to a Driving Rain Leak: Percentage of Moisture Content of the Interior Face of the Exterior OSB Sheathing in the Base Case and Interior Retrofitted Above Grade Wall Assembly (Southeast Orientation)..... 83

Abbreviations

ACH	Air Change per Hour
CDD	Cooling Degree Day
COP	Coefficient of Performance
CHBA	Canadian Home Builders Association
CVRMSE	Coefficient of Variation for the Root Mean Square Error
DWHR	Drain Water Recovery Unit
ECM	Energy Efficient Motor
EF	Energy Factor
EPS	Expanded Polystyrene Rigid Foam Insulation
ERV	Energy Recovery Ventilator
EUI	Energy Use Intensity
FD	Rain Deposition Factor
FE	Rain Exposure Factor
HDD	Heating Degree Day
HRV	Heat Recovery Ventilator
MRP	Major Research Project
NLA	Normalized Leakage Area
NMBE	Normalized Mean Bias Error
NRCan	Natural Resources Canada
NREL	National Renewable Energy Laboratory
NZER	Net Zero Energy Ready
NZE	Net Zero Energy
O.C.	On-center

OSB	Orientated Strand Board
POLY ISO	Polyisocyanurate Rigid Foam Insulation
PV	Photovoltaic
SHGC	Solar Heat Gain Coefficient
TEDI	Thermal Energy Demand Intensity
XPS	Extruded Polystyrene Rigid Foam Insulation

1 INTRODUCTION

Residential houses have experienced improvements in construction practices driven by building code policies directing lower energy consumption levels and by other municipal, provincial, and government regulations that mandate reduced energy consumption for housing in an attempt to reduce greenhouse gas emissions as a solution to limiting the progression of climate change. The Ontario Provincial Government has stated that by 2030 all new residential houses will achieve the performance level of Net Zero Energy Ready (NZER) (Ontario Provincial Government, 2016). A house that has been constructed to this level of energy performance achieves a yearly actual energy consumption less than or equal to the on-site renewable exported energy. The word ready, identifies to the owner there is an opportunity for the incorporation of renewable technologies at a later date and the cost associated with the renewable technologies has been significantly reduced during the design and construction processes by the integration of a specific airtightness value and a highly insulated building enclosure.

In Ontario, residential houses account for 19% of the total greenhouse gas emissions emitted (Ontario Provincial Government, 2016). With 54.3% of the occupied private dwellings constructed as single detached houses there is a tremendous need to retrofit this building type in order to meet the greenhouse gas emission reduction targets for Ontario (Statistics Canada, 2017). Developing residential houses to the performance level of NZER has been identified as a means to reduce greenhouse gas emissions simply by reducing the net total emissions through energy reductions of the house (Ontario Provincial Government, 2016). Decarbonization can even be taken a step further with the complete elimination of fossil fuels used in the combustion process of heating a house. Electrification offers a fuel source that can truly be 100% carbon neutral. Not only could a NZER house produce all the energy it requires, with electrification the house could have zero emissions as well.

NZER houses aim to provide an optimized and affordable platform to ensure costs associated with renewable energy technologies are kept to a minimum. This is achieved through the design and construction of a super air sealed and insulated building enclosure. The building enclosure is then paired with efficient mechanical systems. This process has proven to be a cost-effective pathway to achieving NZER performance in residential houses in Ontario and right across Canada (Natural Resources Canada, 2019). The single detached residential houses located in the Plateau neighbourhood of East Stoney Creek that this research paper will utilize towards the development of a Greater Hamilton Area (GHA) archetype, feature insulation levels that correlate to the minimum requirements of the 1975 Ontario Building Code

(OBC). Although there were requirements for the thermal performance of the building enclosure these requirements were implemented to ensure deterioration of the house did not occur. The notion of thermal performance to limit the energy consumption of a house or to provide a comfortable environment for the occupants was not a consideration of the 1975 OBC (Blaszak, 2010).

Thus, there is an opportunity for deep energy retrofits to the building enclosure that will lead to significant reductions in energy consumption for the houses in the Plateau neighborhood, which in turn would lessen the production of greenhouse gas emissions. The problem associated with this opportunity lies within what level of modification to the existing building enclosure is required to meet the performance objectives of NZER? This research focused on meeting NZER performance objectives of the Canadian Home Builders Association (CHBA) NZER Renovation Pilot Program. Even if the building enclosure can be altered to meet this program, the owner needs to identify retrofit solutions that do not adversely affect the durability and also maintain a comfortable environment for the occupants.

There is limited published research data that describes the energy consumption characteristics of 1980's single detached residential houses. This leads to the need for selecting a location with similar attributes to that of the study area. The process yields reasonable levels of accuracy that serve as a good starting point for the energy consumption level of an existing single detached residential house. CanmetENERGY, a division of Natural Resources Canada (NRCan), launched the Urban Archetypes Project in 2007, which looked at the energy consumption level of residential houses across various municipalities throughout Canada. The research looked to quantify the energy profile of a community utilizing The Urban Archetypes Project Methodology (Natural Resources Canada_CanmetENERGY, 2006). The methodology allows for a comparative analysis of the energy consumption for a typical housing unit from different neighbours but classified as the same community (Natural Resources Canada_CanmetENERGY, 2006). The available energy consumption data from the project indicates a value of 183GJ/yr for a single detached residential house built in the late 1970's (Natural Resources Canada_CanmetENERGY, 2006).

The development of an archetype model for inclusion in the progression of a baseline energy model has shown to be an accurate way of representing various housing units in a geographical area. The precision of the archetype relies on following a defined set of parameters during development and calibration. Data collection on a house's characteristics is the first step in defining an accurate archetype model. This data can then be segmented into groupings of equivalent houses. Initial energy modelling can then proceed to discover the consumption level of the house in the advancement of a baseline energy model. To further

improve the baseline model, calibration to existing benchmark energy consumption values and utility bill data should occur.

The main question to address during a NZER retrofit is whether to tackle the renovation from the exterior or the interior. Either route will have it challenges and advantages. In either application the building enclosure must achieve a specific level of airtightness and incorporate a certain level of thermal resistance. Insulation levels in the building enclosure should be improved until the remaining energy load of the house can be generated by the selected renewable technology. This implements a strategy that first reduces energy waste in the overall cycle. Approaches to reduce energy consumption of a single detached residential house should be correlated to solutions that improve upon durability and comfort attributes as well. Following this process will encourage participation, leading to increase rates of adoption, and ultimately a larger impact on decreasing greenhouse gas emissions emitted from single detached residential houses.

The objective of this major research project (MRP) is to define the current level of energy consumption for a 1980's single detached two-storey residential house found in the Plateau neighborhood of East Stoney Creek a community within the City of Hamilton, which will represent an archetype for the GHA. The research will be completed through field investigations, collection of utility bill data, and integration of existing research literature to accurately define the archetype model. Energy modelling will be completed using HOT2000 and will define retrofit building enclosure solutions and mechanical systems that allow satisfaction of the CHBA NZER Renovation Pilot Program. Insight will be provided to help guide industry stakeholders towards above grade wall retrofit solutions that offer long lasting durability.

1.1 Research Objective and Questions

The objective of this research was to contribute towards the development of a bottom-up archetype model based on a provincial retrofit strategy by specifically developing a single-family archetype that represented a sub-urban house from the GHA.

In order to accurately address the research objective, the research adopted two questions:

1. What building characteristics can be associated with a 1980's two-storey single detached house that will represent an archetype for the GHA and, on average, how much energy did the existing non-retrofitted house consume in one calendar year?

2. How can the archetype achieve compliance with the CHBA NZER Renovation Pilot Program?

The research data from this MRP will help to inform industry stakeholders on how to properly engage retrofit solutions that reduce the energy consumption of existing single detached residential houses without negativity affecting the durability or comfort. The intention is that this research will lead to more owners implementing retrofit solutions to lower a houses energy consumption, which in turn results in a reduction of the greenhouse gas emissions.

1.2 Research Methodology

To accurately analyze the research questions, a phased structure was implemented. Phase one created an archetype model that characterized a single detached residential house from the Plateau neighborhood of East Stoney Creek that would serve as an archetype model for the GHA. Field investigations were conducted to obtain data that supported development of the model. The formation of a baseline energy model occurred in phase two and the model was calibrated with utility bill data provided by an owner from the Plateau neighborhood. In phase three, retrofit strategies were applied until the energy model had satisfied the objectives of the CHAB NZER Renovation Pilot Program. In phase four, a hygrothermal analysis of the retrofitted above grade wall assemblies was conducted to determine the long-term durability of the various strategies.

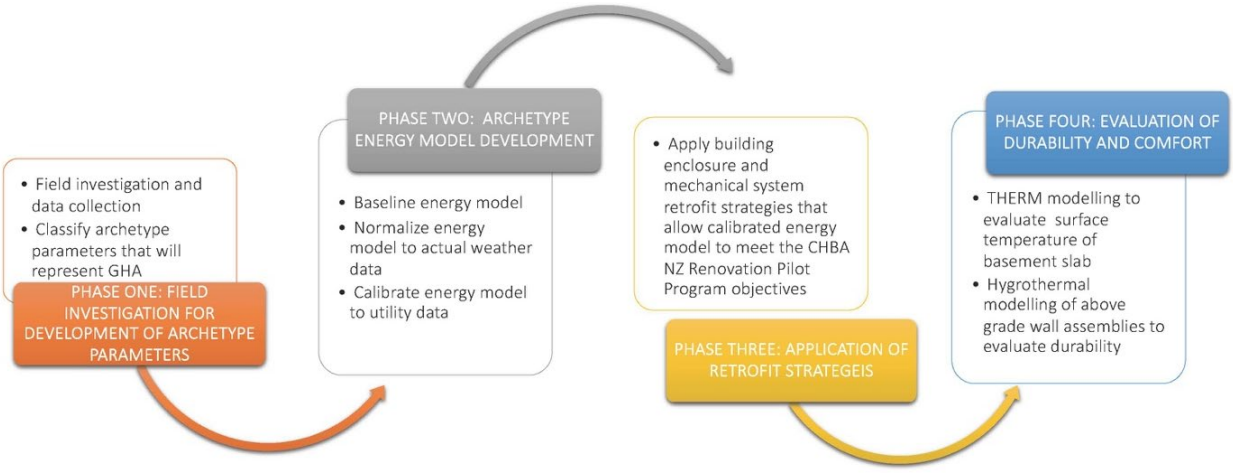


Figure 1: Sequential Methodology for Research

2 LITERATURE REVIEW

One of the purposes of this literature review was to establish an energy consumption value based on building characteristics that represented 1980's single detached residential houses. Research on energy modelling approaches were investigated, with specific parameters incorporated into this research. A summary will be provided that synthesizes retrofit strategies that could be applied to single detached residential houses that decrease the energy consumption. An analysis was conducted from existing literature to define known moisture issues with retrofit strategies for a residential house that had a low energy consumption.

2.1 Energy Consumption of 1980's Residential Housing in Ontario, Canada

In 2007, CanmetENERGY in Ottawa, a division of NRCan, studied 31 neighbourhoods in eight communities to better understand the energy consumption profile of existing residential houses (Natural Resources Canada_CanmetENERGY, 2006). The research looked to develop baseline energy profiles for existing residential houses that could be used in the development of an archetype model to evaluate retrofit strategies. The project used The Urban Archetype Project Methodology, which allowed a comparison of housing units in different neighbourhoods within the same community (Natural Resources Canada_CanmetENERGY, 2006). From the eight communities that were assessed, Clarington, Ontario represented the geographical location with the weather most similar to that of Stoney Creek, Ontario. Selecting a location with a similar weather pattern is critical to ensure alignment in annual heating and cooling loads, which drive the majority of the energy consumption for a house. The report noted, housing in the neighbourhood of Newcastle Village, built between 1961 – 1977, had a yearly energy consumption of 183GJ (Figure 2) (Natural Resources Canada_CanmetENERGY, 2006).

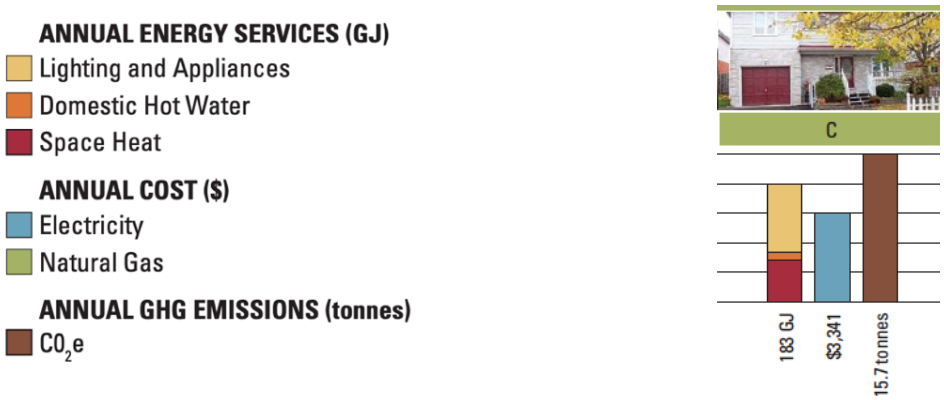


Figure 2: Energy Consumption for Single Detached Housing in Clarington, Ontario (Natural Resources Canada_CanmetENERGY, 2006)

2.2 Defining an Accurate Archetype Model

For approximately the last 10 years graduate students in the department of Building Science at Ryerson University, under the direction of the Program Chair Dr. Russell Richman, have made contributions to the development of archetype models for the advancement of deep energy retrofits in existing residential houses (Figure 3). The graduate students have made strides in developing a single archetype model that allows representation of numerous houses from a neighborhood or community in Toronto, Ontario. These archetype models then underwent an applied analysis of retrofit strategies through energy model simulations to determine what measures are required to meet specific low energy housing standards. The research complied for the GHA archetype represents the first time the methodology has stepped outside of Toronto and is the first step in continuing the archetype model development for the rest of Ontario that will allow existing residential housing to meet low energy standards.

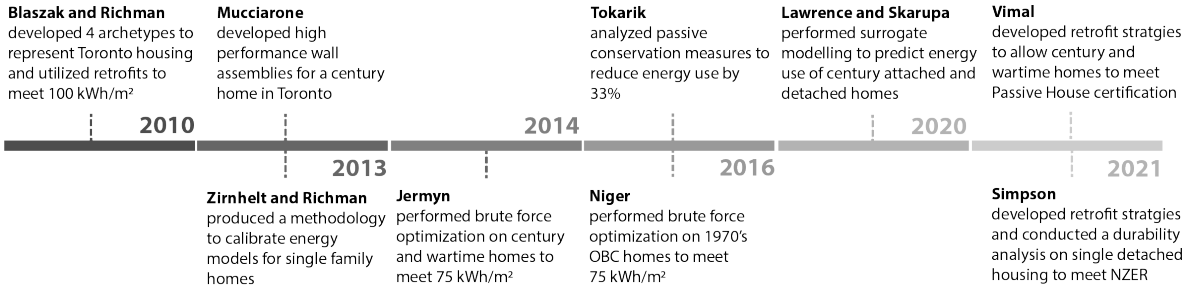


Figure 3: Timeline of Graduate Research at Ryerson University into Archetype Model Development for Deep Energy Retrofits of Existing Residential Houses (Vimal, 2021)

An archetype is defined as a category that uses geometric and non-geometric parameters to identify groups of houses and it is a virtual representation of a number of houses in a specific region that share similar physical attributes. Blaszak and Richman (2013) noted, when creating an archetype model that will represent many houses, the creator must balance accurately representing the housing stock, while exercising caution by not generating too many archetypes. Groupings of houses is extremely useful as it can be tremendously difficult to gather specific data on individual housing units. Due to this, the archetype concept has become exceedingly popular (Ali et al., 2019). This type of category for classifying a housing stock forms a bottoms-up energy model and is known to deliver a high level of accuracy with little computational effort (Ali et al., 2019). It should be acknowledged that the development of an accurate archetype is an involved undertaking. Using assumptions to short cut the development process can led to substantial errors in the final outputted energy model values.

There are two paths for obtainment of information relating to the development of an archetype model (Ali et al., 2019). Census data can be used to gather a sense of conditions locally and nationally and then survey data can be used to fill in specific information gaps, which will allow improved calibration of the final energy model. To help improve the accuracy of an archetype model many industry stakeholders have implemented data driven methods during the development phase (Ali et al., 2019). The data driven methods could include data preprocessing, feature selection, outlier detection, and clustering methods (Ali et al., 2019). In 2019 Ali et al. noted, defining a strategy that paired geometries with data driven methodologies in an attempt to yield archetype models that better represented a collection of houses in a specific region. The process Ali et al. established involves the five following steps (Figure 4).

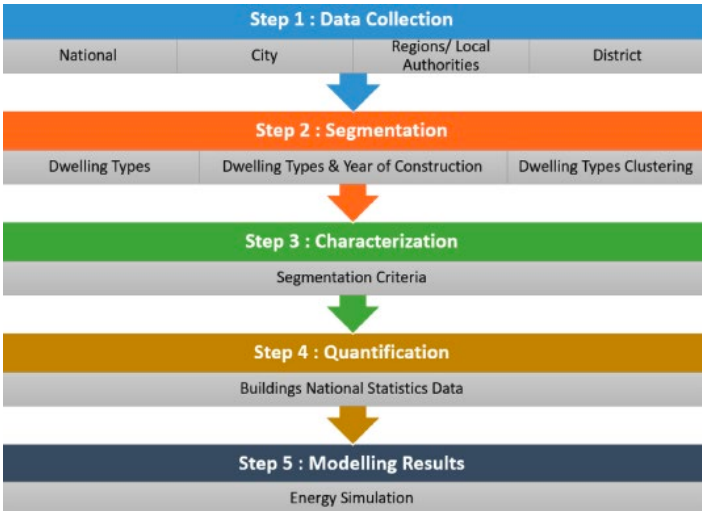


Figure 4: Overarching Methodology for Multi-Scale Housing Archetype Development (Ali et al., 2019)

2.3 Data Collection for the Development of a Baseline Energy Model

Assessment of utility bill data for an existing house is the most logical route for determination of the energy consumption profile (Hubler et al., 2010). To ensure the cultivation of accurate utility bill data and to provide an opportunity to exclude anomalies, at least three years of utility bill data should be collected (Hubler et al., 2010). Once the utility bill data is obtained the results should be adjusted to match the monthly outputs from the meter (Hubler et al., 2010). This is a simple task completed by multiplying the weighted daily average energy use by the number of days per month, known as calendar normalization (Hubler et al., 2010). To further check the precision of the energy model it is useful to benchmark the consumption data against published research data (Hubler et al., 2010). Research should be conducted to review existing studies to gather comparable data that will help to check the reasonableness of the baseline energy model. Hubler et al. (2010), noted that the information provided by the International Performance Measurement and Verification Protocol (IPMVP) (US DOE 2002) and ASHRAE Procedures for Commercial Building Energy Audits for a pre-audit checklist are too vague. In their opinion it resulted in critical data being missed in the calibration process of an energy model (Hubler et al., 2010). To overcome this challenge, an extensive energy audit checklist was developed to ensure vital data was captured (Figure 5) (Hubler et al., 2010).

Site and Building Information	**Notes**
Description of site & location	Note orientation, nearby bodies of water, shading, roadways, etc.
Building Type and Age (yrs)	
Total square footage (ft^2)	
Floor to floor height	Note plenum height & number of stories
Owner/leasing structure	
Occupancy and Zoning Information	**Notes**
Occupancy schedule by zone	Weekdays vs. weekends, seasonal changes?
Diagram of thermal zoning	Mark thermostat (Tstat) locations
Occupant density by zone	Note full time employees vs. transient
Thermostat setpoints by zone	Off-hours setback? Programmable?
Other setpoints	e.g. relative humidity setpoints
Building Envelope	**Notes**
Wall/Roof/Ceiling R values	Need IR camera or thermostat
Window U-value	Note if this includes framing
SHGC and visual transmittance	
Window area (ft^2) per facade	Note any shading devices
Note infiltration controls	e.g. weather-stripping at doorways
Blower door test results	
Wall and roof solar reflectance	
Lighting	**Notes**
Interior and exterior lighting inventory	Note lamp & ballast types, wattage and quantities
Illuminance and luminance measurements by zone	
Lighting power density (LPD)	
Description of interior and exterior lighting controls	Note location of occupancy sensors
Description of daylight access	Evaluate potential for daylight
Surface reflectance values	

Miscellaneous Equipment	Notes
Description of misc. loads	Plug/process loads, appliances, etc.
Equipment power density (EPD)	Useful to have watt-meter
Description of controls	
HVAC Equipment	**Notes**
Description/Type	Note server rooms & associated systems
Age (yrs)	
Capacity (Btu/hr, cfm)	
Operation schedules	
Efficiency	
Rated fan power	Note motor efficiency & fan operation
Fraction of outside air (OA)	Note OA controls (e.g. economizer, demand control ventilation, etc)
Supply air temp (°F)	Reset schedules?
Equipment model numbers	
Domestic hot water information	Efficiency, insulation, tank size, etc.
Control and Maintenance	**Notes**
Building automated controls?	Obtain points list & control sequences
Maintenance and operating logs	Schedules and contractor contact info

Figure 5: Energy Audit Checklist (Hubler et al., 2010)

Weather data plays an important role in aligning the energy consumption of the model with the actual energy consumption of the house (Hubler et al., 2010). The objective is to replace as much of the Typical Meteorological Year (TMY) weather data with actual known values during the time period that correlates to the know energy consumption measurement. This data is referred to as the Actual Meteorological Year (AMY) (Matutinovic, 2014).

Questionnaires and surveys help to define the energy usage of parameters within the house that connect to the occupant influenced energy demand. It has been well established that occupant behaviour can have an amplified effect on the energy consumption of a residential house (Ben & Steemers, 2020). To account for this effect, Ben and Steemers (2020), suggest the implementation of five classifications of categories for archetypes to improve alignment with occupant behaviour. The categories noted included active spender, conscious occupier, average user, conserver, and inactive user (Ben & Steemers, 2020). These groupings also help to define what retrofit measures an occupant is likely to undertake (Ben & Steemers, 2020).

In the thesis, Using Calibrated Simulation to Quantify the Energy Savings from Residential Passive Solar Design in Canada, the author detailed the steps to create a calibrated energy model. The reference house used for the research was the Canadian Centre for Housing Technology (CCHT) and information on the architecture of the two houses is available through NRCan. The architectural features of the house helped to define an accurate energy model that correlated well to the actual energy usage. The key parameters identified by Zirnhelt (2013) for the calibrated energy model are noted in Figure 6.

Feature	Value
Floor Area (Living Space)	208 m^2
Total Window Area	35 m^2
South Facing Window Area	16.2 m^2
Window Type	double glazed, low-e, argon filled, insulated spacer
Window Properties	SHGC = 0.52[a], U = 1.76 W/m^2K
Attic R Insulation R Value	8.08 m^2K/W[b]
Above Grade Wall Insulation R Value	2.61 m^2K/W – walls without windows 2.36 m^2K/W – walls with windows
Basement Interior Insulation R Value	1.75 m^2K/W
Basement Slab	75 mm concrete, un-insulated
Air tightness rating (at 50 Pa)	1.5 ACH
Gas Furnace Efficiency	80.2%
Heat Recovery Ventilator Efficiency	84%
Internal Gains	19.35 kWh/day

[a] Overall window properties, including frame

[b] R values include thermal bridging

Figure 6: Key Features of the CCHT Twin House (Zirnhelt, 2013)

In 2014 Jermyn adopted the data collection methods of Zirnhelt (2013) when he analysed Toronto's urban single-family housing stock for deep energy retrofits. The data that was used to develop the archetypes was obtained from Blaszak and Richman (2013) and the recruitment of homeowners to participate in a questionnaire survey to provide supplementary data occurred (Denver, 2014). Homeowners were also asked to provide entry inside, as well as, access to the exterior to permit the development of detailed measurements outlining the houses geometry (Denver, 2014). The recruitment of participates focused on colleague referrals which prevented the obtainment of a truly random sampling (Denver, 2014). There was effort applied to try and obtain equal sampling from each neighborhood and identified archetype, however, the researcher was not able to complete this objective. Although the objective was not met, the research did conclude clear patterns of repetition throughout the data sets that permitted the definition of typical housing sizes and shapes (Denver, 2014). In total the Toronto neighborhoods represented 11310 houses, of which, 2557 (23%) were analysed in the research (Denver, 2014). In the creation of the baseline energy models only archetypal houses were considered, while the remaining archetypes were classified as outliers and removed from the research (Denver, 2014).

2.4 Calibration Process for an Energy Model

Literature on the calibration process of a single detached residential house is limited, however, to ensure consistency in the results of energy modelling for housing a standardized approach should be implemented. The method should touch on a process for gathering data, as well as, how to calibrate the energy model prior to the implementation of retrofit solutions. Hubler et al. (2010), developed a simple step-by-step approach for gathering data and calibration of an energy model. Their method provided a reasonable level of accuracy when compared to actual utility bill data. The principle objective for energy model calibration is to apply professional judgment to align the model to the actual energy usage of a known house or what is reasonably known about the house. It is a task that requires careful attention to detail and adjustment of collected data. A procedural summary has been developed by Hubler et al. (2010), that serves as a guideline for the calibration process (Figure 7). The precision of the baseline energy model solely depends on the quality of data inputs with steps taken to ensure accuracy in the pre-audit tasks (Hubler et al., 2010). It is suggested that calibration starts prior to the development of the energy model as pre-audit data can be organized into three categories; firmly defined parameters, partially understood, and unknowns (Hubler et al., 2010) . Research studies should be consulted to help identify values for the partially understood and unknown parameters



Figure 7: Process for Energy Model Calibration (Hubler et al., 2010)

Once all the parameters can be supported with accurate data then an initial energy model can be simulated. The initial model should be checked against benchmark data to ensure the model is behaving similar to other houses that have equivalent attributes (Hubler et al., 2010). This review will aid in identifying any major errors in the initial energy model. The next step is to calibrate individual energy loads with utility bill or benchmark data. Hubler et al. (2010) suggest looking for periods of time when an individual load is the only load being consumed. In the fall and spring season often heating and cooling equipment is not in use and this offers an opportunity to calibrate energy connected with internal loads and ventilation (Hubler et al., 2010). Next, heating and cooling loads should be calibrated by adjustment of the building enclosure parameters. Minor adjustments of the building enclosure parameters should be attempted to fine tune the

alignment of the energy model with the actual utility bill data. Graphical representation of the energy model output versus the actual energy consumption of the house permits simple identification to ensure monthly consumption values are aligned (Hubler et al., 2010).

Tokarik (2015), focused his energy model calibration efforts on methodical evidence-based practises rather than trial and error procedures. The methods integrated into Tokarik research were developed by researchers Yoon, Lee, and Claridge, 2003 and Raftery, Keane, and O'Donnell, 2011. In the research by Yoon et al, (2003) the research group developed an analytical approach formatted around the base load of the energy model. The data was sourced from sub-meter readings, as well as, monthly utility bills (Yoon et al., 2003). The research groups calibration process can be defined in the following steps (Tokarik, 2015):

1. Formation of the baseline energy model.
2. Compare the energy model base load to the sub-metered data and utility bills. In the research study the base load was defined without the inclusion of heating and cooling energy independent of weather. The function of this step is to confirm any internal gains.
3. Begin calibration of the baseline energy model to the spring and fall seasons (shoulder). This is similar to the step noted by Hubler et. al. (2010), as the building typically operates in the spring and fall seasons without the influence of the heating or cooling system.
4. Conduct interviews with the building owner to confirm schedules that influence the occupant load.
5. Calibrate the energy model to account for the heating and cooling seasons (winter and summer). In this process attention should be applied to the mechanical systems and the controls of these systems.
6. To confirm the calibration of the energy model conduct percentage error calculations referenced by ASHRAE.

Raftery et al (2011) felt decisions in the calibration process must be methodical and based on measurable evidence. When adjustments were applied to the energy model the new information must be more accurate than the data it is replacing. The formula developed by the research group implements a reliability and accuracy that obtains enhanced alignment with the actual built building. The hierarchy for their energy model calibration process has been noted in Figure 8.

Hierarchy	Source Type
1	Logged measured data
2	Spot measured data
3	Surveys and physical verification
4	Interviews
5	Material data-sheets
6	Operation and maintenance manuals
7	As-built documentation
8	Benchmark of best practice models
9	Standards and guidelines
10	Initial model

Figure 8: Data Source Hierarchy of Reliability for Model Calibration (Raftery et al., 2011)

In the calibration process undertook by Zirnhelt (2013) (Figure 9), the focus of agreement between the simulated and measured energy consumption was not only sought after on an annual basis, however, a deeper dive was evaluated that looked for agreement on a daily basis. Furthermore, Zirnhelt took advantage of all known model input parameters and matched energy consumption parameters wherever it was possible (Zirnhelt, 2013). In the calibration process a parameter was defined as significant when it had a sizable impact on the heating energy consumption and was firmly known, or there was the ability to measure the parameter, or data was available from a literature review (Zirnhelt, 2013). Throughout the calibration process Zirnhelt (2013) placed a focus on systematically identifying and fixing minor errors that had a major impact on the heating energy consumption of the energy model to ensure its accuracy. Parameters that were defined as uncertain were left to the end of the calibration process where they could be manipulated to help fix minor errors in the energy model (Zirnhelt, 2013).

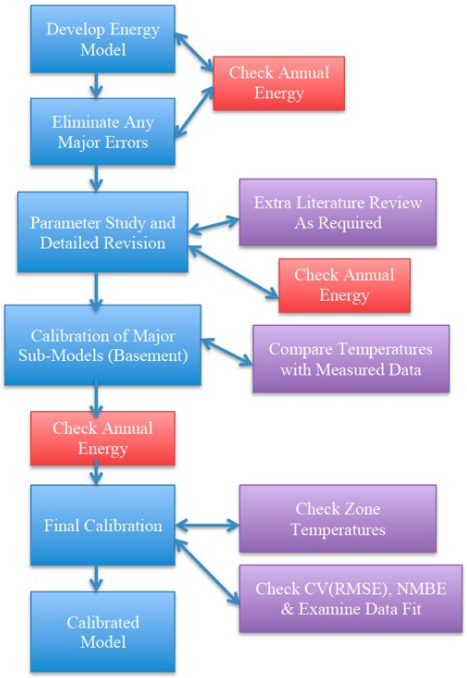


Figure 9: Calibration Process (Zirnhelt, 2013)

Acceptable levels of model error to actual data values are outlined in ASHRAE Guideline 14 – Measurement of Energy, Demand, and Water Savings. The guideline allows an error value of +/-5% for monthly data and +/-10 for hourly data for the normalized mean bias error (NMBE) calculation, while the coefficient of variation for the root mean square error (CVRMSE) method has a higher tolerance for error of +/-15% (monthly) and +/-30% (hourly) (Figure 10). In order for an energy model to be declared calibrated the percentage errors must be less than what has been noted in ASHRAE Guideline 14. However, there is no guidance in the ASHRAE Guideline when calibrating with daily values (Zirnhelt, 2013). In his thesis, Zirnhelt, implemented an average of the monthly and the hourly values to define the percent error acceptable values when daily values were utilized (Zirnhelt, 2013). This lead to the development of 22.5% for the CVRSME calculation and 7.5% for the NMBE calculation (Zirnhelt, 2013).

$$CVRMSE = 100 * \frac{\sqrt{\frac{\sum(y_i - \hat{y}_i)^2}{n-1}}}{\bar{y}} \quad (1)$$

$$NMBE = 100 * \frac{\sum(y_i - \hat{y}_i)}{(n-p) * \bar{y}} \quad (2)$$

y = measured value
$\hat{y}$ = model predicted value
$\bar{y}$ = mean value of the measured data

n = number of samples
p = P-value; for this purpose p = 1

Figure 10: Statistical Methods to Quantify Error Between Predicted and Measured Energy Use (ASHRAE Guideline 14 – Measurement of Energy, Demand, and Water Savings)

2.5 Limitations of Energy Models Developed in HOT2000 v11

HOT2000 is an energy modelling simulation tool that is widely used across Canada for various low energy houses and has been specifically designed for low-rise residential construction. The software was developed by NRCan to support housing programs that allow the expansion of more energy efficient houses. In the calculation of energy consumption, the software uses a steady-state model coupled with monthly mean weather data. Although the program is used extensively, there are limitations to the accuracy in the energy analysis performed by HOT2000 based on how the program was assembled. The following paragraphs describe the limitations associated with energy models developed with HOT2000.

2.5.1 Lack of Scheduling for Lighting, Appliance, and Mechanical System Operation

Within the HOT2000 software there is no user-defined option available to create a lighting, appliance, or mechanical schedule that reflects how and when these loads are used in the house by the occupants (Toronto and Region Conservation and Ryerson University, 2011). Instead, the program defaults to a year-round value or a specific setpoint to represent these loads. More advanced simulation programs allow a complete development of a schedule for lighting, appliances, and mechanical system operation. This allows the energy model to be tailored to how the occupants actually used the house.

2.5.2 Limited Selection of Building Materials and Mechanical Equipment

HOT2000 has seen limited updates in the programs ability to simulate new and advanced building materials or mechanical equipment. This can lead to discrepancies between the energy model and actual built house. The lack of updates in HOT2000 could limit the use and ultimate adoption of innovation building materials and mechanical equipment. More complex energy simulation software provides a larger range of selection or permits the user to create a custom file to represent a specific building material or mechanical system.

2.5.3 Ground heat loss in Foundations

Heat loss through a foundation is a complex calculation that is often poorly represented in energy modelling programs. This causes an inaccurate definition of the energy consumption as the foundation can significantly contribute to the heating requirements of a house. HOT2000 utilizes a regression-based algorithm for the calculation of heat loss through the foundation called BASESIMP. This new algorithm that has been incorporated into HOT2000 was extensively tested and validated against the Mitalas method. The BASESIMP algorithm does not solve energy balances for soil within the program, rather, it relies on the

detailed calculations that are found outside of the program. A finite-element-based program known as BASECALC was utilized to calculate 33,000 simulations of heat loss through a foundation, which represents the data base that BASESIMP references in its calculations (Beausoleil-Morrison, Ian; Mitalas, 1997). The 33,000 results are then regressed using algebra or a statistical method (Beausoleil-Morrison, 2021). The regressions can then be input into the equation noted in Figure 11 to quickly calculate ground heat loss through a foundation. It is important to indicate these methods and this process ignores ground temperature fluctuations that are related to solar radiation, convection, and long wave radiation (Beausoleil-Morrison, 2021). Further, the method does not factor in the effect of indoor temperature on ground heat loss in a foundation as the method utilizes a steady-state linear regression analysis.

$$q_{e \rightarrow grd} = \mathcal{A} + \mathcal{B} \cdot \sin(\omega t - \mathcal{C})$$

Figure 11: Ground Heat Loss Calculation for BASESIMP (Beausoleil-Morrison, 2021)

2.5.4 Inadequate Accuracy due to the Utilization of the Bin Method

HOT2000 utilizes a simplistic method to approximate a houses annual energy consumption based on the bin method. For example, the program provides weather data for the selected location in temperature allotments known as bins (Hanam, 2010). The number of hours associated with each bin is noted as an occurrence and the program assumes the house utilizes the exact same energy consumption for each outdoor bin temperature. This then translates into an energy load profile being developed for each bin that allows the determination of the house's energy consumption. One of the main issues related to the use of the bin method for weather data is the lack of accountment for the performance variation in mechanical equipment that is directly dependent on changes in weather. As opposed to performing the calculation based on the centerline value for each bin, it would be more accurate to take the mean value of the bin. The rational for the use of the bin method in HOT2000 at the time of its development were related to the high cost of computer processing speed and the related amount of storage required when performing the calculations (Hanam, 2010).

2.5.5 Inability to Precisely Model Solar Gains

The HOT2000 software has been built upon a steady-state monthly heat balance that does not allow accurate modelling of solar gains (Kisilewicz, 2007). The absorption, storage and eventual release of solar

radiation is not accurately captured in the bin method format. This can be especially critical for houses that feature high levels of insulation with an increased thermal mass (Kisilewicz, 2007). More advanced energy simulations tools provide an improved representation of solar gains, which can offset significantly the heating load for the house when the principles of solar gain have been implemented.

2.5.6 Predicated Energy Usage Comparing HOT2000 to EnergyPlus and a Measured Model

Li et al (2020) compared the results of a HOT2000 energy model versus an EnergyPlus energy model (Figure 12). In their research it was observed when modelling with EnergyPlus, 0.8% less total energy consumption occurred in the model compared to HOT2000 (Li et al., 2020). The EnergyPlus model had a substantially higher space heating consumption value of 9750kWh and for space cooling and mechanical ventilation utilized 51.8% more energy than HOT2000 (Li et al., 2020). In the research the definition of "other" energy consumped was defined as, inclusions of all other energy usage, with the exception of space heating and cooling (Li et al., 2020). In this category EnergyPlus predicted 34.9% less than the HOT2000 energy model (Li et al., 2020). When the research adjusted the comparison to a monitored building, EnergyPlus had a slightly higher space heating and cooling energy consumption (4.8%) to the monitored building, while the HOT2000 model was substantially less at 21.3% (Figure 13) (Li et al., 2020). HOT2000 dramatically over predicated "other" energy consumption compared to the monitored building at 46.4%, while EnergyPlus slightly over predicated at 10% (Li et al., 2020).

	Energy consumption (in kWh)				
Comparison	Space heating	Space cooling	HRV and fans	Other	Total
HOT2000	7,322	0	880	9,484	17,686
EnergyPlus	9,750	275	1,336	6,175	17,536
Difference (kWh)	2,428	275	456	−3,309	−150
Difference (%)	33.2	–	51.8	−34.9	−0.8

Figure 12: Energy Modelling Comparison of HOT2000 vs. EnergyPlus (Li et al., 2020)

	Space heating and cooling		Energy consumption Other		Total	
Data source	kWh	Compared with monitored (%)	kWh	Compared with monitored (%)	kWh	Compared with monitored (%)
Monitored	9,300	–	7,081	–	16,381	–
EnergyPlus	9,750	4.8	7,786	10.0	17,536	7.1%
HOT2000	7,322	−21.3	10,364	46.4	17,686	8.0%

Figure 13: Energy Modelling Comparison of Monitored Building to HOT2000 vs. EnergyPlus (Li et al., 2020)

2.5.7 Effect of HOT2000 Energy Model Inaccuracy on National Building Code Step Development

With the uncertainty in energy consumption data noted when modelling with HOT2000, the question was raised, how could this impact the development of the Step Code in the National Building Code? Given that HOT2000 is based upon the bin method, the heat loss calculation can be written as noted in Figure 14. Foroushani (2021) noted, if the uncertainly around weather data and air properties could be ignored than heat loss is mainly driven by U_j (total transmission coefficient), A_j (surface areas of building envelope components), and V (volumetric rate of air leakage). When performing a Thermal Energy Demand Intensity (TEDI) calculation (Figure 14) a 95% confidence in uncertainty correlates to 3.0kWh/m^2/yr for the high-uncertainty scenario and 1.2kWh/m^2/yr for the low-uncertainty scenario (Foroushani, 2021). Generating a model in HOT2000 assuming the same level of uncertainty means the reference energy model can be as inaccurate as 4.2kWh/m^2/yr on the high-certainty scenario and 1.7kWh/m^2/yr for the low-uncertainty scenario (Foroushani, 2021). In percentage terms this translates to 6.9% and 2.8% in the energy consumption of the reference house TEDI value (Foroushani, 2021). The results of the research displayed that the difference in the TEDI value can be as high as step number three (10%) of the Step Code and on average the TEDI differential calculations that utilized HOT2000 software have uncertainties that are equivalent in performance to that of step two (5%) in the code (Foroushani, 2021).

$$\mathrm{TEDI} = \frac{Q_{\mathrm{aux}}}{A} \qquad \left[\frac{\mathrm{kWh}}{\mathrm{m^2yr}}\right]$$

$$Q_{\mathrm{loss}} = \sum_i N_i \left[\sum_j U_j A_j + \rho C_p \dot{V}\right] \left(T - T_{\mathrm{o},i}\right)^+$$

Figure 14: TEDI and Qloss Formulas (Foroushani, 2021)

2.6 Strategies to Reduce Energy Consumption in Existing Residential Houses Through Building Enclosure Retrofits

Building and energy codes are mandating higher levels of energy efficiency for new residential construction. To date, these codes have not enforced requirements for existing residential houses. However, that could change in the coming years as it is critical existing buildings move towards a performance goal that reduces energy consumption in an effort to mitigate the progression of climate change (Ontario Provincial Government, 2016). According to Finch and Hanam (2013), a highly insulated and airtight building enclosure is required to achieve NZER performance and that the building enclosure should reduce the

heating and cooling load of the house to an optimal level where it then makes financial sense to engage renewable technologies to handle the remaining energy load. It was also noted, that the building enclosure is but one element and that an entire building approach is necessary to achieve the classification of NZER.

2.6.1 Attic and Roof Retrofits

The main objectives when retrofitting a building enclosure assembly with an aim to decrease the total energy consumption of the house, is to reduce the heat loss or gain across the assembly and ensure the improvement has not negatively affected the durability. This can be achieved with the addition of thermal resistance to the assembly and ensuring material selection and construction practises are able to address and handle moisture loads.

The most common approach to improving the attic space (ceiling separating conditioned space from unconditioned space) is to simply top up the insulation to the desired thermal resistance. This approach misses critical airtightness measures that should be implemented prior to the inclusion of addition thermal resistance. Attention to detail should be applied to any ceiling penetration to allow the formation of a continuous air barrier (Finch & Hanam, 2013). Due to the complexities of maintaining a continuous air seal across an existing ceiling, a flash and batt system is an effective retrofit strategy. In this application approximately 50mm of two lbs spray foam is applied to the entire ceiling surface. This forms a continuous air control layer in addition to providing thermal resistance (Finch & Hanam, 2013). The remaining thermal resistance can be achieved with lower cost cellulose or mineral fibre insulation (Finch & Hanam, 2013). Figure 15 provides an overview of the flash and batt system.

There is also the option to conduct an exterior retrofit of the roof assembly. In this application, thermal resistance would be moved from the ceiling separating conditioned from unconditioned space and applied on top of the roof sheathing to achieve the desired level of thermal resistance. Figure 15 indicates the various components in this retrofit strategy. The exterior retrofit strategy makes most sense for a cathedral or vaulted ceiling.

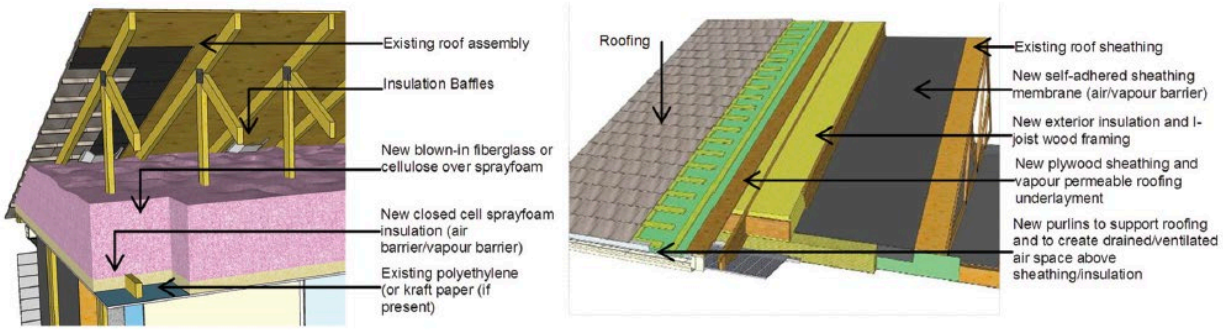


Figure 15: Flash and Batt and Exterior Roof Insulation Retrofit Applications (Finch & Hanam, 2013)

2.6.2 Above Grade Wall Retrofits

The first decision for an above grade wall is to either implement an exterior or interior retrofit. If cladding or window replacement is occurring or the owner wants to remain at the residence during the retrofit, then incorporating additional levels of insulation on the exterior of the building enclosure is a viable option (Finch & Hanam, 2013). In this approach board insulation would be applied on top of the existing exterior sheathing once the existing cladding has been removed. Examples of board insulation include extruded polystyrene (XPS), expanded polystyrene (EPS), polyisocyanurate (POLY ISO), and semi-rigid mineral fibre insulation. Depending on the material properties of the board insulation it could be possible to detail the insulation as the primary water and air control layer. In applications where that approach is not possible, a sheet membrane will need to be installed in front or behind the insulation board. Establishment of these critical control layers will ensure a houses energy consumption is reduce, while maintaining the durability of a highly insulated assembly.

For an interior retrofit approach, there will be a significant disruption to the interior environment and therefore, it is not possible for the owners to remain (Finch & Hanam, 2013). An interior retrofit would be desirable when the removal of the exterior cladding is not possible (I.e. historical reasons) or the condition of the cladding is still deemed acceptable (Finch & Hanam, 2013). As the existing 38x89mm or 38x140mm wall stud cavity can only accept a certain maximum amount of thermal resistance dependant on its depth, an extra wall is often built-in front of the structural wall. The assembly formed is referred to as a double stud wall and the purpose of the second wall is to hold additional thermal resistance that will increase the overall value of the above grade wall assembly. A layer of continuous installation can be placed between the double stud wall to limit the depth of the additional stud wall or to simply further enhance the thermal resistance (Loomis & Pettit, 2015). Commonly, glass fibre, mineral wool, cellulose, or spray foam insulation

are utilized during an interior retrofit. Figure 16 provides an example for an interior and an exterior retrofit for an above grade wall assembly that would measurably reduce the energy consumption of a residential house.

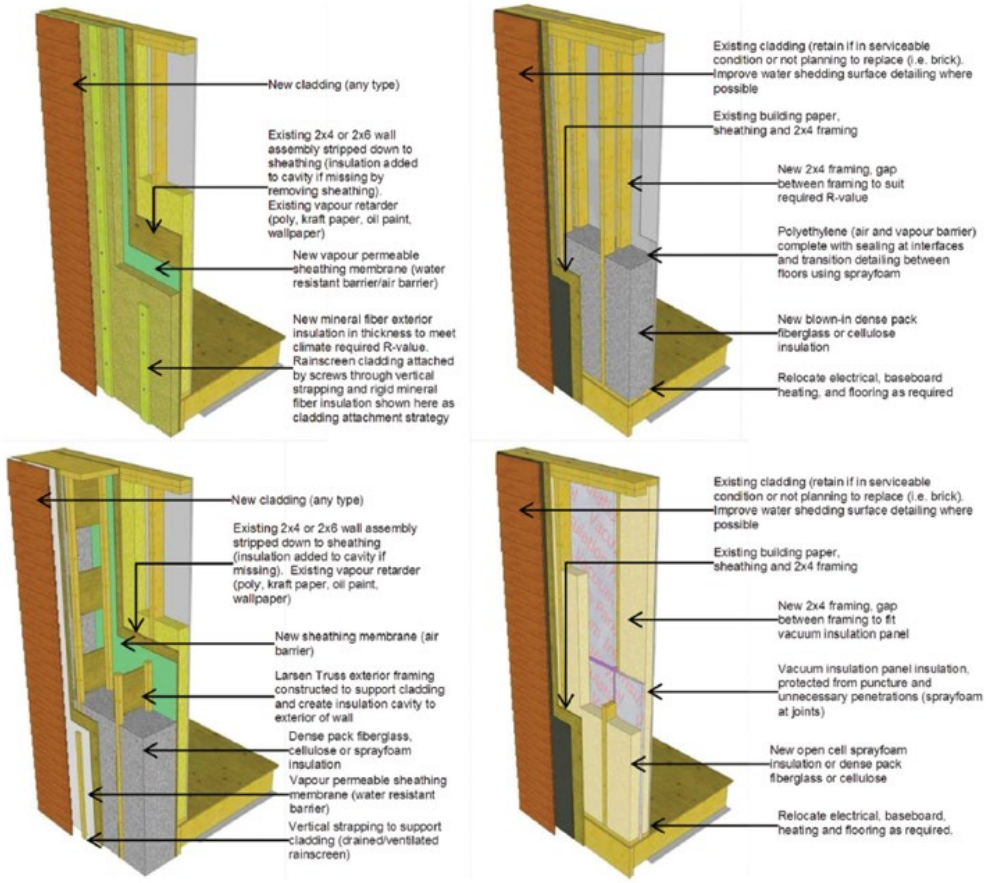


Figure 16: Above Grade Wall Retrofits: Interior and Exterior Approaches (Finch & Hanam, 2013)

2.6.3 Below Grade Wall and Slab Retrofits

Similar to the above grade wall, the first decision for improvement to a below grade wall is either alteration from the exterior or the interior. Often exterior retrofits are not engaged as the additional insulation may extend past the existing cladding, which may present an aesthetic appearance that is not pleasing to the owner. It also results in the requirement for a flashing detail that would start behind the existing cladding and extend overtop and down the new insulation. That detail presents a challenge if the existing cladding will not be altered. The insulation that is exposed above grade must be covered as it cannot be left unprotected. There is also the cost of excavation to consider when retrofitting a below grade wall from the exterior. These specific exterior retrofit challenges often push a project towards implementing an interior

retrofit. Interior retrofits of below grade walls are much simpler, however, interior living space will be consumed (Finch & Hanam, 2013). The best practice for an interior retrofit involves a layer of continuous insulation directly against the below grade wall with a studded wall in front filled with insulation. In either retrofit approach it is critical to ensure a continuous air control layer has been implemented (Finch & Hanam, 2013). Reducing air leakage will benefit in a decline of the buildings energy consumption, improve the durability of the assembly, as well as, the comfort within the space for the occupants. Figure 17 provides guidance on an interior and exterior retrofit strategy.

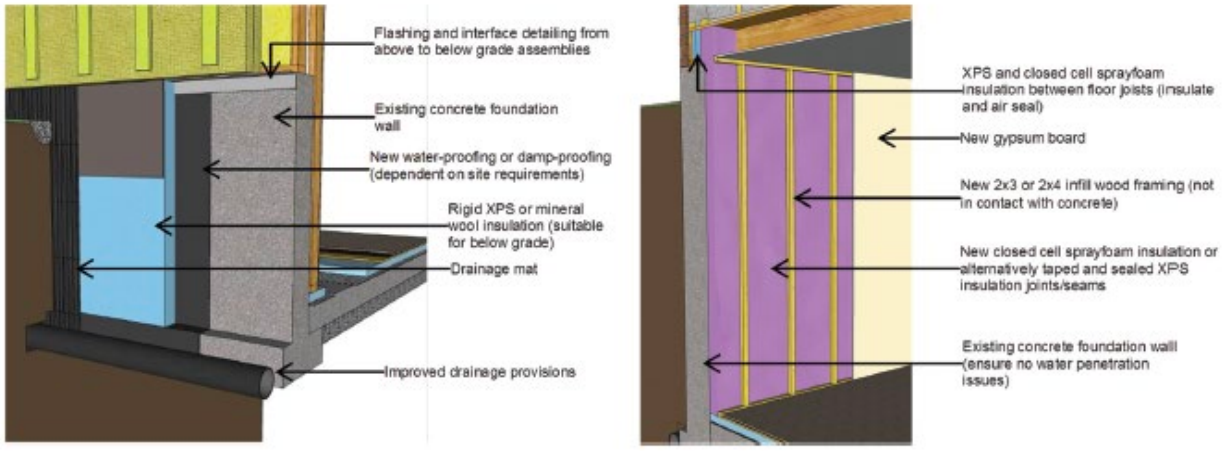


Figure 17: Below Grade Wall Retrofits: Interior and Exterior Approaches (Finch & Hanam, 2013)

Heat loss moves from areas that are warm to areas that are cold (Straube & Burnett, 2005). Leaving the slab uninsulated may limit the reduction in energy consumption of a highly insulated below grade wall assembly can offer as a thermal bridge will be present at the wall to slab connection. If there is enough height from the top of the floor slab to the underside of the floor joists (or finished ceiling) board insulation can simply be placed on top of the existing floor slab. Sealing of the board insulation should occur to form a continuous air control layer that then should be connected to the below grade wall assemblies air control layer. Figure 18 details an interior retrofit approach for an existing slab. Finch and Hanam (2013) caution, in this application any interior load bearing partition walls will experience colder temperatures. They suggest the bottom plate be replaced with pressure treated lumber for structural walls or raise the bottom plate to sit on top of the board insulation for non-structural walls (Finch & Hanam, 2013). Insulation could be placed under the slab; however, the existing slab would have to be removed and excavation of soil would need to occur. Unless the basement height is being increased or structural work is being implemented, this route may be cost prohibitive (Finch & Hanam, 2013).

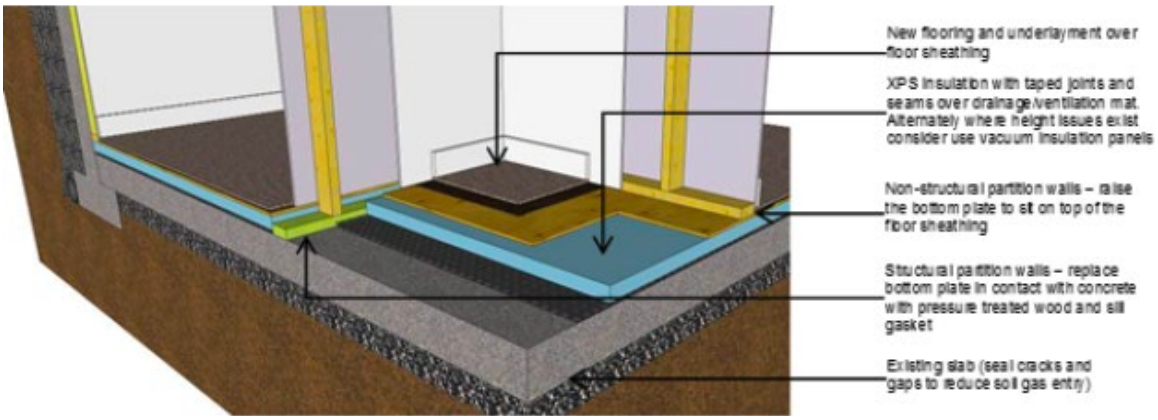


Figure 18: Floor Slab Retrofit (Finch & Hanam, 2013)

2.6.4 Attributes of Windows for Low Energy Residential Houses

For windows to meet the standards of a high-performance energy retrofit a few parameters should be met. First, the heat loss properties should be improved, which can be achieved with the inclusion of a third pane of glass. A triple glazed window features additional technologies that further improve the windows U-value such as low-e coatings, gas fills between the panes, and low conductivity edge spaces and frames, (Finch & Hanam, 2013). Windows manufactured to this specification can achieve a U-value as low as 0.17, which offers an opportunity for significant energy savings (Finch & Hanam, 2013). Next, measures should be taken to ensure the transfer of the water and air seal of the window to the above grade wall assembly or below grade wall assembly is achieved. It is also critical that a continuous pathway around the window is provided to allow water to drain out to ensure long term durability. This objective can often be compromised if spray foam insulation is used to fill around the entire window. A high-performance wall assembly is often thicker in depth than the existing wall assembly, which can affect the correct placement of the window to maximize thermal performance. The optimal placement for the window is always in line with the insulation layer (Finch & Hanam, 2013). This position will yield the highest thermal resistance of the entire assembly and minimize the potential for condensation (Finch & Hanam, 2013). Figure 19 provides two details that position the window in line with the insulation layer and gives guidance on integration of water and air control layers to ensure a continuous seal.

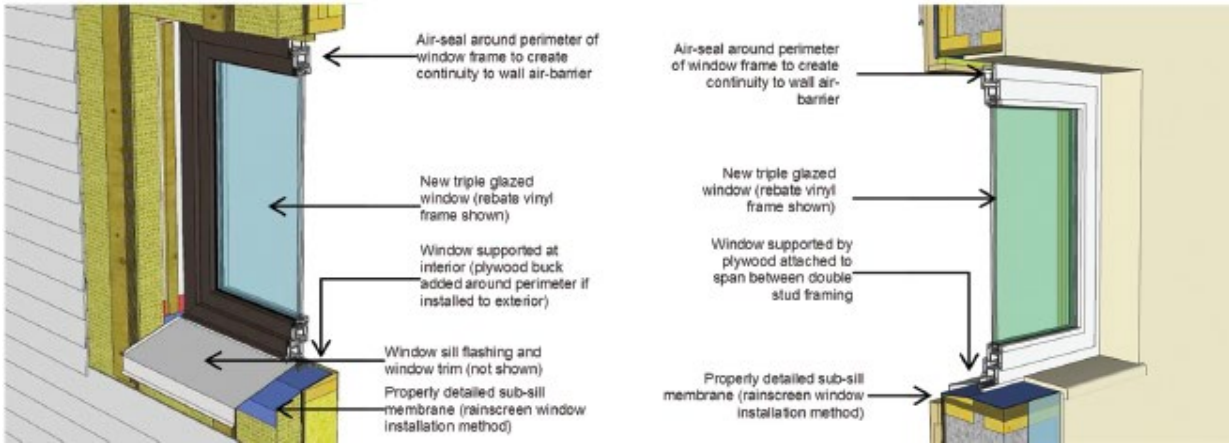


Figure 19: High-performance Window Retrofit Installation Procedure (Finch & Hanam, 2013)

2.7 Potential Moisture Issues with Highly Insulated Building Enclosures

Retrofitted residential houses that meet the performance objectives of NZER have significantly higher levels of insulation in the building enclosure. This means the assemblies are thickener in depth, which is a benefit for reducing the heat loss that results in a decrease in energy consumption of the house. However, as heat flow across the building enclosure has been reduced so too has the drying potential if and when the assembly may get wet. Therefore, it is important to implement details in the design and construction of the building enclosure to limit wetting as the capacity to dry has been reduced. The ability to dry in at least one direction, if not both, should also be incorporated into the building enclosure as a mechanism of safety (Straube & Burnett, 2005).

2.7.1 Dense-Packed Cellulose Roof Assemblies

The fact that some dense-packed roof assemblies have experienced little to no moisture damage is a result of two factors. One, the dense packing of cellulose insulation into a framed cavity does have some level of air sealing (Schumacher & Lepage, 2012). Fitzgerald, Nelson, and Shen noted, in their study, that air leakage can be reduced by approximately 39% - 54% with the use of dense packed cellulose (Fitzgerald et. al., 1990). These values should be taken with a grain of salt as the retrofitted houses were extremely leaky to begin with. The second factor had nothing to do with the assembly but rather the natural or maintained conditions of the house. If the winter time relative humidity was low the dense-packed cellulose assembly would experience little wetting (Schumacher & Lepage, 2012).

Failure of a dense-packed cellulose roof assembly can be traced back to two moisture sources. Built-in moisture can be trapped in the assembly during construction and air leakage, even small amounts, can deposit damaging amounts of moisture after construction (Schumacher & Lepage, 2012). Through field experience, Fitzgerald has collected extensive photographs of damaged dense-packed cellulose roof assemblies (Fitzgerald et. al., 1990). Extensive laboratory testing has also demonstrated failure of the common retrofit approach due to moisture infiltration (Figure 20) (Fazio et al., 2000).

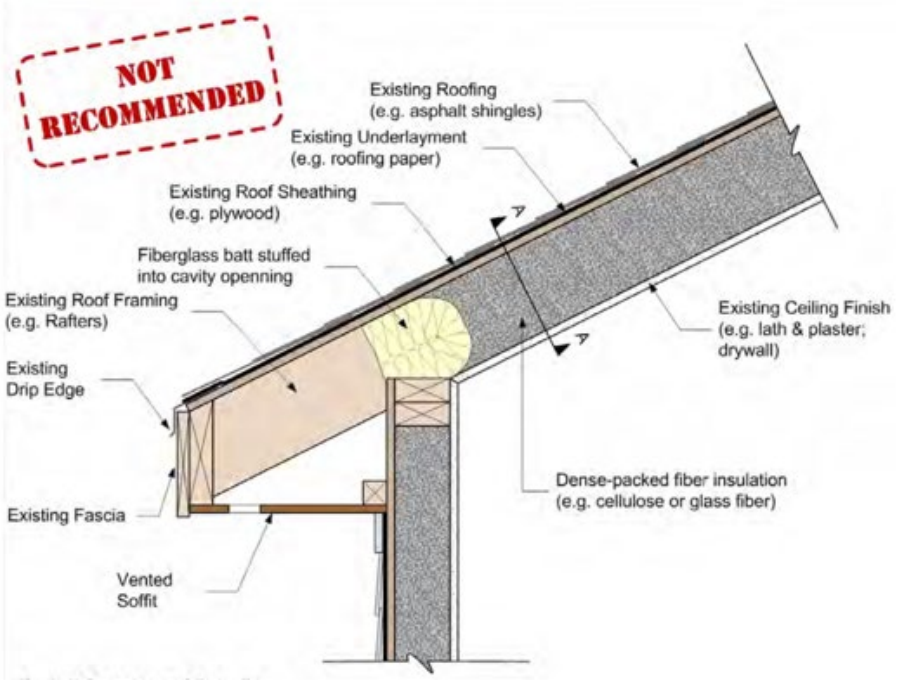


Figure 20: Example of Common Practice for Dense-Packed Cellulose Roof Insulation (Schumacher & Lepage, 2012)

To ensure a better success rate for a dense-packed cellulose roof assembly there are a few measures that can be undertaken. First, remove the source of moisture as much as possible (Schumacher & Lepage, 2012). This means managing bulk moisture with the use of appropriate roofing materials, underlayments, flashing, and a maintenance schedule (Schumacher & Lepage, 2012). Check the moisture content of the roof assembly prior to installation of the vapour control layer and control indoor relative humidity levels through calibrated ventilation systems (Schumacher & Lepage, 2012). On paper it may seem possible to eliminate all sources of moisture, however, in reality there will be some moisture that is trapped during construction or gets into the assembly after construction (Schumacher & Lepage, 2012). Therefore, it is critical to ensure the drying of the assembly out-weighs the safe storage capacity (Straube & Smegal, 2009). Design

alterations of the common, but not recommended, dense-packed cellulose assembly can be integrated that will improve the margin of safety. There are four suggested alterations that can be implemented:

I. Addition of exterior insulation above the roof deck.
II. Spray foam insulation applied to the underside of the roof deck.
III. Ventilation of the underside of the roof deck.
IV. Ventilation of the top side of the roof deck.

These techniques will increase the temperature of the first condensation plane (interior face of roof sheathing) or provide a continuous path of air follow to permit drying of sensitive materials (Schumacher & Lepage, 2012).

2.7.2 Double-Stud Above Grade Wall Assemblies

Double stud wall assemblies can achieve a high thermal resistance, at a low cost, while using traditional building materials and practices (K Ueno, 2015). The studs can be filled with cellulose, spray foam, glass fibre or mineral wool insulation. Double stud wall assemblies have a higher risk of moisture damage due to the low temperatures the interior face of the exterior sheathing will experience (K Ueno, 2015). This finding has been well documented in various research papers (Straube & Smegal, 2009). A failure is typically classified by the growth of mold or the growth of decay fungi on sensitive materials (K Ueno, 2015). Keeping the moisture content of wood below 20% has shown to prevent the growth of mold (Carll & Highley, 1999). K. Ueno (2015) noted, the wood sheathing experienced a moisture content greater than 20% and in some applications peaks beyond 30% were measured. It is important to note that mold does not grow below 5°C or above 50°C (Viitanen & Ojanen, 2007). During winter months the risk of growth is small, however, as the season changes and if the assembly does not dry out quickly, the conditions could be favourable for the growth of mold (K Ueno, 2015). Although field review of the double-stud wall assembly displayed little evidence of mold growth, caution is recommended in constructing this type of assembly (K Ueno, 2015).

2.7.3 Failure Mechanisms of Below Grade Wall Assemblies

The lower portion of a below grade wall will experience its coldest temperatures in the spring months, conversely, the upper portion will experience its coldest temperatures during the winter months. This is due to the thermal mass of the soil and a phase shift in the exterior temperature (Kohta Ueno, 2007). The scenario represents an opportunity for moisture formation if the relative humidity of the basement air is

above the DEW point temperature of the exterior environment. Moisture accumulation is greatest at corners and intersections of a below grade wall as these areas represent the highest concertation of heat loss (Kohta Ueno, 2007). Insulating the foundation wall on the interior increases the risk for condensation formation as the surface temperature has been reduced even further (Kohta Ueno, 2007). The transportation method for moisture formation at these surfaces or intersections is air leakage (Kohta Ueno, 2007). The concept of springtime or wintertime condensation on the lower and upper portion of the below grade wall is not new. Rogers (1938) noted, "(foundation walls and floors) should be protected against internal dampness due to condensation of moisture from warm humid air on the cooler masonry in contact with earth. Such condensation is often as much the cause of dampness in basements as actual bulk water leakage. This trouble appears most frequently during mild rainy spring weather when the ground is still cold and the air warm and humid. The coincidence of this occurrence with warm rains has led to many owners to mistake condensation for subsoil leakage" (p. 14).

If the below grade wall is exposed to an inward thermal gradient, a large inward vapour pressure gradient can form (Kohta Ueno, 2007). If an impermeable layer, such as 0.15mm polyethylene is installed on the interior of the below grade wall assembly, condensation in large amounts can form on the exterior face of the impermeable material (Kohta Ueno, 2007). Caution should be taken placing impermeable materials on the interior face of a below grade wall assembly as the main drying direction is towards the interior (Kohta Ueno, 2007).

2.8 Mechanical Systems for Net Zero Energy Ready Houses

In Ontario, the standard technology used to heat a single detached residential house is a gas furnace (NRCan Local Energy Efficiency Partnerships (LEEP) Team, 2017). These units can offer an Annual Fuel Utilization Efficiency (AFUE) of up to 98% (NRCan Local Energy Efficiency Partnerships (LEEP) Team, 2017). For cooling, the furnace is connected to a central air conditioning unit when the house has a ducted distribution system for air movement. The efficiency of the central air conditioning unit is measured by the Seasonal Energy Efficiency Rating (SEER). Due to advancements in technology, gas furnace and central air conditioning units have been replaced with cold climate air source heat pumps in low energy houses (Natural Resources Canada, 2019). The decision to engage an ASHP was based on the ability of the technology to transfer a higher ratio of the energy in into heating or cooling energy (energy out). The builders in the ecoEII Net Zero Energy (NZE) and NZER project selected a cold climate air source heat pump

(ASHP) with a Heating Seasonal Performance Factor (HSPF) equal to or greater than 7.0 (Natural Resources Canada, 2019).

To achieve the designation of NZE or NZER by the CHBA Renovation Pilot Program a residential house must obtain a high level of airtightness. However, in order to maintain the indoor air quality for the occupants, it is necessary to bring in outdoor air through mechanical ventilation. The outdoor air must be heated or cooled to a specific temperature and the relative humidity conditioned to ensure it does not negatively affect occupant comfort. A heat recovery ventilator (HRV) or energy recovery ventilator (ERV) are pieces of equipment that efficiently exchange indoor air for outdoor air. The two technologies are slightly different. An HRV extracts heat from exhaust air and uses it to heat the incoming air. In addition to the extraction of heat an ERV also captures a portion of the moisture from the exhaust air. In cold winter months this helps to prevent the air from drying out and in warm summer months it helps to dehumidify. Participating builders in the ecoEII NZE and NZER project selected an HRV or ERV unit that ranged in efficiency from 67% to 60% and 84% to 72% when operated at 0°C and -25°C (Natural Resources Canada, 2019).

There are various options to consider for heating domestic hot water, such as, an electric or gas hot water tank, desuperheater of a ground source heat pump with electric backup, thermal solar collectors with electric backup, or a heat pump water heater (independent or connected to a ground source heat pump). A traditional hot water tank is often not selected as the unit does not have the efficiency required for a NZER residential house and leads to the highest energy consumption of the four options (Biaou & Bernier, 2005). In a research paper by Biaou and Bernier (2005), they concluded the use of thermal solar collectors for domestic hot water heating used the least amount of energy. A heat pump, then a desuperheater of a ground source heat pump followed next in terms of least amount of energy consumed (Biaou & Bernier, 2005). Although the thermal solar collectors represent a pathway to the least amount of energy consumed, numerous NZE and NZER residential houses used the roof space for solar photovoltaic (PV) panels. Since the roof area is required for renewable technology the use of thermal solar collectors to heat hot water is not an option. Builders in the ecoEII NZE and NZER project selected heat pump water heaters with an energy factor (EF) between 2.73 – 3.27 (Natural Resources Canada, 2019).

2.8.1 Implementing Mechanical Systems that Achieve Occupant Comfort

Satisfying the objectives of energy does not necessarily correlate to a comfortable environment for the occupants. Standard industry practices for mechanical systems have led to comfort issues within a residential house. As the energy efficiency for residential houses improves, the design heat load decreases

(NRCan Local Energy Efficiency Partnerships (LEEP) Team, 2017). Depending on the climatic location of the residential house the cooling airflow constraint may be higher than the heating air flow constraint (NRCan Local Energy Efficiency Partnerships (LEEP) Team, 2017). Often the duct sizing is based on the cooling load requirements. If the airflow rate is too high for the heating load it could lead to short cycling of the mechanical system.

Houses built today have a higher fenestration to wall ratio compared to older homes (NRCan Local Energy Efficiency Partnerships (LEEP) Team, 2017). Depending on the orientation and solar heat gain coefficient of the windows these parameters could play a large role in affecting the size of the heating or cooling load. Lot widths are decreasing across Ontario, which leads to taller single detached residential houses that typically at some point in time, will have a finished basement (NRCan Local Energy Efficiency Partnerships (LEEP) Team, 2017). With the mechanical systems located in the basement, challenges arise with distribution of treated air to ensure occupant comfort on each floor.

Fortunately, there are measures that can be taken to overcome these challenges and provide occupants with a comfortable environment. With the heating load of a residential house decreasing there was a need for a revised standard that reflects the new landscape of an energy efficient house. Taking into account the performance attributes of a NZER residential house, alterations were applied to the CAN/CSA-F280 standard that allowed a better correlation to the actual design heat loss of a house. Implementing a two stage or modulating furnace allowed for longer run times, which decreased mechanical equipment short cycling that could lead to uncomfortable spaces within a residential house (Figure 21).

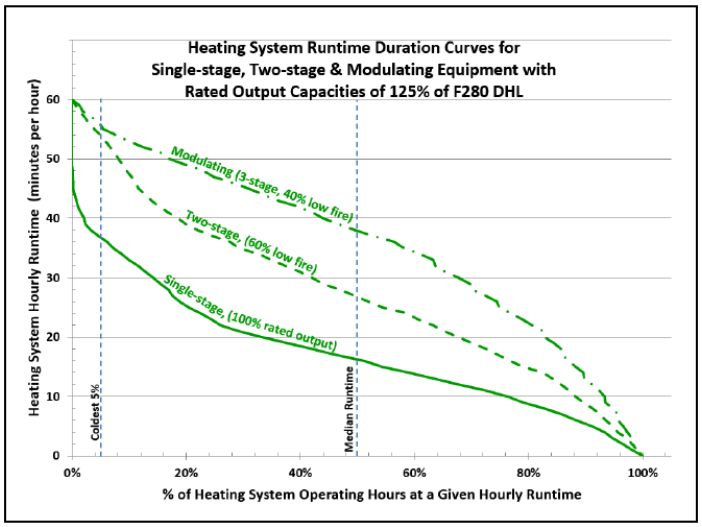


Figure 21: Heating System Runtime Duration Curves (NRCan Local Energy Efficiency Partnerships (LEEP) Team, 2017)

Windows can have a large impact on the designed cooling load for a single detached residential house as the cooling load can be sensitive to the intrusion of solar heat gains (Figure 22) (NRCan Local Energy Efficiency Partnerships (LEEP) Team, 2017). These calculations may impact the selection of the air conditioning condenser, duct sizing for distribution of air flow, and the size of the circulation fan (NRCan Local Energy Efficiency Partnerships (LEEP) Team, 2017). There are two key parameters that should be evaluated for each orientation of the building elevation, window U-value and the solar heat gain coefficient (SHGC). The U-value will help determine how much heat gain could occur through the glass and frame, while the SHGC will determine the percentage of sunlight that is transmitted through the glazing as heat. In both cases, lower values indicate better performance. Due to this, coordination of window selection should be paired with the selection of mechanical equipment (NRCan Local Energy Efficiency Partnerships (LEEP) Team, 2017).

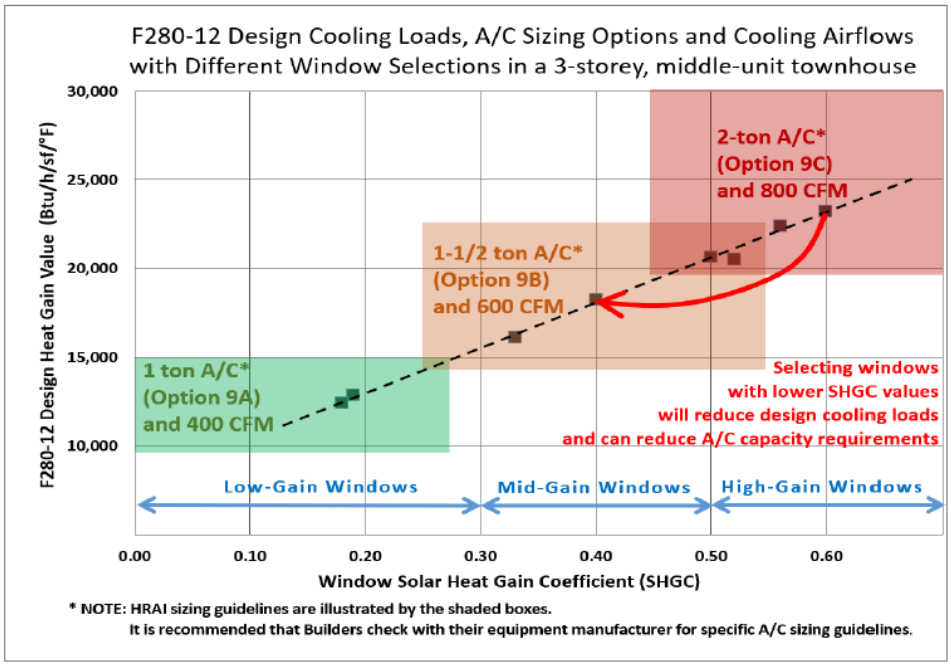


Figure 22: CAN/CSA-F280-12 Design Cooling Loads, A/C Sizing Options, and Cooling Airflows with Different Window Selections (NRCan Local Energy Efficiency Partnerships (LEEP) Team, 2017)

Humid environments can often lead to occupant complaints (NRCan Local Energy Efficiency Partnerships (LEEP) Team, 2017). Incorporation of a dehumidification system prior to the mechanical system coming on to decrease the air temperature can lead to a reduction in the relative humidity of a space, which could enhance interior comfort for the occupants (NRCan Local Energy Efficiency Partnerships (LEEP) Team,

2017). In addition, dehumidification reduces the potential for the development of mold growth, thus increasing the durability of a house (NRCan Local Energy Efficiency Partnerships (LEEP) Team, 2017).

An even distribution of temperature throughout a single detached residential house is a challenging task. Warm air rises to the highest elevation, while cool air drops to the lowest point. Couple this with a single thermostat located in a central location on the main floor and the recipe for temperature stratification can be present (NRCan Local Energy Efficiency Partnerships (LEEP) Team, 2017). Incorporating a zoned mechanical system will aid in the even distribution of conditioned air throughout the entire house. Field trials conducted by McMaster University from November 2009 to March 2011 found that occupants of two-storey and three storey single detached residential houses with fully zoned mechanical systems had 90% of the occupants report an increased level of comfort (NRCan Local Energy Efficiency Partnerships (LEEP) Team, 2015). A zoned system can also assist in a reduction in utility costs by decreasing the temperature in unoccupied areas of the house when the spaces are not in use for extended periods of time during the day or night (NRCan Local Energy Efficiency Partnerships (LEEP) Team, 2015).

Often the air distribution system for the mechanical system is installed without a complete seal of the duct work. This can result in between 30 – 40% leakage of conditioned air in a ducted system for a single detached residential house (NRCan Local Energy Efficiency Partnerships (LEEP) Team, 2017). This leads to a percentage of conditioned air not reaching its intended location, which could result in occupants dissatisfied with the comfort provided by the mechanical system. There are two tested air sealing methods that have shown to substantial reduce air leakage from a ducted air distribution system. The first method relies on a paint applied mastic or metical tape to seal all joints and connections of the duct system (NRCan Local Energy Efficiency Partnerships (LEEP) Team, 2017). To ensure sealing of the ducts has reduced air leakage to calculated allowable rates, the duct work is pressurized with a device referred to as a Duct Blaster (NRCan Local Energy Efficiency Partnerships (LEEP) Team, 2017). This test is commonly performed prior to the installation of gypsum board encase any areas require additional sealant (NRCan Local Energy Efficiency Partnerships (LEEP) Team, 2017). With this strategy duct air leakage rates are reduced down to between 5 to 15% for the entire system.

In applications where access to the duct work is not available, such as a retrofit, a mist applied sealant that is distributed throughout the duct work can be implemented. Supply and return vents are covered and a mist applied aerosol is circulated throughout the duct work with specialized equipment. The mist aerosol attaches to the edges of any leakage pathway and gradually seals the pathway over the duration of the

installation (NRCan Local Energy Efficiency Partnerships (LEEP) Team, 2017). This method of duct sealing is able to reduce the total air distribution system leakage down to between 1 to 5% (NRCan Local Energy Efficiency Partnerships (LEEP) Team, 2017).

2.9 Canadian Home Builders Association Net Zero Energy Ready Renovation Pilot Program

At the conclusion of the ecoEII NZE and NZER program there was appetite from the industry to continue the progression of the low energy residential housing standard. With that, CHBA established a NZE Housing Council in 2014 to help guide the continued development (CHBA, 2020c). In the early spring of 2017, the council launched the first version of the NZE and NZER Home Labelling Program for new construction (CHBA, 2020c). Recently, work has begun on the development of a NZE and NZER standard for existing housing. There is a three-year plan that will include the development of the standard, implementation of pilot projects to test the standard, and a public launch to create awareness about the new energy efficiency program (CHBA, 2020c). The stated goal of the CHBA programs are to allow builders to participate in a voluntary energy efficiency program that can deliver market-ready solutions that are constructed with off-the-shelf technologies (Canadian Home Builders Association, 2020b).

For a residential house to become completely zero energy, renewable technologies are required (Canadian Home Builders Association, 2020b). If renewable technologies will be installed at a later date, the classification of the house would be NZER. The intent of this research is to focus on NZER construction without the integration of renewable technologies. This process essentially is a house that had its energy consumption reduced to an optimal point where the remaining energy load can be generated with a renewable technology. Although renewable technologies will not be analyzed in this research, a calculation must occur to determine how much energy a single detached residential house can generate from a renewable technology. The majority of NZE or NZER residential houses labelled by CHBA have utilized the roof space for solar PV panels for the generation or future generation of renewable energy (Natural Resources Canada, 2019).

The CHBA NZER Renovation Pilot Program does not limit which renewable technologies can be implemented. The program simply requires that a rating of 0 GJ/yr is achieved through energy modelling that conforms with the EnerGuide Rating System v15 using HOT2000 in conjunction with the Technical Information in the CHBA Project Registration Workbook (Canadian Home Builders Association, 2020b). The Renovation Pilot Program sets forth minimum effective thermal resistance values for assemblies in the building enclosure as well as the performance attributes for the windows (Figure 23 and Table 1). For

certification to the CHBA NZER Renovation Pilot Program, a calculation of the building enclosure performance is required in addition to meeting the minimum effective thermal resistance values (Canadian Home Builders Association, 2020b). The calculation is done in HOT2000 and ensures the building enclosure performance target is at least 33% better than the minimum requirements in the National Building Code of Canada (NBC).

Building Assembly	Heating Degree Days[2]					
	<3000	3000-3999	4000-4999	5000-5999	6000-6999	≥7000
	RSI (R)					
	NBC Climate Zones					
	4	5	6	7a	7b	8
Ceilings below attics	6.91 (39.2)	8.67 (49.2)	8.67 (49.2)	10.43 (59.2)	10.43 (59.2)	10.43 (59.2)
Cathedral ceilings and flat roofs	4.67 (26.5)	4.67 (26.5)	4.67 (26.5)	5.02 (28.5)	5.02 (28.5)	5.02 (28.5)
Walls above grade[3]	2.78 (15.8)	3.08 (17.5)	3.08 (17.5)	3.08 (17.5)	3.85 (21.9)	3.85 (21.9)
Floors over unheated spaces	4.67 (26.5)	4.67 (26.5)	4.67 (26.5)	5.02 (28.5)	5.02 (28.5)	5.02 (28.5)
Foundation walls below or in contact with the ground	1.99 (11.3)	2.98 (16.9)	2.98 (16.9)	3.46 (19.6)	3.46 (19.6)	3.97 (22.5)

Figure 23: Minimum Effective Thermal Resistance of Opaque Assemblies (Canadian Home Builders Association, 2020b)

Table 1: Fenestration and Door Efficiency Requirements (Canadian Home Builders Association, 2020b)

Minimum Energy Efficiency Requirements: Fenestrations and Doors	
Standard	**Notes**
ENERGY STAR Certified, *or*	• For the climate zone they are installed in
Tested CSA A440.2-14, *or*	• Fenestration Energy Performance
Tested National Fenestration Rating Council's NRFC 100, *and*	• Procedure for Determining Fenestration Product U-factors
Tested NFRC 200, *and*	• Procedure for Determining Fenestration Product Solar Heat Gain Coefficient and Visible Transmittance at Normal Incidence
Constructed with Minimum	• Double-glazed with Low-e Glass • Inert Gas-fill • Insulated Spacers, *and* • Thermally Broken Frame *or* Sash Where it is Metal

3 PHASE ONE: FIELD INVESTIGATION FOR DEFINITION OF ARCHTYPE PARAMETERS

3.1 Archetype Development Limitations

The original intention of this research was to conduct an in-depth analysis of a neighbourhood in the GHA that would allow the development of an archetype model to represent a two-storey single detached residential house. Field surveys and questionnaires were planned and prepared for distribution in the Plateau neighborhood of East Stoney Creek, a community in the City of Hamilton, that would support the alignment of the archetype model to represent the GHA at large. The social distancing measures set in place by the provincial government combined with the uncertainty around how COVID-19 spread and the average age of the occupants in the study neighbourhood, a high-risk group, limited the willingness for owners to participate in the research.

Therefore, data collected for this research was built around a single house from the Plateau neighborhood. Field investigation data collection was able to extend beyond the sole house where elements were quantified from a visual assessment. Of the total 444 houses in the Plateau neighborhood, 221 houses were identified through visual field investigation to have identical or similar physical geometry compared to the only reference house where detailed data was obtained (Table 2). These findings correlate to the majority of houses in the Plateau neighborhood having archetypal features (50%). Houses in the neighborhood that had characteristics that deviated from the defined archetypal were classified as outliers and discarded from the research.

Table 2: Total and Percentage of Various Housing Types Visually Observed in the Plateau Neighbourhood of East Stoney Creek a Community within the City of Hamilton

Single Detached Residential House						
Street	**Archtypal**	**Larger 2 Storey**	**Smaller 2 Storey**	**1.5 Storey**	**1 Storey**	**Total No. Houses**
Southmeadow Ct	0	0	0	2	4	6
Maple Dr	49	9	7	15	18	98
Millen Rd	0	3	1	1	2	7
Burt Ct.	2	0	0	5	7	14
Connor Ct	3	1	0	2	7	13
Hilts Dr	14	0	0	11	11	36
Plateau Pl	12	0	0	3	0	15
Mathers Dr	18	5	0	2	1	26
Jenny Ct	0	0	0	1	3	4
Fernview Ct	13	2	0	1	1	17
Ben Tirran Crescent	41	0	0	10	6	57
Wyvis Ct	11	0	0	0	0	11
Dewitt Rd	5	0	0	1	0	6
Horn Ct	3	0	0	4	0	7
Dundee Dr	3	0	10	2	0	15
Ben Nevis Dr	4	0	9	0	5	18
Alder Ct	10	0	2	1	1	14
Macdui Dr	15	5	2	1	6	29
Orr Crescent	13	24	0	2	2	41
Adriatic	5	3	1	0	1	10
Total	221	52	32	64	75	444
Percentage	50%	12%	7%	14%	17%	100%

Notes to Table 2:

1. *The area defined as the Plateau neighborhood of East Stoney Creek, a community within the City of Hamilton, has been illustrated in Appendix 8.1.*

Lawrence (2020) and Cecilia (2020) developed surrogate models for semi-detached and detached residential houses for the region of Toronto, Ontario. Modifications were made to the houses from Jermyn's field study and EnergyPlus was selected to run thousands of simulations. The concluded models predicted energy consumption with less than a 10% difference compared to the actual utility bills of the field measured houses (Cecilia, 2020). Further, the research demonstrated a single surrogate model can be utilized for a large or small house without losing accuracy (Cecilia, 2020). There method of surrogate modelling could be extended to this research which would allow 83% of the single detached residential houses in the Plateau neighbourhood to be captured. Further, this research combined with Ceilia and Lawrence surrogate modelling has the potential to include almost 14,000 single detached residential houses in the City of Hamilton that were constructed between 1980 – 1989 (Figure 24).

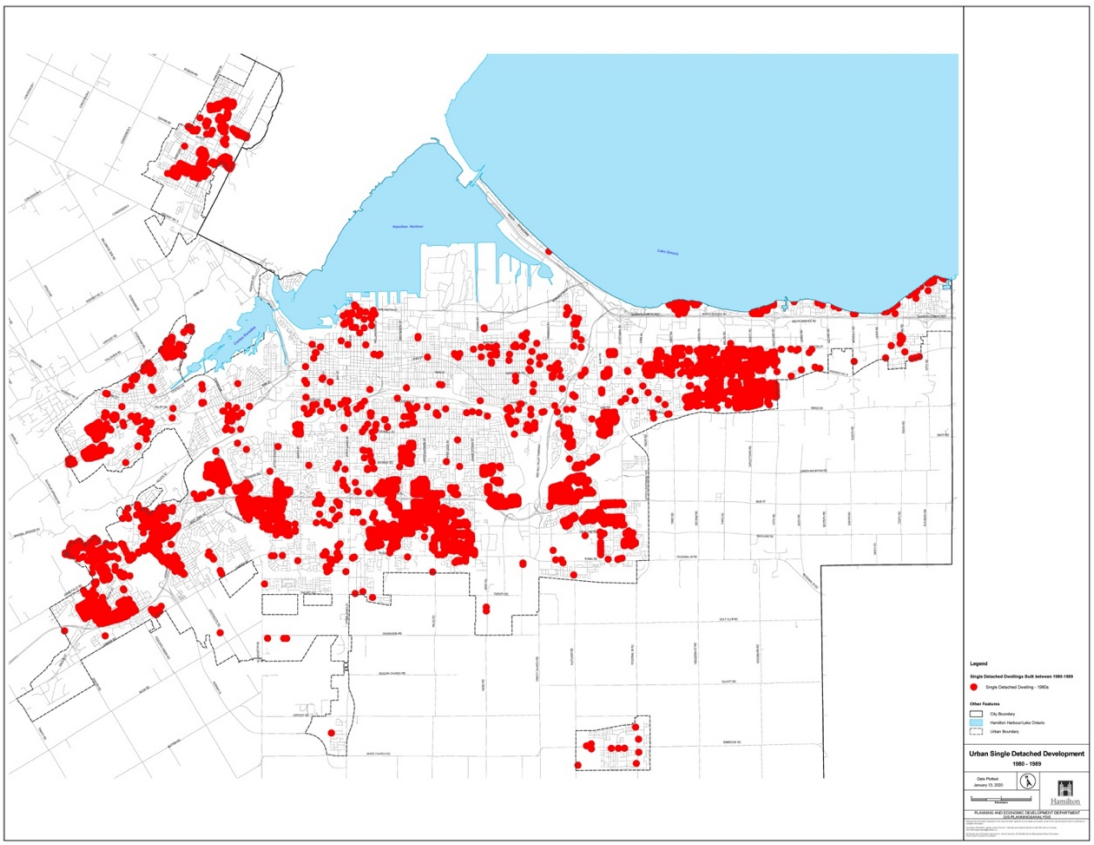


Figure 24: Urban Single Detached Development of Houses Constructed in the 1980's in the City of Hamilton (Planning and Economic Development Department GIS Planning and Analysis City of Hamilton, 2020)

3.2 Data Collection

In order to ensure data collection was completed in a standardized process the methodology developed by Zirnhelt (2013) was adhered to for this research. The parameters noted in Table 3 highlight critical pieces of information that must be obtained during the data collection phase to allow the development of a precise archetype model.

Table 3: Parameters Selected for Data Collection (Zirnhelt, 2013)

Category	Parameter
Geometry	Building Footprint Storey Height Dimension Glazing and Doors

	Floor Plan Shading Device and Overhangs
Envelope	Material and Material Properties Window Construction Door Construction Airtightness
Basement	Basement Material and Material Properties Below Grade Wall Construction
Internal gains	Types of Major Appliances Occupancy Schedule
HVAC	Type of Heating and Cooling Location of Thermostat Total Ventilation Flow Rate

The Plateau neighbourhood of East Stoney Creek, a community within the City of Hamilton, was selected for this research as it represents an area of residential houses that range in value between $500,000 to $1,200,000 and can be representative of suburban single-family residential detached houses in the GHA (Wasley, 2020). The houses in the Plateau neighbourhood are single detached often with an attached garage, have a building profile of two stories in height, and range in square footage from 2000 to 3500. Table 4 provides a list of common features of a single detached residential house in the Plateau neighborhood that were obtained during visual field investigations and Figure 25 provides a visualization of an archetypal house for the neighorhood.

Table 4: Common Features of a Single Detached Residential House in the Plateau Neighborhood of East Stoney Creek

GHA Archetype Characteristics: 1980's Two-Storey Single Detached Housing	
Building Element	**Description of element**
No. of Stories	Two
Building Shape	Rectangular
Decade of Construction	1980 – 1989

Cladding	Mainly Brick Minor Portions Siding
Fenestration Percentage	Original Unaltered Window Openings Less than 15% Most Windows and Door Units had been Replaced
Roof Types	Open Gable Hip Intersecting Hip and Valley
Building Structure	Poured Concrete Foundation (Below Grade Walls) Light-wood Framed (Above Grade Walls) Insulation: Attic Ceiling, Above Grade Walls Below Grade Walls and Under Slab are not Insulated



Figure 25: Representation of a Typical House in the Plateau Neighbourhood of East Stoney Creek a Community in the City of Hamilton

An in-depth investigation was conducted on a single residence to gather detailed measurements that would aid in the creation of an accurate building footprint size, internal room dimensions, exterior building enclosure measurements, and to give indication what a typical floor plan consists of. Figures 26, 27, and 28

represent a typical basement, first floor, and second floor plan of the archetype for development of a baseline energy model in the Plateau neighbourhood of East Stoney Creek that will represent the GHA.

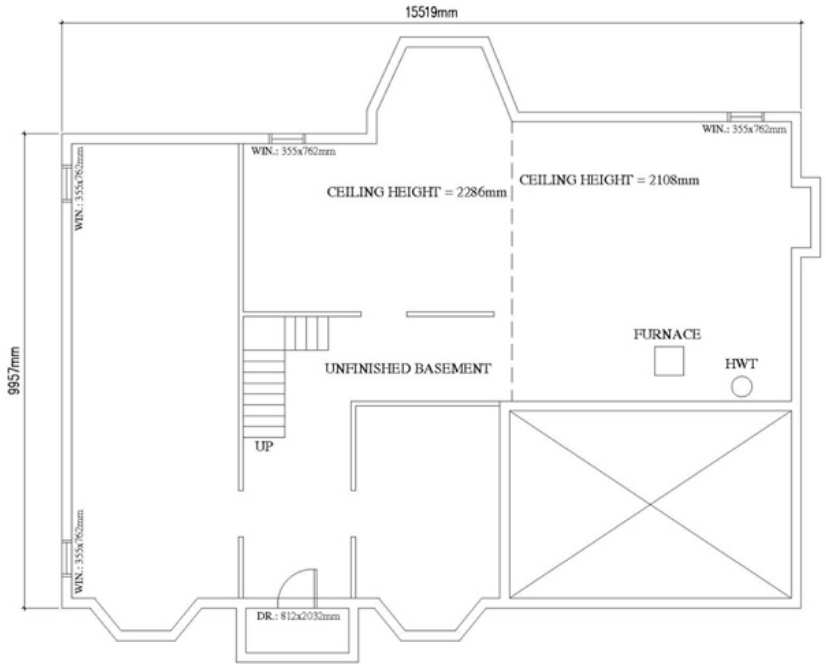


Figure 26: Typical Basement Floor Plan of the Archetype Model for the Plateau Neighborhood (Information Collected from Owner)

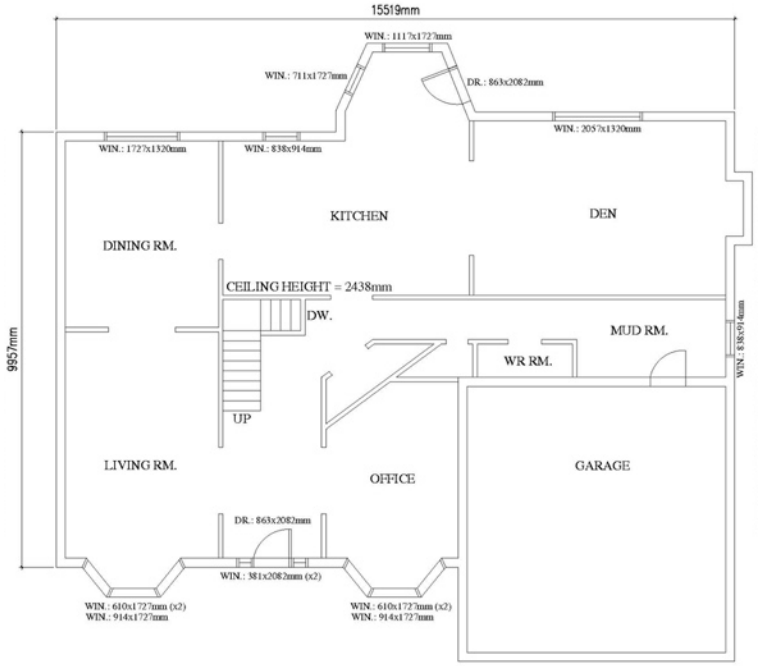


Figure 27: First Floor Plan of the Archetype Model for the Plateau Neighborhood (Information Collected from Owner)

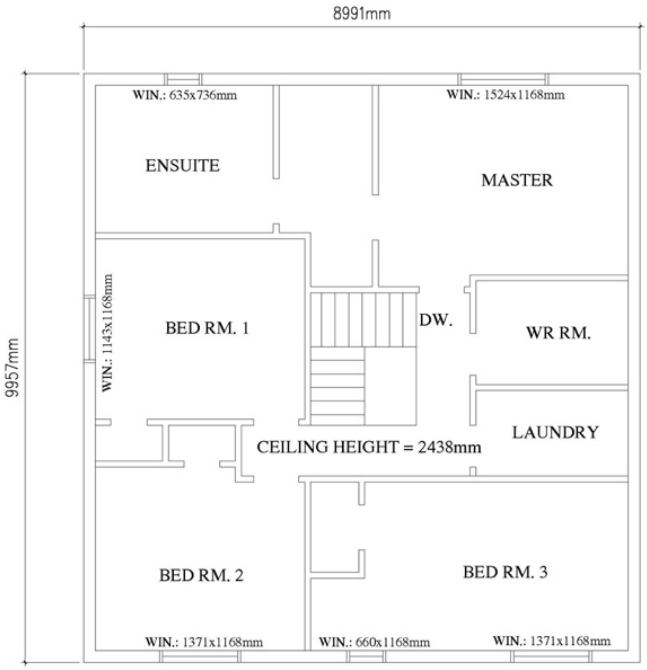


Figure 28: Second Floor Plan of the Archetype Model for the Plateau Neighborhood (Information Collected from Owner)

An energy audit on one of the houses in the Plateau neighborhood revealed critical data related to the materials used in the above grade exterior walls and the ceiling assembly separating conditioned from unconditioned space. The majority of the houses had unfinished basements and therefore, the conclusion was drawn the space was uninsulated. In the few applications where the basement space was finished the owners were not certain what insulation materials were used or the quantity of insulation installed. Information related to major appliances was secured during informal discussions with owners. However, the owners simply stated the type of appliance and were not certain on the energy consumption.

Visual observation during field investigations indicated all of the residential houses had at least one air conditioning unit for the propose of cooling the house during warm periods. Informal discussions with owners indicated a natural gas furnace was used for heating. Owners commonly noted the thermostat was located on the first floor within close proximity to the kitchen. There was no gathered information on the total ventilation flow rate of a single detached residential house as an HRV or ERV had not been installed. The only mechanical and controlled ventilation was provided through the use of exhaust fans located in some of the washrooms.

At the conclusion of the data collection, the parameters noted in Table 5 will symbolize the physical features of the GHA archetype that is representative of a single detached residential house from the Plateau

neighborhood of East Stoney Creek. For comparison the Clarington, Ontario and 1970's OBC Toronto, Ontario archetype models have been included in Table 5 as well. Although the reference cases for this research are not an exact match to the GHA archetype it was critical to include reference cases to allow the baseline energy model of this research to be benchmarked against a data point to ensure the model was behaving similar to houses that had comparable attributes. The initial comparison also helps to identify any major errors that might occur in the baseline energy model of this research.

Table 5: Summary Description of the GHA Archetype vs. Clarington and Toronto, Ontario Archetypes

Archetype	GHA	Clarington, Ontario Newcastle Village (C) (Natural Resources Canada_CanmetENERGY, 2006)	Toronto 1970's OBC (Blaszak, 2010)
House Type	Single Detached	Single Detached	Single Detached
Heated Floor Area	215m^2	191m^2	216m^2
Building			
No. of Storeys	2	2	2
Plan Shape	Rectangular	Rectangular	Rectangular
Vintage	1980's	1961 – 1977	1970's
Lot Placement	Adjacent to Neighbours	Adjacent to Neighbours	Adjacent to Neighbours
Features	1 or 2 Vehicle Garage	Single Vehicle Garage	Partly Raised Basement Narrow Awing
Roof	Light-wood frame (Hip and Gable) Vented attic space	Hip and Gable	Hip
Structure	Light-wood frame (above grade) Concrete Foundation (below grade)	Light-wood Frame	Light-wood Frame
Cladding	Brick (Vented and Drained)	Brick and Vinyl Siding	Brick

Insulation (RSI)	*Calculated in HOT2000*		
Ceiling	5.28	4.0	4.18
Walls	2.90	1.9	1.71
Foundation	0.20	1.7	1.16
Slab	0.20	-	-
Air Leakage (ACH) @ 50Pa	5.12 ELA: 1681cm^2	-	5.75
Glazing (%)			
Front	20	-	20
Side	10	-	5
Rear	20	-	25
Mechanical			
Heating	Natural Gas Furnace (AFUE 95%)	Electrical baseboard heaters	Natural Gas Furnace (AFUE 80%)
Cooling	Central Air System (SEER 14)	-	Central Air System (COP 3)
Domestic Hot Water	Natural Gas Tank (EF 57%)	Electrical Tank (EF 82%)	Natural Gas Tank (Induced Draft Fan)

Notes to Table 5:

1. *HOT2000 calculates the effective thermal resistance of an assembly in accordance with the produces noted in the report Comparison of Thermal Performance of Lightweight Steel-Framing and Wood Stud Walls Natural Resources Canada* (Parekh, 2000)

4 PHASE TWO: ARCHETYPE ENERGY MODEL DEVELOPMENT

4.1 HOT2000 Input Parameters

Any data that was collected during this research was complied, organized, and then averaged prior to the inclusion into the HOT2000 modelling software. To ensure accuracy, the baseline energy model was calibrated following the methods outlined in the literature review. As the intent of this research is to

determine what retrofit measures are required to transform the GHA archetype into meeting the objectives of the CHBA NZER Renovation pilot Program, it is mandatory that the energy analysis be completed with the software program HOT2000. Although HOT2000 was originally developed for the Canadian R2000 Housing Program, it has undergone progressive updates that now allow its use for other low energy housing programs.

4.1.1 General House Information

The first step in generating an energy model in HOT2000 is to input general physical features of the house being studied. Figure 29 provides parameters that were inputted into HOT2000 for general house information in the development of the baseline energy model. Most of the reference houses in the Plateau neighborhood have a front facing of east or west, with some front facing of north or south. As the detailed measurements came from a house facing west, this front orientation was utilized in the HOT2000 model. Weather files for HOT2000 are limited in their selection. As Stoney Creek or Hamilton, Ontario is not an option within the program, Toronto data was applied as it represents the closest weather pattern to that of the study area. The heating degree day (HDD) value noted for Toronto in HOT2000 is 3520. The default window airtightness standard was applied to the HOT2000 model (CSA-A1) as well.

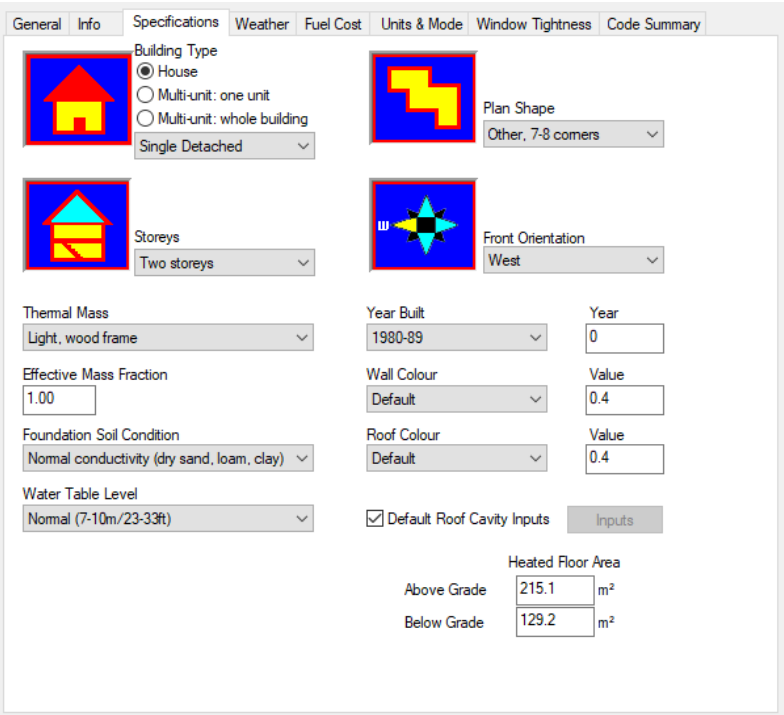


Figure 29: General Archetype Information Entered into HOT2000 Baseline Energy Model

4.1.2 Building Enclosure Assemblies

The houses in the Plateau neighborhood feature a second-floor ceiling to attic space, as well as a first-floor ceiling to attic space that is typically located behind the two-vehicle garage. The construction, ceiling type, location, R-value (RSI), roof slope, heel height for the first and second floor ceilings remained constant in the HOT2000 model (Figure 30). The measurements for the length of eave or base as well as the ceiling area are noted in Table 6.

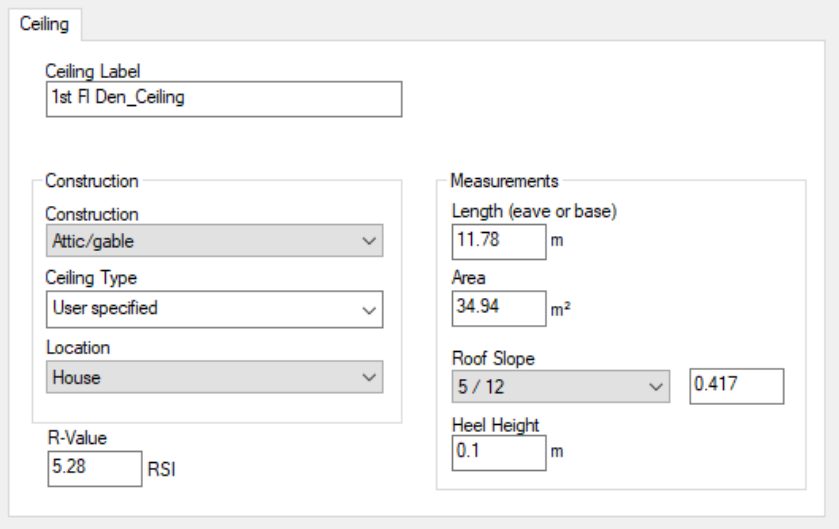


Figure 30: Ceiling Information in the Development of the Baseline Energy Model in HOT2000

Table 6: Ceiling Measurements for Length of Eave or Base and Area of the Baseline Energy Model in HOT2000

Parameter	Measurement	
	Length of Eave or Base (m)	Area (m^2)
1st Floor Ceiling Above Den	11.78	34.94
1st Floor Ceiling Behind Kitchen Bump Out	4.98	3.54
2nd Floor Ceiling	17.98	85.87

The above grade walls for the first and second floor featured the same input parameters. A custom wall type was created in the HOT2000 model to ensure an accurate representation of the above grade wall assembly (Figure 31). Dimensions for the above grade wall parameters were adjusted based upon the assembly and with information gathered during the in-depth investigation of the one house. Accounting

for thermal bridging in the above grade wall assembly, the effective thermal resistance ranged from RSI 2.59 to 2.92 as calculated by HOT2000.

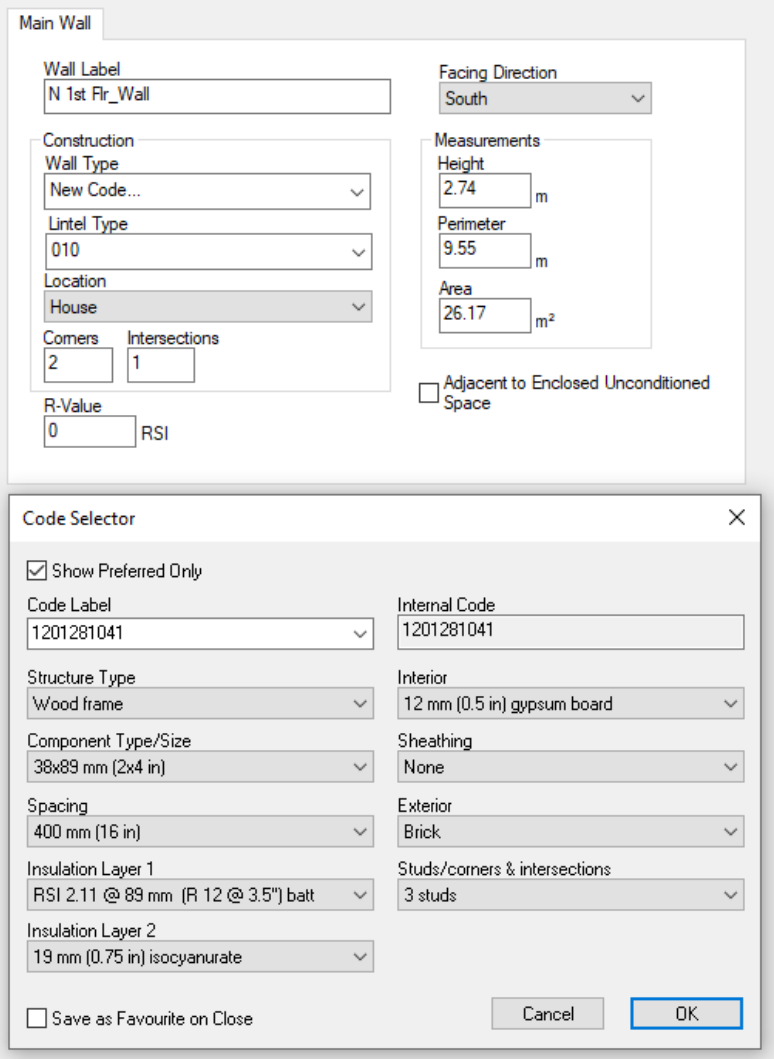


Figure 31: Detailed Information of Materials Used in Development of a Above Grade Wall Assembly in the Baseline HOT2000 Energy Model

To replicate the performance of the window units a custom file was created in HOT2000 and the attributes of the windows are noted in Figure 32. Only the window measurement box changed in the HOT2000 model dependent on which window was located in the elevation. All of the window measurements that were used in the development of the energy model can be found in Appendix 8.2. It was observed during field investigation that the entry front, rear, and garage doors were not original components. The doors were confirmed either wood or steel construction (foam insulation filled core). Measurements of the entry doors can be found in Appendix 8.3. Although the steel doors featured a foam core, the solid wood door had an

improved thermal resistance of RSI 0.37 compared to RSI 0.29 in HOT2000. This should be expected as the thermal conductivity of steel is higher than wood, which allows a higher rate of heat transfer.

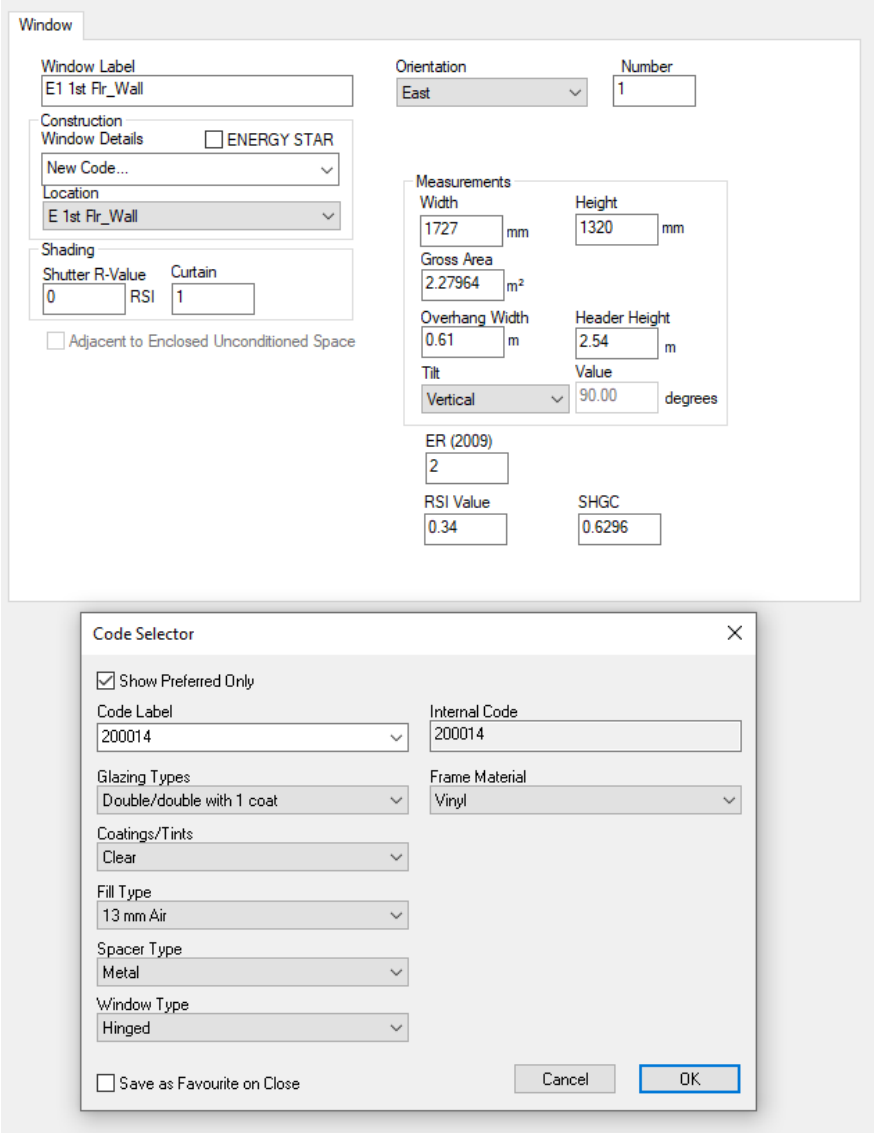


Figure 32: Detailed Information of Window Parameters Defined in HOT2000 for the Development of the Baseline Energy Model

For the foundation assembly, HOT2000 offers various configurations to match different construction types. A common feature of the houses in the Plateau neighborhood is a step down to the den space on the first floor. This step down results in a reduction of ceiling height in the basement space. The ceiling height in this area was found to be 2.11m, while areas that did not have a lowered height were 2.29m . The perimeter and total area of the two basement spaces were 24.28m and 34.94m^2 and 41.91m and 94.29m^2.

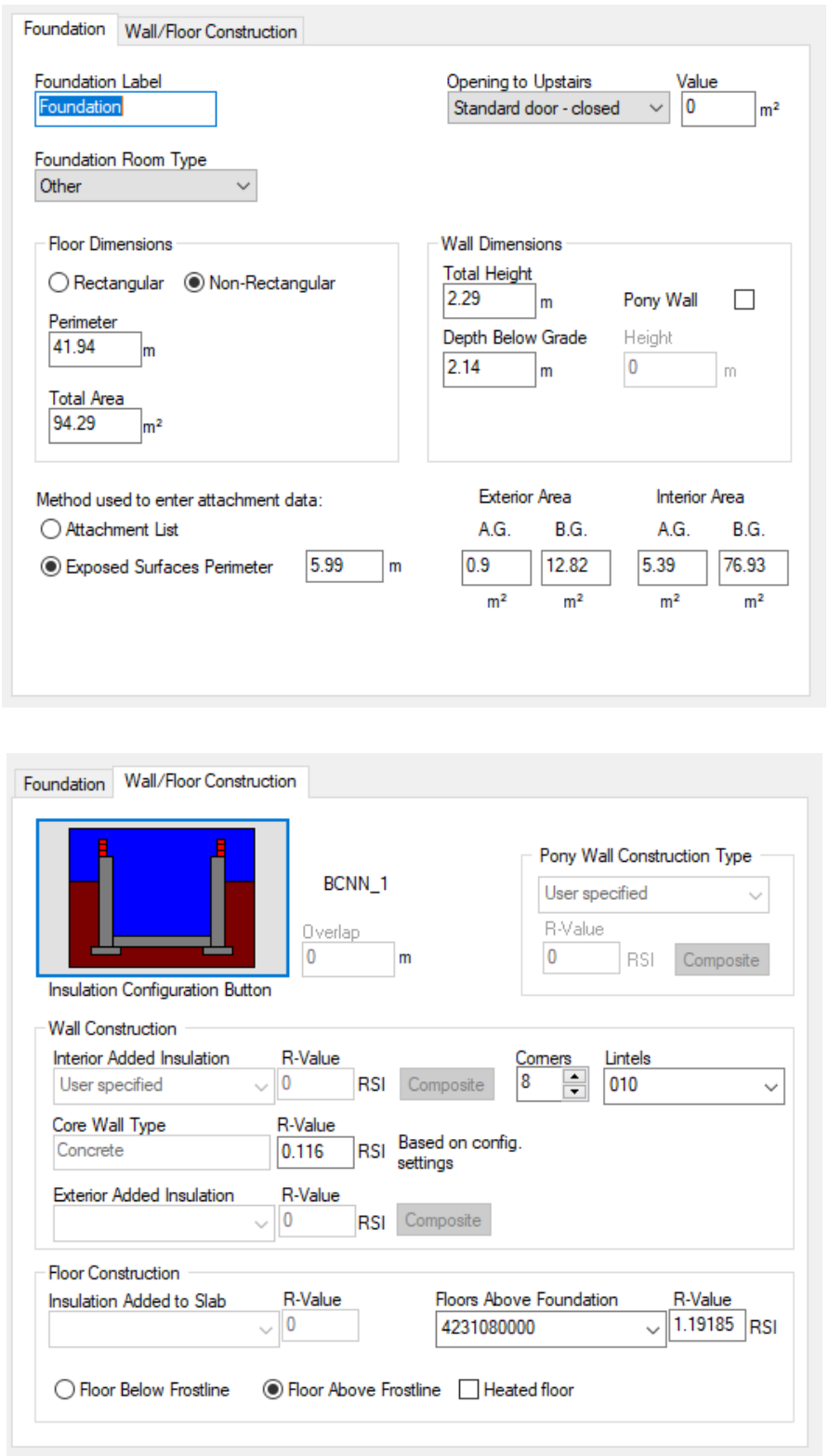


Figure 33: Detailed Information of Foundation Parameters Defined in HOT2000 for the Development of the Baseline Energy Model

4.1.3 Temperatures

Based on standard modelling conventions for a heating dominated climate and the information obtained from investigations in the Plateau neighborhood the setpoint of the heating system in HOT2000 was set to 20°C. With advancement in thermostat technology and most individuals believing there is an opportunity for energy savings the average nighttime heating set point was reduced to 19°C for a duration of 8 hours. For the cooling load the setpoint in HOT2000 was set to 25ºC and there is no option for a nighttime setback of the cooling system. HOT2000 permits a deviation of an allowable temperature rise before it is assumed the occupants open windows to release the excess heat. This provides the opportunity to reduce the load of the main heating element. During investigations no accurate data could be obtained and therefore the default input was used in HOT2000 (allowable rise of 5.5ºC).

4.1.4 Occupant Base Loads

The Plateau is a neighborhood in transition. Many of the houses are occupied by one or two seniors and the neighbourhood is starting to see the introduction of younger families that feature three, four, of five family members (average representation of a typical Canadian household). As occupancy of a house increases, it correlates to an increase in the energy consumption. The average occupancy load was entered and modelled in HOT2000 for the baseline energy model. Through visual observations it was found most owners were typically present at their residence 65% of time in a single day. Values for at home presence during COVID-19 were not inputted for this research as it does not represent a typical characteristic of usage. In the future, if more individuals transition to a full-time home office work environment it may then represent a typical characteristic of usage.

The hot water temperature for bathroom faucets and showers could not be determined and therefore default values of 55°C and 41°C were engaged. Standard flow rates of 8.3L/min. and 9.5 L/min were used for bathroom faucets and shower heads. It was initially approximated that an average shower duration was ten minutes and each occupant took five showers per week. All houses had a clothes washer, dryer, and dishwasher installed. On average the majority of the residences had a natural gas stove and at least one refrigerator. Default values in HOT2000 were used for all six appliances as accurate feedback on usage was not obtained. With the introduction of energy efficiency awareness programs over the last decade in Ontario almost all residences in the Plateau neighborhood had converted to LED bulbs for lighting purposes. As occupant activities can play a large role in the energy consumption of a residential house, HOT2000 includes a miscellaneous electrical load of 9.7kWh.

4.1.5 Natural Air Infiltration

From April 2007 to Mach 2012 the Federal Government of Canada offered homeowners a retrofit program (ecoENERGY) that provided grants up to $5,000 towards energy efficiency improvements of a house. Although the data collection was voluntary, to participate in the program the house had to undertake a pre-retrofit evaluation (Khemet, 2019). Within the evaluation was a requirement for a pre-retrofit blower door test in accordance with the CAN/CGSB-149 test standard (Khemet, 2019). In total over 900,000 houses were tested across Canada, which at the time represented 12% of the national housing stock (Khemet, 2019). Analyzing the data from the program revealed single detached residential housing ranged in ACH at 50Pa from 0.40 to 45.79 across Canada with the average value for this data 7.63 ACH (Natural Resources Canada, 2020). These results indicate a wide range of possible values when conducting air leakage testing on existing single detached residential houses in Canada.

In his research, Towards a Methodological Approach to Builder Specific, Preconstruction Airtightness Estimates for Light-framed, Detached, Low-Rise Residential Buildings In Canada, Khement developed two equations for predicting the preconstruction ACH of existing houses when general parameters about a house were known (Figure 34). Equation 15 based on three predictor variables was able to predict 32% - 35% ($p < 0.001$) of the whole house air leakage rates (Khemet, 2019). Equation 16 had a significantly higher prediction rate at 46% - 48% ($p < 0.001$) (Khemet, 2019). The key variable in either equation was the year of construction and the regression models in certain cases were found to have an equal or improved prediction than existing literature (Khemet, 2019). Implementing the equations with the data from the GHA archetype yielded a value of 4.30 ACH for equation 15 and 6.59 ACH for equation 16 (Appendix 8.4).

$$\mathbf{ACH = 135.304 - 0.005(Volume) + 1.048(Storeys) - 0.065(Year)} \quad (15)$$

$$\mathbf{ACH = 126.649 - 0.005(Volume) + 0.939(Height) - 0.057(Year) - 0.001(HDD) - 0.288(Ceiling)RSI - 0.218(Foundation)RSI - 3.264(Window)RSI - 0.400(Wall)RSI} \quad (16)$$

Figure 34: Equations for the Determination of the Preconstruction ACH in Existing Low-Rise Residential Buildings in Canada (Khemet, 2019)

A single house in the Plateau neighborhood had a blower door test performed. The test was conducted prior to any major retrofits with the exception of window and door replacement. Although the windows

and doors were replaced it was observed during field investigation that no air sealing measures were introduced that would limit air leakage between the window and wall air control connection. The tested ACH @ 50Pa was recorded at 5.12 with a house volume of 879.1m^3. This translated into an equivalent leakage area (ELA) of 1680.7cm^2. Although this value will be utilized for the production of the baseline energy model it is important to note as the air leakage value is from a single house in the Plateau neighborhood it may not represent the air leakage performance of the entire neighborhood. This could lead to houses in the neighborhood having an increased energy consumption compared to what has been captured in this research. Additional air sealing measures may be required in houses that have higher air leakage rates.

4.1.6 Ventilation

None of the houses in the Plateau neighborhood featured a whole house ventilation component or system as the time period of the 1980's had no ventilation requirement in the building code. Supplemental ventilation occurs during the operation of a dryer, range hood, and washroom exhaust fans. The operation schedule for these pieces of equipment was left to the default value as a precise indication of how often or how the ventilation component was operated could not be obtained.

4.1.7 Heating and Cooling System

The main heating source for a house in the Plateau neighborhood was a natural gas furnace. The furnace units have been upgraded since the 1980's to more efficient systems. Efficiency of the furnace ranged from 95% to 98%. Due to the high efficiency of the furnace it was paired with an energy efficient motor (ECM) and a continuous pilot ignition. Consumption values of the pilot light could not be confirmed and therefore the default value in HOT2000 was used. Cooling was provided by a central air system that is connected to the furnace. During field investigation SEER ratings of the system ranged from 14 to 18. In limited discussions with owners it was typically indicated air conditioning units were turned on in May and shut off in September. From the perspective of HOT2000 the default design month of July was selected. As limited data was obtained for the air conditioning unit all other input parameters were left to the default values contained within HOT2000.

4.1.8 Domestic Hot Water

The majority of the residences had a natural gas hot water tank for the production of hot water. The units varied from induced draft fans to direct vent, in both cases with a pilot light. These units were always located in the basement and on average had a tank volume of approximately 150 L. These units had an energy factor (EF) of 0.57. All other parameters for the domestic hot water tank were left to the default values in HOT2000.

4.1.9 Baseline Energy Model

HOT2000 complies natural gas and electrical consumption data on a per month basis. However, utility bill data is not provided in the form of the first and last day in a month. Therefore, to align the utility data with the output energy consumption of HOT2000, the utility bill data must be calendarized. The process of calendarizing utility bill data involves correctly allocating utility bill usage and the corresponding cost data for each day in a month. This is accomplished by dividing the data into day sized segments and allocating these segments to the appropriate month. Without calendarization it would be difficult to compare data on a per month basis. Table 7 and 8 provide the calendarized natural gas and electricity data that was used in the development of the baseline energy model for this research. The collected natural gas and electricity utility bills can be found in Appendix 8.5.

Table 7: Calendarized Natural Gas Utility Bill Data of the Baseline Energy Model

Calendarized Natural Gas Bills (2018)						
Month	**No. Days**	**No. Days Billing Period**	**Days Pre. Billed**	**Usage Month**	**Usage Preivous Month**	**Total (m^3)**
Dec. 2017	*31*	*23*	*8*			
Jan.	31	20	11	282.73	183.92	**466.65**
Feb.	28	16	12	210.58	169.64	**380.22**
Mar.	31	18	13	243.80	171.10	**414.90**
April	30	19	11	105.52	148.99	**254.51**
May	31	20	11	24.61	61.09	**85.70**
June	30	18	12	14.54	14.77	**29.31**
July	31	19	12	20.98	9.69	**30.68**
Aug.	31	18	13	15.24	14.36	**29.60**
Sept.	30	17	13	23.07	11.01	**34.07**
Oct.	31	16	15	94.15	20.35	**114.50**
Nov.	30	17	13	167.98	76.49	**244.47**
Dec.	31	20	11	207.15	108.69	**375.00**
Jan. 2019	*31*	*20*	*11*			

Calendarized Natural Gas Bills (2017)						
Month	**No. Days**	**No. Days Billing Period**	**Days Pre. Billed**	**Usage Month**	**Usage Preivous Month**	**Total (m3)**
Dec. 2016	*31*	*23*	*8*			
Jan.	31	20	11	283.40	174.85	**458.25**
Feb.	28	18	10	231.00	141.70	**372.70**
Mar.	31	18	13	167.82	166.83	**334.65**
April	30	18	12	72.10	111.88	**183.98**
May	31	19	12	17.95	48.06	**66.01**
June	30	18	12	11.51	11.33	**22.85**
July	31	19	12	10.47	7.68	**18.14**
Aug.	31	17	14	8.31	7.71	**16.02**
Sept.	30	16	14	9.23	6.84	**16.08**
Oct.	31	19	12	78.06	6.93	**84.99**
Nov.	30	20	10	189.41	41.09	**230.50**
Dec.	31	22	9	318.40	85.24	**403.64**
Jan. 2018	*31*	*20*	*11*			

Table 8: Calendarized Electricity Utility Bill Data of the Baseline Energy Model

Calendarized Electrical Bills (2018)						
Month	**No. Days**	**No. Days Billing Period**	**Days Pre. Billed**	**Usage Month**	**Usage Preivous Month**	**Total (kWh)**
Dec. 2017	*31*	*31*	*0*			
Jan.	31	26	5	399.85	105.97	**505.82**
Feb.	28	21	7	291.45	107.65	**399.10**
Mar.	31	24	7	331.46	97.15	**428.61**
April	30	27	3	335.21	41.43	**376.64**
May	31	30	1	448.95	12.42	**461.36**
June	30	29	1	615.57	14.96	**630.53**
July	31	31	0	773.23	0.00	**773.23**
Aug.	31	24	7	698.79	174.60	**873.40**
Sept.	30	23	7	447.35	203.82	**651.17**
Oct.	31	22	9	271.32	175.05	**446.37**
Nov.	30	23	7	343.68	86.33	**430.01**
Dec.	31	25	6	478.68	89.66	**568.33**
Jan. 2019	*31*	*22*	*9*			

Calendarized Electrical Bills (2017)						
Month	**No. Days**	**No. Days Billing Period**	**Days Pre. Billed**	**Usage Month**	**Usage Preivous Month**	**Total (kWh)**
Dec. 2016	*31*	*26*	*5*			
Jan.	31	31	0	716.77	0.00	**716.77**
Feb.	28	26	2	712.25	46.24	**758.49**
Mar.	31	31	0	695.37	0.00	**695.37**
April	30	30	0	695.37	0.00	**695.37**
May	31	31	0	598.79	0.00	**598.79**
June	30	25	5	502.77	81.00	**583.77**
July	31	27	4	515.62	92.19	**607.82**
Aug.	31	23	8	460.15	137.19	**597.34**
Sept.	30	23	7	372.58	102.06	**474.64**
Oct.	31	27	4	387.00	64.80	**451.80**
Nov.	30	6	24	439.82	206.97	**646.79**
Dec.	31	31	0	570.45	0.00	**570.45**
Jan. 2018	*31*	*26*	*5*			

Figure 35 and 36 indicate the consumption of the natural gas and electricity for the baseline energy model compared to the actual consumption of the calendarized utility bills. The complete HOT2000 energy simulations are noted Appendix 8.6. The baseline energy model is over predicting natural gas consumption throughout the heating season and is struggling to reflect the actual cooling load of the house during warmer months. This is likely connected to the limitations of the bin method and how the calculation is performed related to the determination of a temperature at a given point in time. Defining a house's energy consumption is highly dependent on obtainment of accurate temperature data. If the method utilized to determine the values related to temperature are inaccurate then it should be expected the percent error calculation of the simulation will deviate far from acceptable levels. In the summer months it is reasonable to expect none of the natural gas consumption is related to heating. Therefore, the overpredictions are related to the production of hot water and suggest the base occupant load in HOT2000 is not representative of actual conditions.

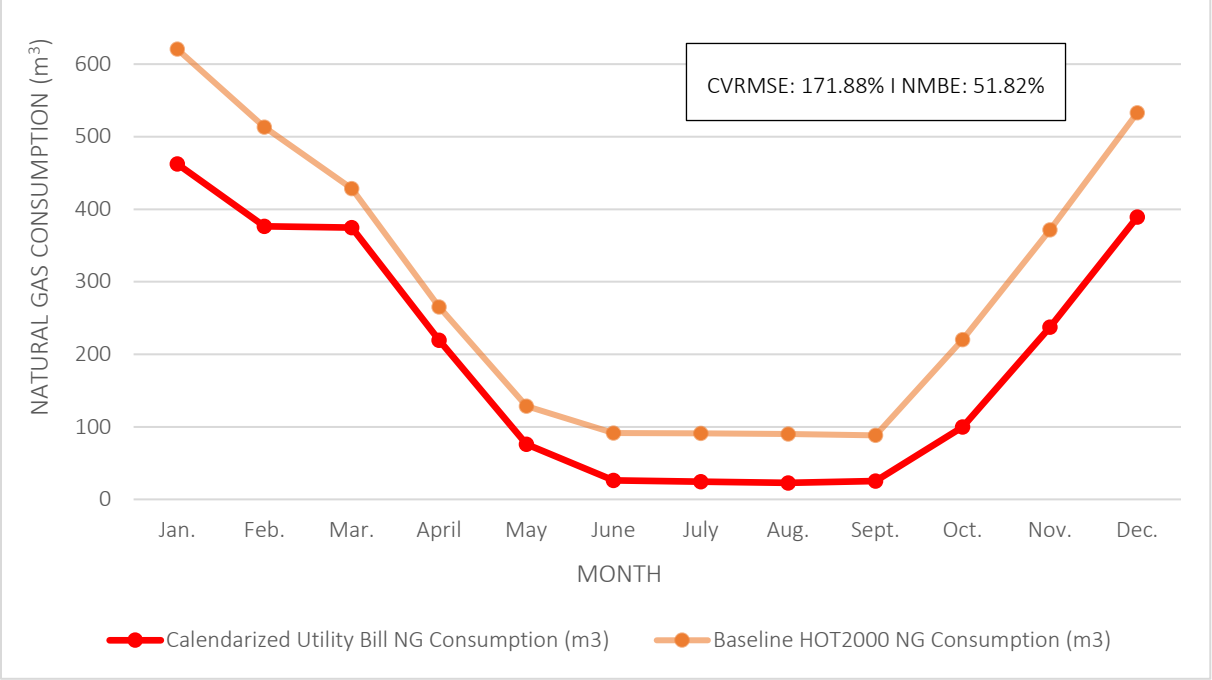


Figure 35: Calendarized Utility Bill Data (Natural Gas) vs. Baseline HOT2000 Energy Model

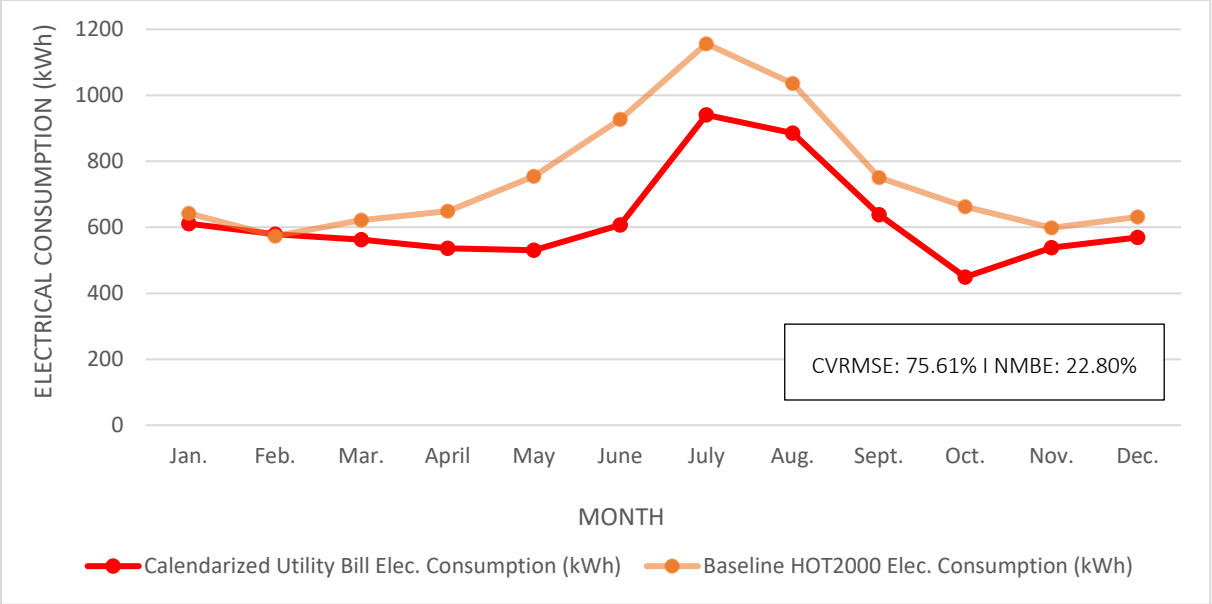


Figure 36: Calendarized Utility Bill Data (Electricity) vs Baseline HOT2000 Energy Model

4.2 Calibrated Baseline Energy Model

Variations in weather patterns play a large role in determining the energy consumption of a residential house (Beheshti et al., 2019). Modelling software will have built in data points that represent weather for a specification location or region. These data points may not correlate to the weather experienced during the time when a meter reading was taken. Therefore, it is critical to normalize the weather data in the energy modelling software to the actual weather that occurred during the time period of the utility bill measurement. The degree-day normalization is the most utilized method for adjustment of weather data (Beheshti et al., 2019). The intent of this approach is to calculate the difference of the base temperature and the average outdoor temperature for a specific length of time. The ratio method is often used, however, the data that is produced is often inaccurate (Beheshti et al., 2019). Implementing a linear regression helps to improve upon accuracy of the outputted data (Beheshti et al., 2019). As this method adopts a linearly proportion to the indoor and outdoor temperature difference it can have difficulty in shoulder seasons in matching the actual energy usage (Beheshti et al., 2019). The newly developed method named, Structure Dependent Weather Normalization, improves alignment with fluctuating weather conditions and yields improved alignment with the actual energy consumption of a residential house (Beheshti et al., 2019). Evaluation of this method would be outside the scope of this research and therefore, a least square fitting linear regression calculation for the normalization of the natural gas and electricity consumption was implemented.

The HDD and CDD values were calculated based on the temperatures for Toronto, Ontario contained within the HOT2000 weather file against a base temperature of 18°C and then multiplied by the number of days in the month. The linear regression analysis was developed by the comparison of the HDD or CDD value to the baseline HOT200 natural gas or electricity consumption. The calculations for the normalized energy consumption data for natural gas and electricity can be found in Appendix 8.7, while Figures 37 and 38 indicate the energy consumption comparison of the calendarized utility bill data and the energy consumption based on the calculated normalized weather data.

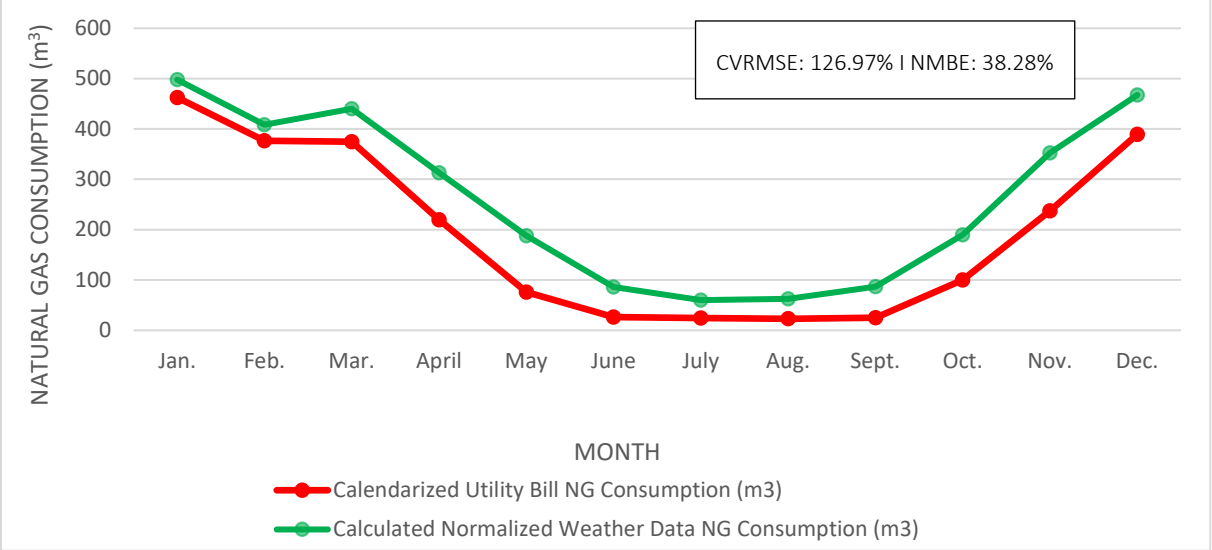


Figure 37: Calendarized Utility Bill Data vs. Normalized Calculated Utility Bill Data (Natural Gas)

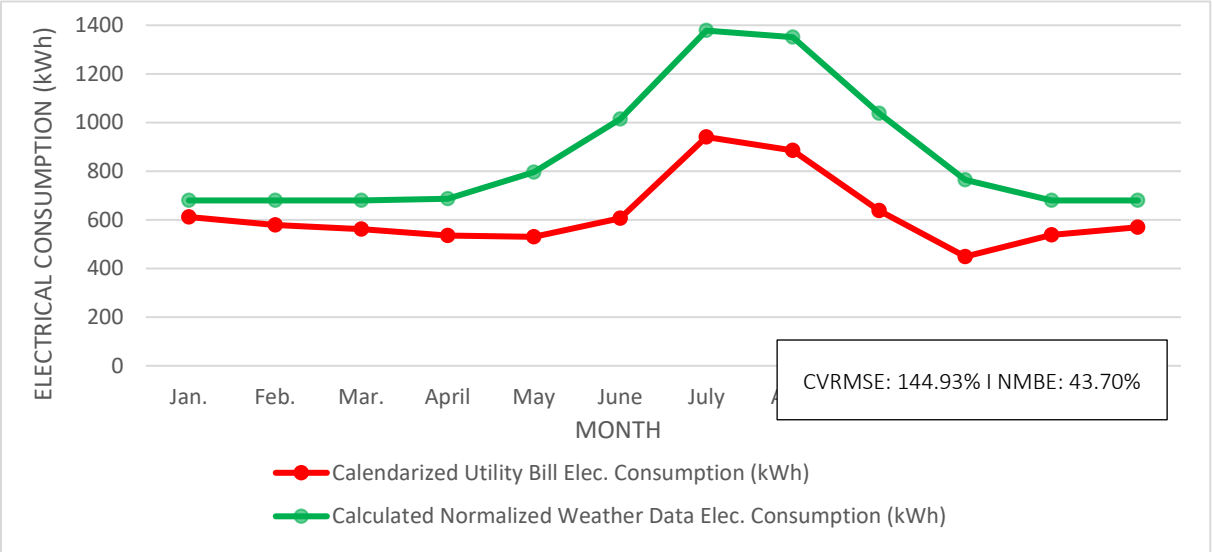


Figure 38: Calendarized Utility Bill Data vs. Normalized Calculated Utility Bill Data (Electricity)

Implementing normalized weather data for the natural gas consumption brought closer alignment to the actual calendarized utility bill consumption. However, the model error to the actual data is still well outside the acceptable limits of ASHRAE Guideline 14. When calculating the CDD values based on the temperatures noted within the HOT2000 weather file only three data points are generated. This leads to a poor fit of the regression line to the energy consumption data versus the CDD values. As a result, the model error to actual data percentage is worse than the baseline energy model. As the baseline energy model was not able to achieve acceptable alignment to the actual utility bill data even with weather normalization there are other parameters within HOT2000 that require adjustment to achieve calibration.

The final step in the development of the baseline energy model was to calibrate specific parameters that would allow close alignment of the energy consumption in HOT2000 with the calendarized utility bill data. The complete energy simulation for the calibrated baseline energy model that represented the GHA archetype can be found in Appendix 8.8. This research took the approach of fine tuning the baseline energy model until calibration was achieved with parameters of the GHA archetype that were partially understood and unknown. Even though there was limited knowledge around these attributes of the GHA archetype, only minor adjustment occurred, or the adjustment was spread out across multiple elements or factors to ensure the opportunity to yield an accurate energy model that represented the GHA occurred. If a parameter was considered firmly defined it was not altered during the calibration process. The parameters that were adjusted during the calibration process for natural gas are noted in Table 9.

Table 9: Calibration Parameters of the Baseline Energy Model to the Calendarized Utility Bill Consumption for Natural Gas

Model Adjustment	Baseline Energy Model Parameter	Calibrated Energy Model Parameter	CVRMSE (%)	NMBE (%)
Nightime Heating Setback	19°C	18°C	166.7	50.3
NG Fur. Pilot Light	25.3 MJ/day	17MJ/day	156.1	47.1
Shower Length	10 mins.	4 mins.	90.8	27.4
No. Showers Per Week	5	3	78.0	23.5
Clothes Washer	Hot	Cold	76.1	22.9
Shower Head Flow Rate	Standard 9.5L/min.	Low Flow 7.6L/min.	72.9	22.0
Bathroom Faucets	Standard 8.3L/min.	Low Flow 5.7L/min.	67.7	20.4
Dish Washer	Default	High Efficiency	66.5	20.0
Model Location	Toronto	Windsor	14.6	4.4

These minor revisions brought close alignment of the now calibrated baseline energy model to the actual natural gas consumption indicated in the calendarized utility bill data (Figure 39). Conducting the NMBE calculation as noted in ASHRAE Guideline 14 revels a percentage error of 4.42% from the baseline energy model to the actual utility bills for natural gas consumption. This is within the allowable 5% permitted in

the guideline. Performing the CVRMSE calculation revels a percentage error of 14.65%, which just meets the maximum allowable percentage error of the guideline.

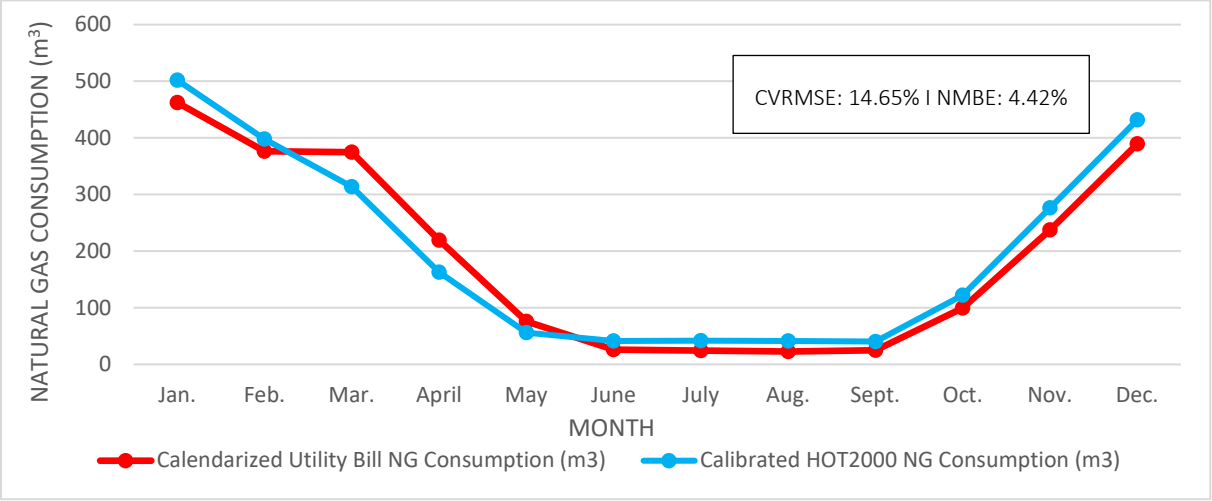


Figure 39: Calendarized Utility Bill Data (Natural Gas) vs. Calibrated HOT2000 Baseline Energy Model

The parameters that were adjusted during the calibration process for electricity are noted in Table 10. Even with these adjustments the calibrated baseline energy model in HOT2000 was still over predicting electrical consumption loads from May to July. This again highlights the struggle HOT2000 has with accurately modelling the cooling load based on the use of the bin method. With the revisions the percent error calculation for NMBE were 2.41%. Performing the CVRMSE calculation revels a percentage error of 8.00%, which is less than the maximum allowable percentage error of the guideline.

Table 10: Calibration Parameters of the Baseline Energy Model to the Calendarized Utility Bill Consumption for Electricity

Model Adjustment	Baseline Energy Model Parameter	Calibrated Energy Model Parameter	CVRMSE (%)	NMBE (%)
Improved Windows	HOT2000 Code: 200014	HOT2000 Code: 233015	74.3	22.4
Cooling Setpoint	25°C	26°C	62.9	19.0
Clothes Washer Annual Energy Consumption	197kWh	145kWh	60.3	18.2
Dish Washer	260kWh/yr	240kWh/yr	59.0	17.8
Refrigerator	639kWh/yr	625kWh/yr	58.3	17.6
Miscellaneous Electric Load	9.7kWh/day	7.5kWh/day	39.5	11.9
Exterior Electrical Load	0.9kWh/day	0.4kWh/day	29.8	9.0
Season Cooling	Start: April End: October	Start: June End: September	16.9	5.1
A/C SEER	14	16	8.0	2.4

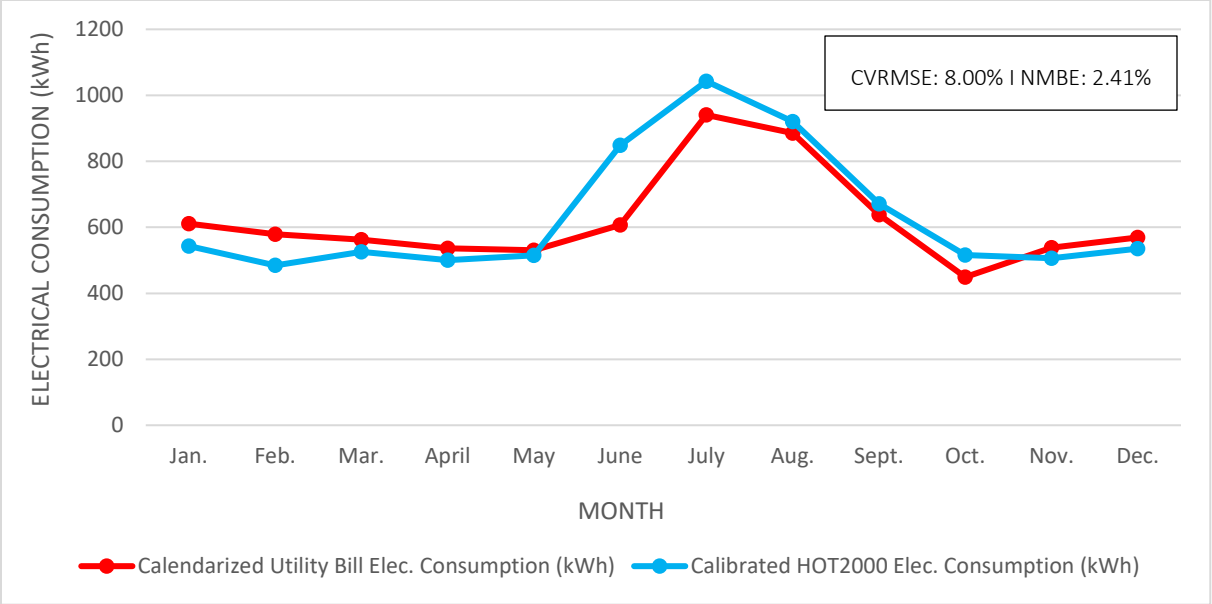


Figure 40: Calendarized Utility Bill Data (Electricity) vs. Calibrated HOT2000 Baseline Energy Model

The final calibrated baseline energy consumption value of the archetype to represent the GHA compared to the reference cases has been noted in Table 11. The GHA archetype had a slightly better ACH value, higher insulation levels in the attic and above grade walls, and significantly more efficient mechanical systems for heating and cooling compared to the Toronto 1970's OBC or the Clarington, Ontario archetypes. It is for these reasons the GHA archetype had a lower energy consumption value.

Table 11: Final Calibrated Baseline Energy Model Consumption Value vs. Reference Cases

Archetype	Energy Consumption	
	GJ/year	EUI (GJ/m^2/yr)
Toronto 1970's OBC (Blaszak, 2010)	194	0.90
Clarington, Ontario (1960 – 1977 reference case)	183	0.95
GHA Calibrated Baseline Energy Model (1980's Plateau neighborhood of East Stoney, Community within the City of Hamilton)	121	0.56

5 PHASE THREE: APPLICATION OF BUILDING ENCLOSURE AND MECHNICAL SYSTEM RETROFIT STRATEGIES

5.1 Calculation of an Energy Budget

Prior to the analysis of the retrofit solutions that will achieve NZER, an energy budget must be developed to determine how much energy a renewable technology can generate. Once this parameter is defined the energy load of the GHA archetype must be decreased until this value has been met. Solar PV panels will be analysed for the GHA archetype as the renewable technology. The optimal orientation for solar collection is due south, with acceptable levels being west or east (Canmet Energy: Natural Resources Canada, 2018). As orientation of an existing house cannot be adjusted, this research will select the north orientation to ensure the retrofit solutions that are developed are applicable to all houses. Not all of the roof area is suitable for the mounting of solar PV panels as some of the area will be required for a walking pathway, certain locations require a setback from the roof ridge or edge, plumbing of roof vents have specific locations, and particular areas of the roof might receive shading from the roof profile of a neighbouring house or a mature tree (Canmet Energy: Natural Resources Canada, 2018).

The National Renewable Energy Laboratory (NREL), a laboratory for the U.S. Department of Energy, has developed an online calculator to determine the potential amount of solar energy in kWh an actual existing house can generate based on its geographical location, orientation, and roof area called PVWatts. The tool utilizes the NREL's new proposed method for estimating rooftop suitability for solar PV panels, which has gone through an extensive calibration and validation processes (Melius et al., 2013). When calculating the solar energy for the GHA archetype in the PVWatts calculator, all parameters were left to the default values expect for array type (fixed – roof mount), tilt degree (22.6°), and azimuth degree (0°, representing north orientation). With these parameters PVWatts generated a yearly value of 25,476kWh/year, which translates to 91.71GJ/year.

Due to the resolution of the NREL solar calculator, the program implements a $1m^2$ boarder around the edges of any obstructions (Margolis, 2020). Further it is recommended for a solar PV system to allow space for a ridge setback, access pathways, sections of roof area that may not be large enough for placement of solar PV panels, and the appropriate orientation and mounting angle (Canmet Energy: Natural Resources Canada, 2018). Accounting for these reductions in the mounting area for the solar PV panels, the calculated

solar energy in PVWatts was reduced by 30%. Therefore, the final solar generation potential based on the roof area of the GHA archetype is 64.4GJ/year.

With the GHA archetype calibrated baseline energy model using 121.13GJ/year, retrofits of the building enclosure, windows, and mechanical systems will have to reduce energy usage by approximately 56.73GJ/year (53.17%) in order to meet the objectives of NZER under the CHBA Renovation Pilot Program. The administrative requirements from CHBA also note NZER houses must complete and adhered to a solar PV Ready Checklist from NRCan (Canadian Home Builders Association, 2020a). The NRCan solar PV Ready checklist can be found in Appendix 8.9.

5.2 Application of Retrofit Strategies

A costing analysis was omitted from this research as the intent was to define a NZER house based on the implementation of passive strategies first then efficient mechanical systems. Applying a costing analysis serves to only guide industry stakeholders to the lowest cost solution. The lowest cost solution may not always be the best path and its not to imply the passive first solution costs significantly more than the lowest cost solution. This research defines the methodology of the passive strategies through the implementation of measures to first reduce a houses energy load then select energy efficient mechanical systems to distribute heating, cooling, and ventilated air, and finally implement a renewable technology to address the remaining energy load of the house (Figures 41).

As this research is focused on existing houses, that hope to achieve NZER through deep energy retrofits, there are limitations on what can be altered to achieve the desired level of energy performance. Figure 42 defines a hierarchy for the steps in the typical process to achieve NZER when the ideologies of the passive strategies have been incorporated. The application of retrofit strategies to the GHA archetype will following this pathway to ensure the base energy load of the archetype has been minimized to the point where the solar PV system can generate the remaining energy load.

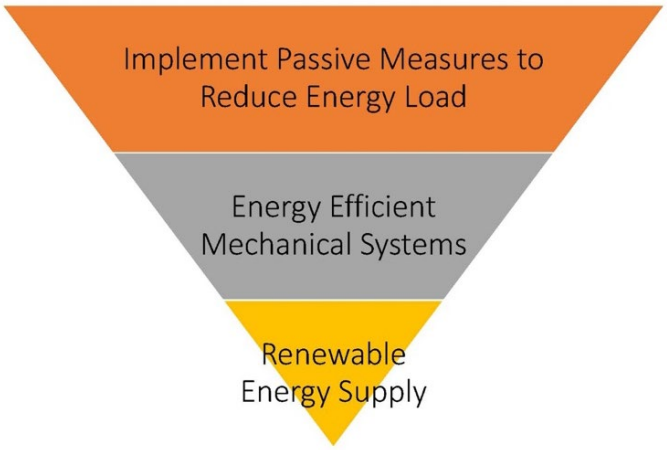


Figure 41: Passive Strategies First to Achieve NZER

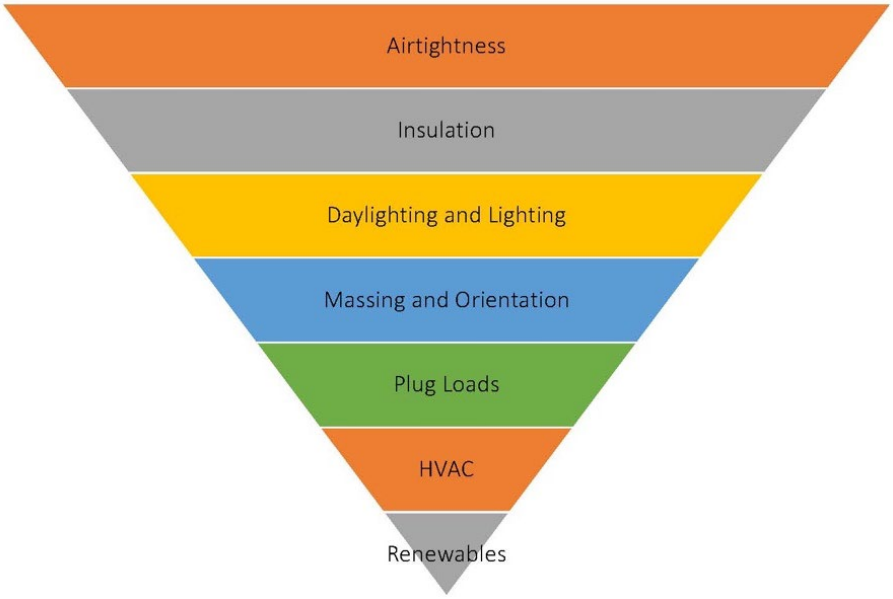


Figure 42: Hierarchy for the Steps in the Passive Strategies First Approach to Achieve NZER

Figure 43 and 44 indicate the percentage of estimated energy consumption by device for the calibrated HOT2000 baseline energy model and percentage of annual heat loss by building enclosure assembly. As Stoney Creek, Ontario is within a cold climate region defined by ASHRAE (ASHRAE, 2016), it is not unexpected that the heating load consumes the majority of energy compared to all the devices. Three factors represent the majority of heat loss for the GHA archetype, air leakage, above grade walls, and windows. To achieve NZER performance it will be critical to address and upgrade the performance attributes of these three components. The main goal of this retrofitting exercise is to reduce the houses

total energy consumption to equal or less than what can be generated in the calculation of the energy budget.

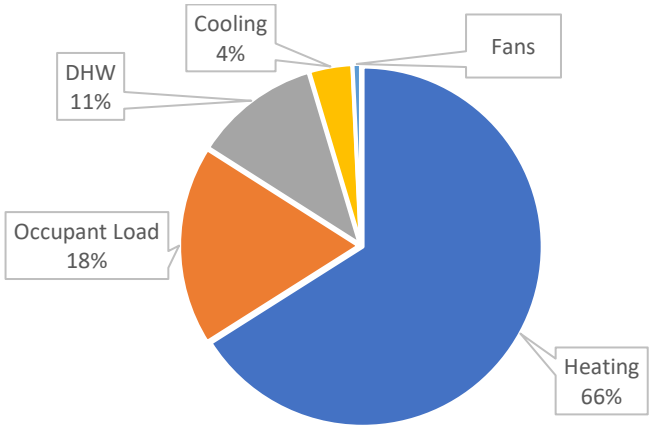


Figure 43: Percentage Estimated Energy Consumption by Device of Calibrated HOT2000 Baseline Energy Model

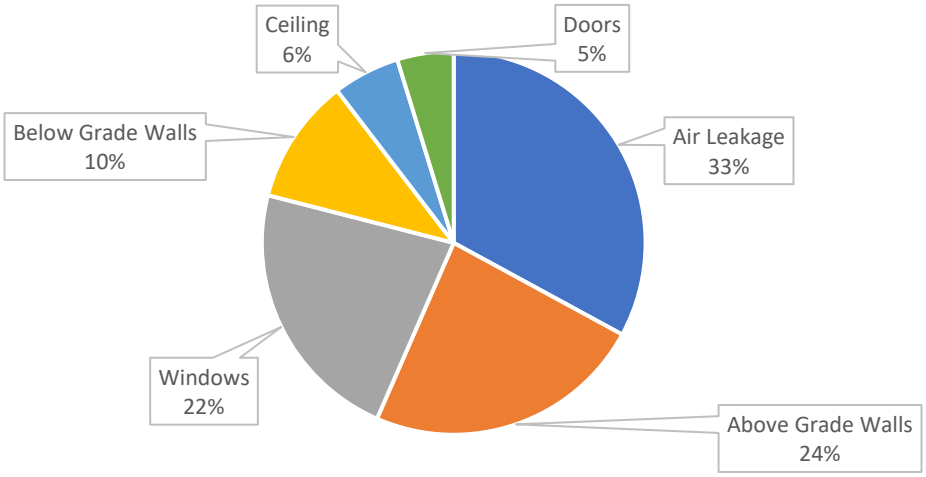


Figure 44: Percentage of Annual Heat Loss by Building Enclosure Assembly

5.2.1 Airtightness

In Section 3.0 of the CHBA NZER Renovation Pilot Program, details are provided on the minimum requirements for the airtightness and maximum air leakage rates. For detached houses, either the ACH at 50Pa or Normalized Leakage Area (NLA) at 10Pa must be met in order to quality for certification (Canadian Home Builders Association, 2020b). The maximum allowable ACH permitted is 1.5 at 50Pa (Canadian Home Builders Association, 2020b). The Passive House Institute EnerPHit Standard has been designed and

developed to significantly reduce the energy consumption of existing houses and permits a maximum airtightness pressurization test result n_{50} of 1.0 (Passive House Institute, 2016). This research also explored the impact on energy consumption when reducing the airtightness value to 1.0 at 50Pa to provide a comparison to the CHBA requirements. It is important to acknowledge the retrofitted ACH values mentioned in this research would require a complete removal of the interior layers back to the studs and the windows or a removal of the exterior cladding, weather barrier, and the windows back to the sheathing. This level of retrofit is required to achieve a continuous air seal in each assembly (ceiling, above grade walls, windows, etc.) and to ensure the continuity of the air seal has been maintained from assembly to assembly. Even with a complete removal of the interior or exterior materials extra time and attention to details will be required in the design and construction stages to achieve the airtightness values mentioned in this research. The results when the reduction of airtightness levels are applied to the energy load of the GHA archetype have been presented in Table 12.

Table 12: Reduction in Energy Consumption with Improved Airtightness

ACH @ 50Pa	Net Heating Load (GJ/yr)	Reduction in Heating Load (GJ/yr)	Net Total Energy Load (GJ/yr) *(Targeting 64.4GJ/yr)*	Energy Reduction Required to Achieve NZER (GJ/yr)
5.12	*79.97*	-	*121*	*-56.60*
5.12[1]	74.11	-	115.33	-50.93
1.5 ACH[1]	50.75	-23.36	91.79	-27.33
1.0 ACH[1]	47.40	-36.71	88.60	-24.20

Notes to Table12:

1. *Minimum effective thermal resistance values in the CHBA NZER Renovation Pilot Program for the building enclosure assemblies have been applied in the HOT2000 energy model.*

5.2.2 Building Enclosure: Above Grade Walls

This research executed a brute force 20% improvement per energy model of the minimum effective thermal resistance value for the above grade wall assembly noted in the CHBA NZER Renovation Pilot Program up to a maximum of a 100% improvement. The results for the energy modelling are noted in Table 13. Improving the effective thermal resistance of the above grade wall assembly resulted in a considerable reduction in the total energy load of the calibrated baseline energy model (3.55 – 10.55GJ/yr). However,

even with an ACH of 1.0 at 50Pa and an above grade wall effective thermal resistance of RSI 6.16, the GHA archetype was not able to achieve NZER performance.

Table 13: Impact on Energy Consumption When Increasing the Effective Thermal Resistance of the Above Grade Wall Assembly

ACH @ 50Pa	% Increase from Min. 3.08 RSI	Above Grade Wall Thermal Resistance (RSI)	Net Heating Load (GJ/yr)	Reduction in Heating Load (GJ/yr)	Energy Reduction Attributed to Insul. Improvement (GJ/yr)	Net Total Energy Load (GJ/yr) (Targeting 64.4GJ/yr)	Energy Reduction Required to Achieve NZER (GJ/yr)
Cailbrated Baseline Energy Model							
5.12	-	*2.90*	*79.97*	-	-	*121.00*	***-56.60***
Cailbrated Baseline Energy Model with Minimum Building Enclosure Requirements from CHBA NZER Renovation Pilot Program							
5.12	-	*3.08*	*74.11*	-	-	*115.33*	***-50.93***
1.5	-	*3.08*	*50.57*	-	-	*91.79*	***-27.39***
1.0	-	*3.08*	*47.4*	-	-	*88.60*	***-24.20***
1.5	20%	3.70	41.91	-38.05	-3.57	81.67	**-17.27**
1.0	20%		38.72	-41.24	-3.55	78.47	**-14.07**
1.5	40%	4.31	39.38	-40.59	-6.11	79.18	**-14.78**
1.0	40%		36.22	-43.75	-6.06	76.01	**-11.61**
1.5	60%	4.93	37.57	-42.39	-7.91	77.41	**-13.01**
1.0	60%		34.43	-45.54	-7.85	74.27	**-9.87**
1.5	80%	5.54	36.05	-43.91	-9.43	75.93	**-11.53**
1.0	80%		32.91	-47.06	-9.37	72.78	**-8.38**
1.5	100%	6.16	34.94	-45.03	-10.55	74.84	**-10.44**
1.0	100%		31.80	-48.16	-10.47	71.70	**-7.30**

Notes to Table 13:

- *Building enclosure parameters and mechanical systems not mentioned in the table have been set to the default values required for compliance with the CHBA NZER Renovation Pilot Program.*
- *The effective thermal resistance values noted in the table do not reflect an actual assembly. These values are representative of the minimum requirements necessary in the building enclosure to achieve NZER for the GHA archetype. The effective thermal resistance of an assembly in the building enclosure would have to be calculated based on actual materials to determine if its use would be acceptable in the GHA archetype. It was not the intent of this research to identify materials for the building enclosure assemblies as it may channel industry stakeholders into a direction of limited selection. The intent rather, was to provide a threshold to achieve NZER in a retrofit for the GHA archetype and then allow industry stakeholders to decide and select materials for the creation of an assembly that would satisfy the minimum threshold.*

5.2.3 Windows

After air tightness and above grade walls, the next logical item to address is the windows as this category represented the third highest amount of heat loss for the calibrated baseline energy model based on the analysis of the percentage of annual heat loss by building enclosure assembly from HOT2000. Two window options were analyzed. The first option featured an enhanced double-glazed window, while the second option included a triple glazed window. The corresponding reduction in total energy consumption attributed to the window improvement ranged from 3.25 to 6.76GJ/yr (Table 14). With an ACH of 1.0 at

50Pa and either an above grade effective thermal resistance of 5.45 or 6.16, with window option 2 the GHA archetype model was not able to achieve NZER performance.

Table 14: Impact on Energy Consumption When Decreasing the U-value of the Windows in the Calibrated Baseline Energy Model

ACH @ 50Pa	Above Grade Wall Thermal Resistance (RSI)	Window Option 1			Window Option 2		
		Net Total Energy Load (GJ/yr) (Targeting 64.4GJ/yr)	Energy Reduction Attributed to Window Improvement (GJ/yr)	Energy Reduction Required to Achieve NZER (GJ/yr)	Net Total Energy Load (GJ/yr) (Targeting 64.4GJ/yr)	Energy Reduction Attributed to Window Improvement (GJ/yr)	Energy Reduction Required to Achieve NZER (GJ/yr)
Cailbrated Baseline Energy Model							
5.12	*2.90*	*121.00*	-	***-56.60***	*121.00*	-	***-56.60***
Cailbrated Baseline Energy Model with Minimum Building Enclosure Requirements from CHBA NZER Renovation Pilot Program							
5.12	*3.08*	*115.33*	-	***-50.93***	*115.33*	-	***-50.93***
1.5	*3.08*	*91.79*	-	***-27.39***	*91.79*	-	***-27.39***
1.0	*3.08*	*88.60*	-	***-24.20***	*88.60*	-	***-24.20***
1.5	3.70	77.93	-3.73	**-13.53**	74.91	-6.76	**-10.51**
1.0		74.85	-3.62	**-10.45**	71.83	-6.64	**-7.43**
1.5	4.31	75.70	-3.48	**-11.30**	72.71	-6.47	**-8.31**
1.0		72.64	-3.37	**-8.24**	69.65	-6.36	**-5.25**
1.5	4.93	73.87	-3.54	**-9.47**	70.88	-6.53	**-6.48**
1.0		70.84	-3.42	**-6.44**	67.88	-6.39	**-3.48**
1.5	5.54	72.60	-3.33	**-8.20**	69.61	-6.32	**-5.21**
1.0		69.59	-3.19	**-5.19**	66.65	-6.13	**-2.25**
1.5	6.16	71.42	-3.42	**-7.02**	68.59	-6.24	**-4.19**
1.0		68.45	-3.25	**-4.05**	65.47	-6.23	**-1.07**

Notes to Table 14:

- *Window Option 1:*
  - *Double glazed with Low-E 0.10 (soft) coating.*
  - *13mm Argon filled with insulated spacer.*
  - *Vinyl frame, hinged window.*
  - *0.56 RSI.*
  - *0.5305 solar heat gain coefficient (SHGC).*
- *Window Option 2:*
  - *Triple glazed with Low-E 0.10 (soft) coating.*
  - *13mm Argon filled with insulated spacer.*
  - *Vinyl frame, hinged window.*
  - *0.75 RSI.*
  - *0.4804 SHGC*
- *Building enclosure parameters and mechanical systems not mentioned in the table have been set to the default values required for compliance with the CHBA NZER Renovation Pilot Program.*
- *The effective thermal resistance values noted in the table do not reflect an actual assembly. These values are representative of the minimum requirements necessary in the building enclosure to achieve NZER for the GHA archetype. The effective thermal resistance of an assembly in the building enclosure would have to be calculated based on actual materials to determine if its use would be acceptable in the GHA archetype. It was not the intent of this research to identify materials for the building enclosure assemblies as it may channel industry stakeholders into a direction of limited selection. The intent rather, was to provide a threshold to achieve NZER in a retrofit for the GHA archetype and then allow industry stakeholders to decide and select materials for the creation of an assembly that would satisfy the minimum threshold.*

5.2.4 Ventilation System

A balanced ventilation system that exchanges indoor air for outdoor air is necessary to ensure occupant health in a house that has a low ACH. To lessen the house's energy load, a system can be installed that will recover a portion of the heat and/or moisture load of the exhaust air. Calculating the minimum ventilation rate with the parameters in HOT200 yielded a value of 90L/s. Rooms associated with the ventilation load include four bedrooms, a kitchen, a living room, a dining room, a utility room, and four other bonus rooms. The ventilation rate of other areas in the basement was set to 10L/s. The operation schedule for the ventilation was set to a continuous run time of 1440 Min./Day, which is a requirement of the CHBA NZER Renovation Pilot Program. HOT2000 performs the ventilation calculations based on the incorporation of selected aspects of the CAN/CSA-F326 Residential Mechanical Ventilation Systems Standard. Those aspects include the calculation of the minimum ventilation rate of the house and an estimation of the airflow rates to create pressure imbalances in the house that exceed those allowed by the standard based on the entered airtightness of the house. The minimum ventilation rate is then calculated based on the number of entered rooms and the volume of the house.

The ventilation units analyzed for this research were models manufactured by vanEE. None of the models had a 100% recovery rate of the heating or cooling energy and therefore, it should be expected to see an increase in the total energy consumption of the calibrated baseline energy model. Three ventilation models were selected, one from vanEE's Bronze (HRV), Silver (HRV), and Gold (ERV) product offerings, which represent a good, better, best solution. The impact of these units on the energy consumption of the model for the GHA archetype has been noted in Table 15. Integration of a full house ventilation system saw an increase in energy consumption between 8.49 – 14.64GJ/yr.

Table 15: Impact on Energy Consumption with the Integration of a Whole House Ventilation System

Ventilation Unit (vanEE)	ACH @ 50Pa	Above Grade Wall Thermal Resistance (RSI)	Window	Net Total Energy Load (GJ/yr) (Targeting 64.4GJ/yr)	Increased Energy Load Due to Ventilation (GJ/yr)	Energy Reduction Required to Achieve NZER (GJ/yr)
Cailbrated Baseline Energy Model						
-	*5.12*	*2.90*	*RSI 0.45*	*121.00*	-	***-56.60***
Cailbrated Baseline Energy Model with Triple Glazed Window (Option 2), Above Grade Wall RSI 6.16, and Attic Insulation RSI 8.67						
-	*5.12*	*6.16*	*Option 2 (Triple Glazed)*	*92.18*	-	***-27.78***
-	*1.5*	*6.16*	*Option 2 (Triple Glazed)*	*69.79*	-	***-5.39***
-	*1.0*	*6.16*	*Option 2 (Triple Glazed)*	*66.83*	-	***-2.43***
Bronze: 200H HRV	1.0	6.16	Option 2 (Triple Glazed)	81.47	14.64	**-17.07**
Silver: 90H-V ECM HRV	1.0	6.16	Option 2 (Triple Glazed)	77.93	11.11	**-13.53**
Gold: G2400E ECM ERV	1.0	6.16	Option 2 (Triple Glazed)	75.32	8.49	**-10.92**

Notes to Table 15:

- *Building enclosure parameters and mechanical systems not mentioned in the table have been set to the default values required for compliance with the CHBA NZER Renovation Pilot Program.*
- *The effective thermal resistance values noted in the table do not reflect an actual assembly. These values are representative of the minimum requirements necessary in the building enclosure to achieve NZER for the GHA archetype. The effective thermal resistance of an assembly in the building enclosure would have to be calculated based on actual materials to determine if its use would be acceptable in the GHA archetype. It was not the intent of this research to identify materials for the building enclosure assemblies as it may channel industry stakeholders into a direction of limited selection. The intent rather, was to provide a threshold to achieve NZER in a retrofit for the GHA archetype and then allow industry stakeholders to decide and select materials for the creation of an assembly that would satisfy the minimum threshold.*
- *Sensible Recovery Efficiency of vanEE Ventilation Units:*
    - *Bronze 200H HRV: 0℃ 65 and -25℃ 60*
    - *Silver 90H-V ECM HRV: 0℃ 76 and -25℃ 64*
    - *Gold G2400E ECM ERV: 0℃ 81 and -25℃ 68*

5.2.5 Heating and Cooling Mechanical Equipment

The maximum efficiency enhancements were applied to the natural gas furnace and the air conditioning unit and the GHA archetype was still not able to achieve NZER performance. One solution to potentially achieving NZER was to engage heating and cooling mechanical equipment that have a higher efficiency rating than a furnace and air conditioning unit. ASHP are an alternative solution that can provide a significantly higher efficiency rating for heating and cooling loads. The efficiency of an ASHP is measured by its coefficient of performance (COP). Often an ASHP can deliver a ratio of two to three times higher for the energy out compared to energy in (Demirezen et al., 2019). However, the efficiency of the ASHP declines as the outdoor temperature decreases (Demirezen et al., 2019). For this reason, the adoption of ASHP's in a cold climate such as Canada had been slow (Hakkaki-Fard et al., 2015). As the technology improves, mechanically and through the use of innovative refrigerant mixtures, adoption rates are increasing in cold climate regions (Hakkaki-Fard et al., 2015).

This research analyzed the integration of an ASHP coupled to a furnace with the conditioned air distributed through the existing ductwork. The ASHP was identified as the primary mechanical system for the production requirements of the heating load down to a specific cut-off temperature (-8ºC). Below that temperature the natural gas furnace would assume responsibility for providing the heating load. The natural gas furnace was set to an AFUE of 98% with an electronically commutated ECM motor. An ASHP was selected from Carrier, model number 25VNA424A**30, that had a COP rating of 2.62 down to a temperature as low as -8ºC for the heating efficiency and 22.5 SEER for the cooling efficiency. The

remaining settings in HOT2000 were left to the default values. Based on the energy reduction, it can be concluded ASHP have a substantial effect on the reduction of a house's energy load due to their high efficiency rating (Table 16).

Table 16: Impact on Energy Consumption with Integration of Air Source Heat Pump

Ventilation	Window	NG Furnace	ASHP	ACH @ 50Pa	Above Grade Wall Thermal Resistance (RSI)	Net Total Energy Load (GJ/yr) (Targeting 64.4GJ/yr)	Energy Reduction Attributed to ASHP (GJ/yr)	Energy Reduction Required to Achieve NZER (GJ/yr)
Cailbrated Baseline Energy Model with Triple Glazed Window (Option 2)								
-	*RSI 0.45*	*AFUE 95%*	-	*5.12*	*2.90*	*121.00*	-	***-56.6***
Cailbrated Baseline Energy Model with Triple Glazed Window (Option 2), Above Grade Wall RSI 6.16, and Attic Insulation RSI 8.67								
vanEE ERV Gold: G2400E ECM ERV	*Option 2 (Triple Glazed)*	*AFUE 98%*	-	*5.12*	*3.70*	*107.39*	-	***-42.99***
				1.5	*3.70*	*84.74*		***-20.34***
				1	*3.70*	*81.71*		***-17.31***
vanEE ERV Gold: G2400E ECM ERV	Option 2 (Triple Glazed)	AFUE 98%	2.62 COP 22.5 SEER	1.5	3.70	71.01	-10.70	**-6.61**
				1.0		69.31	-12.40	**-4.91**
				1.5	4.31	69.80	-12.56	**-5.40**
				1.0		68.13	-11.24	**-3.73**
				1.5	4.93	68.84	-11.83	**-4.44**
				1.0		67.17	-10.52	**-2.77**
				1.5	5.54	68.13	-11.11	**-3.73**
				1.0		66.42	-9.87	**-2.02**
				1.5	6.16	67.55	-10.66	**-3.15**
				1.0		65.86	-9.28	**-1.46**

Notes to Table 16:

- *Building enclosure parameters and mechanical systems not mentioned in the table have been set to the default values required for compliance with the CHBA NZER Renovation Pilot Program.*
- *The effective thermal resistance values noted in the table do not reflect an actual assembly. These values are representative of the minimum requirements necessary in the building enclosure to achieve NZER for the GHA archetype. The effective thermal resistance of an assembly in the building enclosure would have to be calculated based on actual materials to determine if its use would be acceptable in the GHA archetype. It was not the intent of this research to identify materials for the building enclosure assemblies as it may channel industry stakeholders into a direction of limited selection. The intent rather, was to provide a threshold to achieve NZER in a retrofit for the GHA archetype and then allow industry stakeholders to decide and select materials for the creation of an assembly that would satisfy the minimum threshold.*
- *For distribution of the heating or cooling energy from an ASHP, the mechanical unit is connected to a furnace and the fan from the furnace blows across an exchanger coil that distributes the heating or cooling energy through a network of ducts. HOT2000 allocates for fan energy used in distribution of heating and cooling energy under the heating/cooling system section with data entered in the fan/pump tab. For the calibrated energy model, the heating systems fan/pump had an ECM, set to auto speed, and with a high-speed power of 167.52W. The cooling systems fan/pump also had an ECM motor and was set to auto, while the indoor fan flow rate had been set to 586.86L/s.*
- *Sensible Recovery Efficiency of vanEE Ventilation Units:*
    - *Gold G2400E ECM: 0℃ 81 and -25℃ 68*
- *Instantaneous Hot Water Unit 0.8 EF with pilot light*
- *The ASHP provides heating down to a temperature of -8°C. For temperatures below -8°C the natural gas furnace provides heating. The cooling load is solely supplied by the ASHP.*

This research also looked at a zero emissions solution for the heating and cooling load (Table 17). The ASHP was kept and functioned for the heating load down to -8°C and provided all the cooling load. The heating and cooling energy are distributed through a dedicated ductwork system that also connects and distributes ventilation air from the ERV unit. For the periods of time through the winter season when the temperature drops below -8°C, heating is provided by a 6kW baseboard heaters. Due to the higher efficiency of the electrical equipment for heating and cooling the GHA archetype is able to achieve NZER with the minimum building enclosure parameters defined in the CHBA NZER Renovation Pilot Program.

Table 17: All Electric Heating and Cooling Equipment Pathway

Ventilation	Window	Baseboard Heaters	ASHP	Hot Water	ACH @ 50Pa	Above Grade Wall Thermal Resistance (RSI)	Net Total Energy Load (GJ/yr) (Targeting 64.4GJ/yr)	Energy Reduction Required to Achieve NZER (GJ/yr)
Cailbrated Baseline Energy Model								
-	*RSI 0.45*	*AFUE 95%*	-	*0.57 EF Tank*	*5.12*	*2.90*	*121.00*	***-56.60***
vanEE ERV Gold: G2400E ECM ERV	Option 2	6 kW (100% Efficiency)	Heating COP 2.62	Conventional Tank 0.83 EF	1.5 1.0	3.08 3.08	59.26 57.51	**5.14** **6.89**

Notes to Table 17:

- *Building enclosure parameters and mechanical systems not mentioned in the table have been set to the default values required for compliance with the CHBA NZER Renovation Pilot Program.*
- *The effective thermal resistance values noted in the table do not reflect an actual assembly. These values are representative of the minimum requirements necessary in the building enclosure to achieve NZER for the GHA archetype. The effective thermal resistance of an assembly in the building enclosure would have to be calculated based on actual materials to determine if its use would be acceptable in the GHA archetype. It was not the intent of this research to identify materials for the building enclosure assemblies as it may channel industry stakeholders into a direction of limited selection. The intent rather, was to provide a threshold to achieve NZER in a retrofit for the GHA archetype and then allow industry stakeholders to decide and select materials for the creation of an assembly that would satisfy the minimum threshold.*
- *Ventilation air from ERV distributed by 69.57W circulation fan.*
- *Heated and cooled air from ASHP distributed by 326.9W high speed fan.*
- *The ASHP provides heating down to a temperature of -8°C. For temperatures below -8°C the baseboard heaters provide heating. The cooling load is solely supplied by the ASHP.*

5.2.6 Domestic Hot Water

With alterations of the building enclosure exhausted and the heating and cooling system optimized, the last area to review for a possible reduction in the total energy consumption of the GHA archetype when natural gas is utilized as the heating fuel, is the production of hot water. The calibrated baseline energy model had a conventional hot water tank with an EF of 0.55. Other options are available for heating water that range from an instantaneous (EF 0.80), instantaneous condensing (EF 0.83), or a condensing hot water

tank (EF 0.86). An Instantaneous hot water unit was modelled first as it is the least efficient solution of all the options. All input parameters for the instantaneous hot water unit were left to the default values in HOT2000. The more efficient unit allowed many of the packages to achieve NZER performance (Table 18). Further, increasing of the efficiency for the hot water unit might allow all the packages to achieve compliance with NZER performance. Table 19 provides insight for removal of the natural gas furnace and hot water unit for all electric solutions.

Table 18: Impact on Energy Consumption with Integration of an Instantaneous Hot Water Unit

Ventilation	Window	NG Furnace	ASHP	ACH @ 50Pa	Above Grade Wall Thermal Resistance (RSI)	Instantaneous Hot Water Net Energy Load (GJ/yr)	Energy Reduction Required to Achieve NZER (GJ/yr)
Cailbrated Baseline Energy Model							
-	*RSI 0.45*	*AFUE 95%*	-	*5.12*	*2.90*	*121 (0.57 EF Tank Water Heater)*	***-56.60***
vanEE ERV Gold: G2400E ECM ERV	Option 2	AFUE 98%	Heating COP 2.62 SEER 22.5	1.5	3.70	66.68	**-2.28**
				1.0	3.70	64.98	**-0.58**
				1.5	4.31	65.43	**-1.03**
				1.0	4.31	63.73	**0.67**
				1.5	4.93	64.45	**-0.05**
				1.0	4.93	62.76	**1.64**
				1.5	5.54	63.72	**0.68**
				1.0	5.54	62.04	**2.36**
				1.5	6.16	63.14	**1.26**
				1.0	6.16	61.47	**2.93**

Notes to Table 18:

- *Building enclosure parameters and mechanical systems not mentioned in the table have been set to the default values required for compliance with the CHBA NZER Renovation Pilot Program.*
- *The effective thermal resistance values noted in the table do not reflect an actual assembly. These values are representative of the minimum requirements necessary in the building enclosure to achieve NZER for the GHA archetype. The effective thermal resistance of an assembly in the building enclosure would have to be calculated based on actual materials to determine if its use would be acceptable in the GHA archetype. It was not the intent of this research to identify materials for the building enclosure assemblies as it may channel industry stakeholders into a direction of limited selection. The intent rather, was to provide a threshold to achieve NZER in a retrofit for the GHA archetype and then allow industry stakeholders to decide and select materials for the creation of an assembly that would satisfy the minimum threshold.*
- *Sensible Recovery Efficiency of vanEE Ventilation Units:*
  - *Gold G2400E ECM: 0℃ 81 and -25℃ 68*
- *The ASHP provides heating down to a temperature of -8°C. For temperatures below -8°C the natural gas furnace provides heating. The cooling load is solely supplied by the ASHP.*

Table 19: All Electrical Heating and Cooling Equipment with Instantaneous Electric Hot Water Unit

Ventilation	Window	Baseboard Heaters	ASHP	Hot Water	ACH @ 50Pa	Above Grade Wall Thermal Resistance (RSI)	Net Total Energy Load (GJ/yr) (Targeting 64.4GJ/yr)	Energy Reduction Required to Achieve NZER (GJ/yr)
Cailbrated Baseline Energy Model								
-	*RSI 0.45*	*AFUE 95%*	-	*0.57 EF Tank*	*5.12*	*2.90*	*121.00*	***-56.60***
vanEE ERV Gold: G2400E ECM ERV	Option 2	6 kW (100% Efficiency)	Heating COP 2.62 SEER 22.5	Instantaneous 0.94 EF	1.5	3.08	59.26	**5.14**
					1.0	3.08	57.51	**6.89**
					1.5	3.70	57.45	**6.95**
					1.0	3.70	55.72	**8.68**
					1.5	4.31	56.15	**8.25**
					1.0	4.31	54.43	**9.97**
					1.5	4.93	55.17	**9.23**
					1.0	4.93	53.46	**10.94**
					1.5	5.54	54.44	**9.96**
					1.0	5.54	52.76	**11.64**
					1.5	6.16	53.81	**10.59**
					1.0	6.16	52.08	**12.32**

Notes to Table 19:

- *Building enclosure parameters and mechanical systems not mentioned in the table have been set to the default values required for compliance with the CHBA NZER Renovation Pilot Program.*
- *The effective thermal resistance values noted in the table do not reflect an actual assembly. These values are representative of the minimum requirements necessary in the building enclosure to achieve NZER for the GHA archetype. The effective thermal resistance of an assembly in the building enclosure would have to be calculated based on actual materials to determine if its use would be acceptable in the GHA archetype. It was not the intent of this research to identify materials for the building enclosure assemblies as it may channel industry stakeholders into a direction of limited selection. The intent rather, was to provide a threshold to achieve NZER in a retrofit for the GHA archetype and then allow industry stakeholders to decide and select materials for the creation of an assembly that would satisfy the minimum threshold.*
- *Ventilation air from ERV distributed by 69.57W circulation fan.*
- *Heated and cooled air from ASHP distributed by 326.9W high speed fan.*
- *The ASHP provides heating down to a temperature of -8°C. For temperatures below -8°C the baseboard heaters provide heating. The cooling load is solely supplied by the ASHP.*

5.2.7 Increased Insulation Levels: Below Grade Walls, Ceiling, and Basement Slab

Although the below grade wall assembly only represents a small portion of the total heat loss of the GHA archetype compared to other elements in the building enclosure, it is worth analyzing to see if adjustments to this parameter can push the archetype model into NZER performance. To determine the impact of increasing the insulation level on the total energy load, insulation was increased in the below grade wall assembly and then modeled in HOT2000. Table 20 indicates the impact of doubling the minimum effective thermal resistance in the below grade wall assembly. Doubling the effective thermal resistance resulted in a minor energy savings of 0.50GJ/yr. This level of energy reduction would not move any of the ASHP packages into the NZER performance target. However, due to the limitations of how heat loss is calculated

in HOT2000 through the ground this conclusion should be verified with a more advanced energy simulation software.

Table 20: Impact on Energy Consumption When Increasing the Effective Thermal Resistance of the Below Grade Wall Assembly

Ventilation	ACH @ 50Pa	Above Grade Wall Thermal Resistance (RSI)	Window	Below Grade Wall Assembly Thermal Resistance (RSI)	Net Total Energy Load (GJ/yr) (Targeting 64.4GJ/yr)	Energy Reduction Required to Achieve NZER (GJ/yr)	Energy Reduction Attributed to Insul. Improvement (GJ/yr)
Cailbrated Baseline Energy Model							
-	*5.12*	*2.90*	*RSI 0.45*	-	*121.00*	***-56.60***	-
vanEE ERV Gold:	1.5	6.16	Option 2	2.98	78.21	**-13.81**	**0.50**
G2400E ECM ERV	1.5	6.16	Option 2	6.16	77.70	**-13.30**	

Notes to Table 20:

- *Building enclosure parameters and mechanical systems not mentioned in the table have been set to the default values required for compliance with the CHBA NZER Renovation Pilot Program.*
- *The effective thermal resistance values noted in the table do not reflect an actual assembly. These values are representative of the minimum requirements necessary in the building enclosure to achieve NZER for the GHA archetype. The effective thermal resistance of an assembly in the building enclosure would have to be calculated based on actual materials to determine if its use would be acceptable in the GHA archetype. It was not the intent of this research to identify materials for the building enclosure assemblies as it may channel industry stakeholders into a direction of limited selection. The intent rather, was to provide a threshold to achieve NZER in a retrofit for the GHA archetype and then allow industry stakeholders to decide and select materials for the creation of an assembly that would satisfy the minimum threshold.*
- *Sensible Recovery Efficiency of vanEE Ventilation Units:*
    - *Gold G2400E ECM: 0℃ 81 and -25℃ 68*

The next parameter that was analyzed for increased levels of insulation and its impact on the reduction of the yearly total energy load was the ceiling assembly. The ceiling assembly was increased from an effective RSI 8.67 to RSI 17.61.(Table 21). The significant increase of insulation in the ceiling assembly almost resulted in an energy savings of 1GJ/yr.

Table 21: Impact on Energy Consumption When Increasing the Effective Thermal Resistance of the Ceiling Assembly

Ventilation	NG Furnace (Heating System below -8°C)	ASHP (Heating System down to -8°C and Cooling System)	Window	Ceiling Thermal Resistance (RSI)	ACH @ 50Pa	Above Grade Wall Thermal Resistance (RSI)	Net Total Energy Load (GJ/yr) (Targeting 64.4GJ/yr)	Energy Reduction Required to Achieve NZER (GJ/yr)
Cailbrated Baseline Energy Model								
-	*AFUE 95%*	-	*RSI 0.45*	*5.28*	*5.12*	*2.90*	*121.00*	***-56.60***
vanEE ERV Gold: G2400E ECM ERV	AFUE 98%	COP 2.62 SEER 22.5	Option 2	17.61	1.5	3.70	70.05	-0.95
					1.0		68.36	-0.95
					1.5	4.31	68.84	-0.96
					1.0		67.17	-0.96
					1.5	4.93	67.91	-0.93
					1.0		66.20	-0.97
					1.5	5.54	67.14	-0.99
					1.0		65.48	-0.94
					1.5	6.16	66.56	-0.99
					1.0		64.92	-0.93

Notes to Table 21:

- *The minimum effective thermal resistance of the ceiling assembly is RSI 8.67.*
- *Building enclosure parameters and mechanical systems not mentioned in the table have been set to the default values required for compliance with the CHBA NZER Renovation Pilot Program.*
- *The effective thermal resistance values noted in the table do not reflect an actual assembly. These values are representative of the minimum requirements necessary in the building enclosure to achieve NZER for the GHA archetype. The effective thermal resistance of an assembly in the building enclosure would have to be calculated based on actual materials to determine if its use would be acceptable in the GHA archetype. It was not the intent of this research to identify materials for the building enclosure assemblies as it may channel industry stakeholders into a direction of limited selection. The intent rather, was to provide a threshold to achieve NZER in a retrofit for the GHA archetype and then allow industry stakeholders to decide and select materials for the creation of an assembly that would satisfy the minimum threshold.*
- *Sensible Recovery Efficiency of vanEE Ventilation Units:*
    - *Gold G2400E ECM: 0℃ 81 and -25℃ 68*

The final parameter that was evaluated was the addition of insulation to the concrete floor slab in the basement. Four options were analyzed, an addition of RSI 0.88, 1.76, 2.64, and 3.52 to the slab. Each of the options offered a minor reduction of the total energy load compared to the calibrated energy model that had no insulation in the slab (Table 22). This led to the conclusion there is little benefit adding insulating to the slab of an existing house for the purpose to reduce the houses total energy consumption when modelled in HOT2000. However, due to the limitations of how heat loss is calculated in HOT2000 through the ground this conclusion should be verified with a more advanced energy simulation software.

Table 22: Impact on the Energy Consumption with the Inclusion of Insulation in the Below Grade Slab

Ventilation	**ACH @ 50Pa**	**Above Grade Wall Thermal Resistance (RSI)**	**Window**	**NG Furnace** (Heating System below -8°C)	**ASHP** (Heating System down to -8°C and Cooling System)	**Slab Thermal Resistance (RSI)**	**Net Total Energy Load (GJ/yr)** (Targeting 64.4GJ/yr)	**Energy Reduction Required to Achieve NZER (GJ/yr)**	**Energy Reduction Attributed to Insul. Improvement (GJ/yr)**
Calibrated Baseline Energy Model									
-	*5.12*	*2.90*	*RSI 0.45*	*AFUE 95%*	-	**-**	*121.00*	**-56.60**	**-**
vanEE ERV Gold: G2400E ECM ERV	1.5	6.16	Option 2	AFUE 98%	COP 2.62 SEER 22.5	0	67.00	**-2.36**	-
						0.88	66.41	**-1.77**	-0.60
						1.76	66.29	**-1.65**	-0.71
						2.64	66.20	**-1.56**	-0.80
						3.52	66.13	**-1.49**	-0.87

Notes to Table 22:

- *Building enclosure parameters and mechanical systems not mentioned in the table have been set to the default values required for compliance with the CHBA NZER Renovation Pilot Program.*
- *The effective thermal resistance values noted in the table do not reflect an actual assembly. These values are representative of the minimum requirements necessary in the building enclosure to achieve NZER for the GHA archetype. The effective thermal resistance of an assembly in the building enclosure would have to be calculated based on actual materials to determine if its use would be acceptable in the GHA archetype. It was not the intent of this research to identify materials for the building enclosure assemblies as it may channel industry stakeholders into a direction of limited selection. The intent rather, was to provide a threshold to achieve NZER in a retrofit for*

the GHA archetype and then allow industry stakeholders to decide and select materials for the creation of an assembly that would satisfy the minimum threshold.

- *Sensible Recovery Efficiency of vanEE Ventilation Units:*
    - *Gold G2400E ECM: 0℃ 81 and -25℃ 68*

6 PHASE FOUR: EVALUATION OF COMFORT AND DURABILITY

6.1 Assessing the Comfort of the Below Grade Slab

Energy modelling in HOT2000 revealed there was little improvement for reducing the energy consumption of the GHA archetype when insulation was added to the below grade concrete floor slab. However, the inclusion of insulation to an assembly can also effect the comfort and durability parameters. The Passive House Institute mandates to maintain comfort no interior horizontal surface shall be below 18°C and to ensure no condensation and mold growth the surface should be maintained above 9.3°C and 12.6°C when interior operating conditions are 20°C with 50% relative humidity (Passive House Institute, 2016).

To analysis the impact insulation had on the comfort and durability of the below grade concrete floor slab modelling was undertaken utilizing THERM v7.7.10. This program conducts two-dimensional conduction heat-transfer analysis based on finite-element calculations. This allows the modelling of complex geometries in building assemblies to determine heat flow through the assembly. The assembly was modelled under wintertime conditions that have an exterior temperature of -20°C and an interior temperature of 20°C. The two assemblies modelled were identical expect for three components that were only found in the assembly with slab insulation. 38mm of EPS insulation was placed directly on top of the existing concrete floor slab, with 38x89mm wood studs laid on top of the insulation, and then 19mm plywood sheathing connected to the wood studs.

The assembly without insulation in the slab had a surface temperature of 13.3°C at the connection point between the interior framed wall and the existing concrete floor slab (Figure 45). Due to the thermal bridge at the foundation to wall connection, the slab assembly did not reach a surface temperature of 20°C until approximately 600mm from the interior face of the framed wall. Introducing insulation on top of the existing floor slab increased the surface temperature of the floor by 5.2°C at the connection between the framed wall and the floor surface (Figure 45). The floor assembly with slab insulation reached a surface temperature of 20°C at approximately 445mm from the interior face of the framed wall assembly. It can be concluded that an uninsulated slab could introduce occupant comfort issues based on the minimum requirements to maintain comfort noted in the Passive House Institutes Standard. Neither slab

configuration had a risk of condensation production leading to the potential development of mold growth as the temperature of both slabs were maintained above the minimum set points.

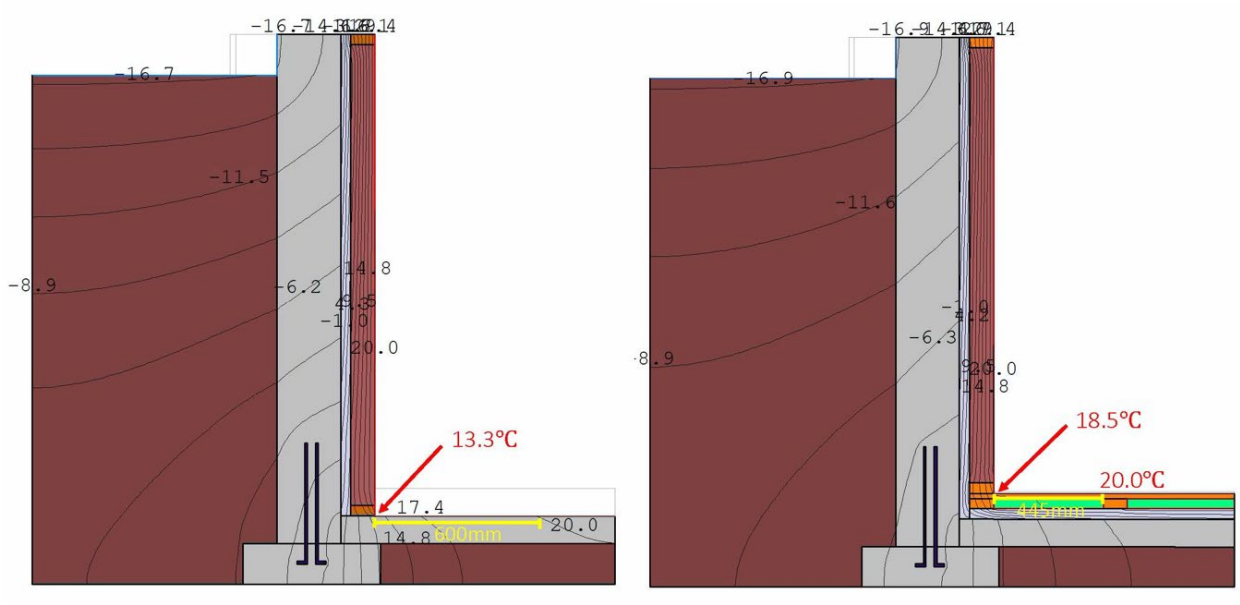


Figure 45: Temperature Analysis to Determine Comfort and Durability of an Uninsulated vs. Insulated Below Grade Slab Assembly

6.2 Hygrothermal Modelling: Retrofitted Above Grade Wall Assemblies

To meet the objectives of the CHBA NZER Renovation Pilot Program the above grade wall assembly required a high effective thermal resistance, which results in a thicker wall assembly. A higher thermal resistance is beneficial as it reduces the houses total energy consumption, however, the decrease in heat flow through the assembly introduces new challenges related to durability. With less heat energy flowing through the assembly the ability of the assembly to dry had been reduced. If the assembly were to get wet, it may stay wet for longer periods of time, which could lead to the development of mold growth if the right conditions are present (Viitanen & Ojanen, 2007).

To determine if the interior and exterior retrofits of the above grade wall assemblies would negatively alter the long-term durability, hygrothermal analysis was undertaken. Hygrothermal analysis was performed using WUFI Pro 6.4 that looked at hourly simulations of a base case, interior retrofitted, and exterior retrofitted wall assembly (Figures 46, 47, 48). The retrofitted above grade wall assemblies were compared to a base case that is known to provide a reasonable level of performance in a cold climate. Finch and Hanam (2013) noted, the performance of these baseline assemblies under normal Canadian climate

conditions is well understood and modeling using WUFI has found good agreement with field measurements and historical performance data of these baseline assemblies.

The objective was to test the retrofitted wall assemblies against a base case scenario to compare the relative performance. The comparison looked at how the assemblies performed under normal operating conditions and then the hygrothermal modelling analysed how the wall assemblies performed when exposed to a driving rain leak. Although an exterior wood sheathing layer is not actually present in either the base case or the retrofitted above grade wall assemblies, it was included in hygrothermal modelling as it is commonly used as a primary indicator to determine moisture performance (Finch & Hanam, 2013). In the report NZER Building Enclosures Retrofits for Houses: An Analysis of Retrofit Strategies, Finch and Hanam (2013) noted, "the sheathing is moisture sensitive and is typically the component most likely to be become damaged by moisture ingress from vapour diffusion, air leakage, or water leakage" (p. 8). The composition of the base case, interior, and exterior retrofitted wall assemblies can be found in the Appendix 8.10.

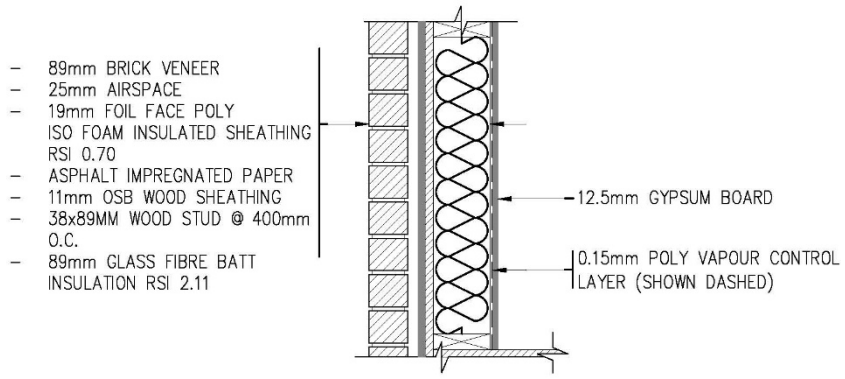


Figure 46: Base Case Above Grade Wall Assembly

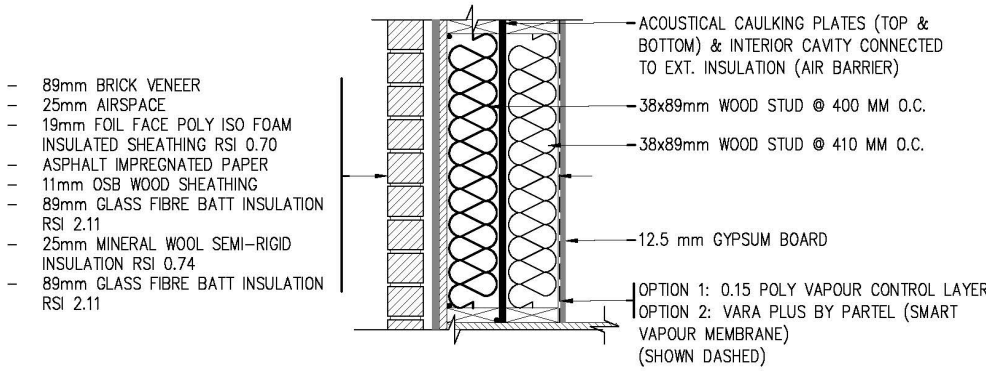


Figure 47: Interior Retrofitted Above Grade Wall Assembly

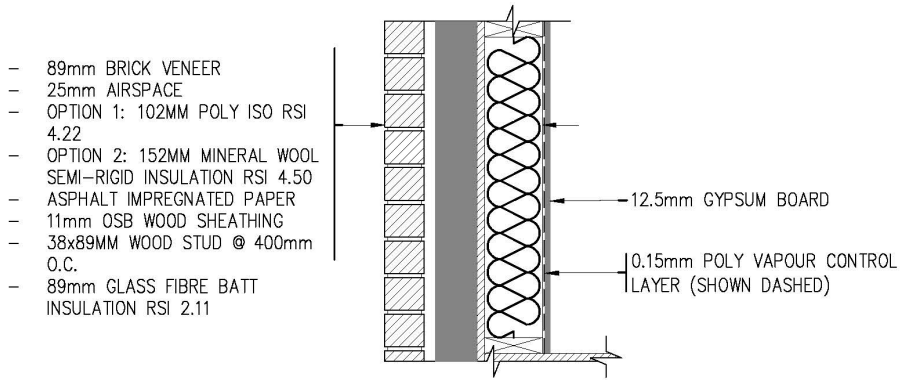


Figure 48: Exterior Retrofitted Above Grade Wall Assembly

6.2.1 Normal Operating Conditions

The first hygrothermal scenario evaluated the wall assemblies under normal operating conditions. These conditions included a 19mm vented air cavity without additional moisture capacity and a 5mm cavity that simulated a 1% driving rain leak behind the cladding layer (Lstiburek et al., 2016). The houses orientation was modelled in a north and south direction as it provides the most informative information when evaluating interior condensation risks (Lstiburek et al., 2016). The rain load was calculated in WUFI to the ASHRAE 160 Standard with a rain exposure factor (FE) of 1.0 and a rain deposition factor (FD) of 0.5. For the surface transfer coefficients, the exterior surface heat resistance was set to 0.0588m^2K/W and the interior surface heat resistance was set to 0.125m^2K/W. Red brick was selected for the short-wave radiation absorptivity, which represented a value of 0.68 and latex paint 1 was selected for the interior sd-Value at 0.2. The remaining constraints were left to the default values provided in WUFI.

The calculation period was run from January 1st, 2020 to December 31st, 2025 providing a five-year hygrothermal analysis. For the exterior climate region, Toronto (cold year) was selected as it had the closest weather characteristics to that of Stoney Creek, Ontario. The interior climate was set to the requirements of the ASHRAE 160 Standard. The heating set point temperature was adjusted to 20°C, while the number of bedrooms was increased to four, the air exchange rate was defined as 5.12 at 50Pa, and the houses volume set to 879m^3.

The results of the hygrothermal analysis indicated that all three assemblies performed well under normal loading conditions as noted in Figure 49 and 50. The interior retrofitted wall assemblies were slightly more wet and took longer to dry compared to the base case wall assembly. This is to be expected as the interior face of the exterior orientated strand board (OSB) sheathing will experience colder temperatures due to

the increased level of thermal resistance. In the north orientation of the interior retrofitted assembly, with a smart vapour control layer, the assembly experienced an increased wetting during summer months into the fall season. It results in the assembly requiring a longer drying period until it regains similar performance to the base case and interior retrofitted wall assembly with 0.15mm poly. These results suggest during warmer temperatures the smart vapour control layer becomes more vapour open and allows a very small amount of moisture to enter the assembly.

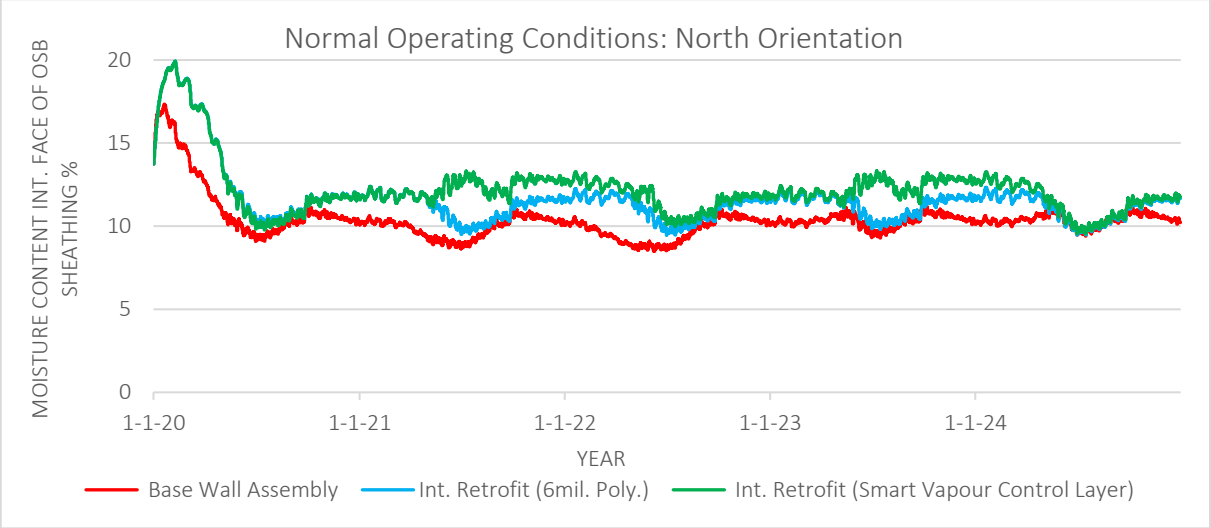


Figure 49: Normal Operating Conditions: Percentage of Moisture Content for Interior Face of Exterior OSB Sheathing in the Base Case and Interior Retrofitted (Double Stud) Above Grade Wall Assembly (North Orientation)

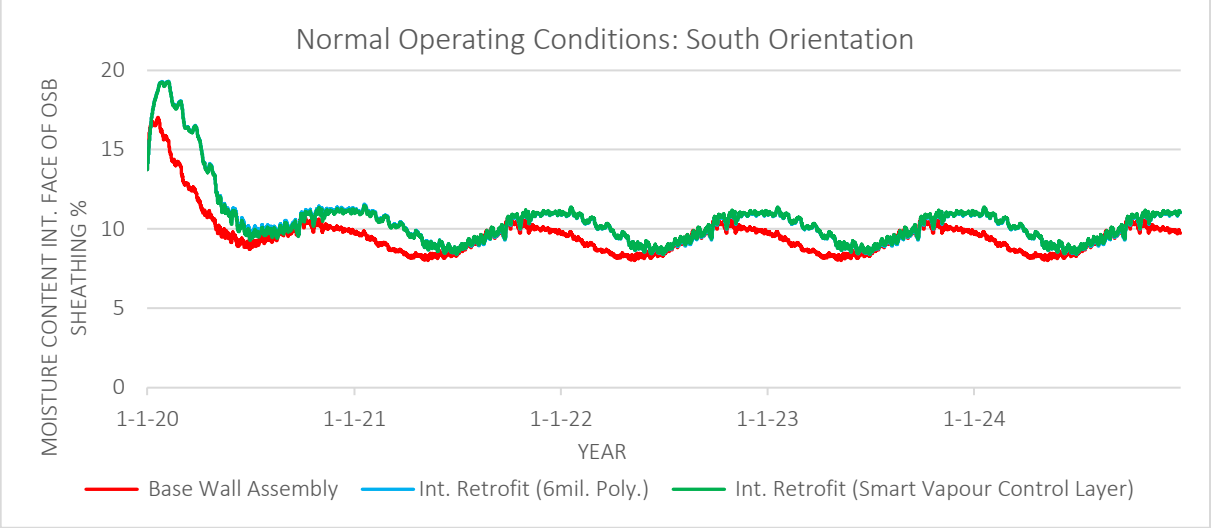


Figure 50: Normal Operating Conditions: Percentage of Moisture Content for Interior Face of Exterior OSB Sheathing in the Base Case and Interior Retrofitted (Double Stud) Above Grade Wall Assembly (South Orientation)

The exterior retrofitted above grade wall assemblies also performed well under normal operating conditions as indicated in Figure 51 and 52. As the exterior retrofitted wall assemblies had increased levels of thermal resistance outboard of the stud wall these assemblies experienced less wetting during cold periods as the interior face of the exterior OSB sheathing is kept above the DEW point temperature for a greater portion of the year. When the exterior retrofitted assemblies did get wet, the assembly with semi-rigid mineral wool insulation dried at a faster rate compared to the assembly with exterior rigid foam board. This result suggests the type of exterior insulation and the permeance rating is directly connected to the outward drying potential of the wall assembly. This becomes critically important if the interior membrane is impermeable as the assembly should be able to dry in at least one direction (Straube & Smegal, 2009).

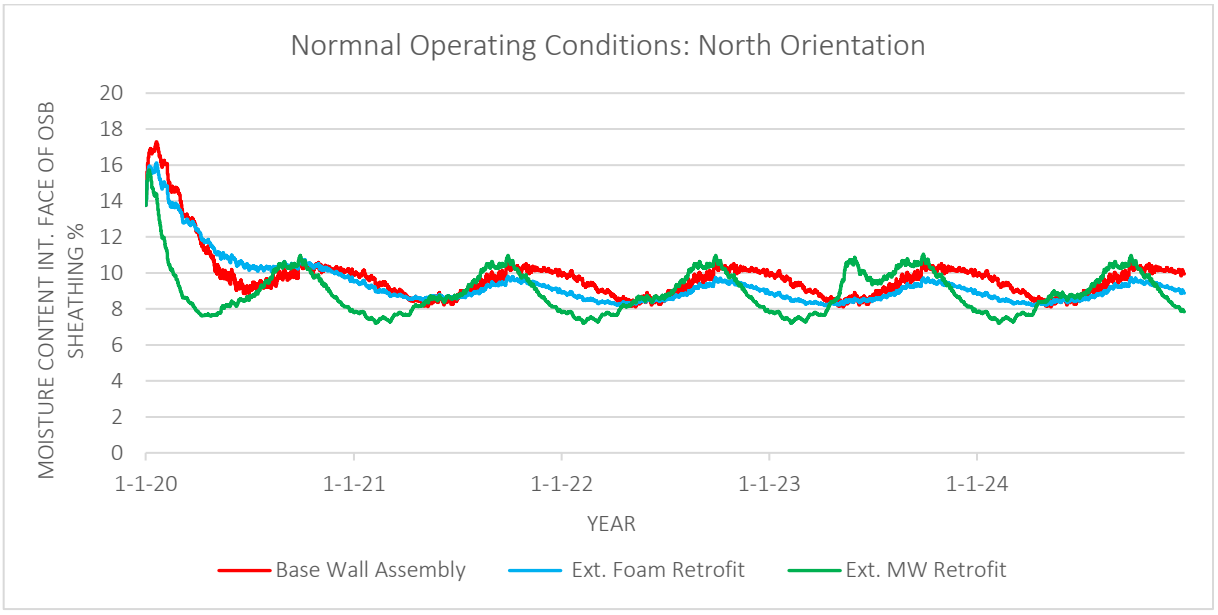


Figure 51: Normal Operating Conditions: Percentage of Moisture Content for Interior Face of Exterior OSB Sheathing in the Base Case and Exterior Retrofitted (Foam Board and Mineral Wool Insulation) Above Grade Wall Assembly (North Orientation)

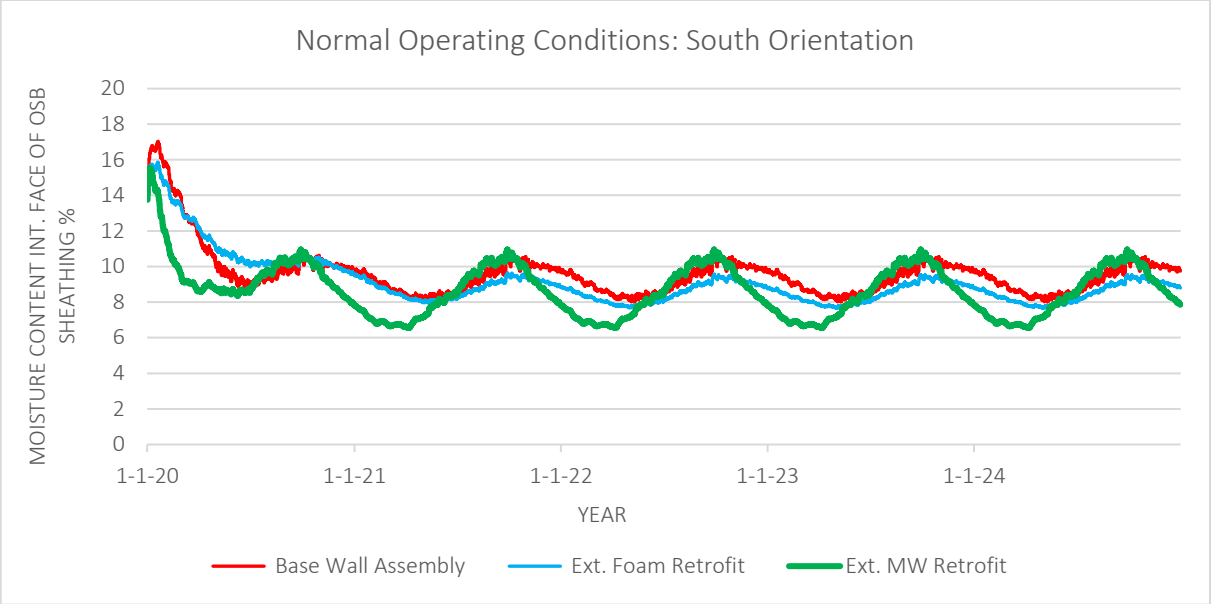


Figure 52: Normal Operating Conditions: Percentage of Moisture Content for Interior Face of Exterior OSB Sheathing in the Base Case and Exterior Retrofitted (Foam Board and Mineral Wool Insulation) Above Grade Wall Assembly (South Orientation)

6.2.2 Exposure to a Driving Rain Leak

A moisture load was placed in-between the water control layer (asphalt impregnated paper) and the front face of the exterior OSB sheathing to simulate a wetting event from a driving rain leak. The 11mm OSB wood sheathing layer was divided into three equal segments with a leak placed on the interior face of the segment closes to the exterior. A fraction of the rain load (two percent) was used, which was cut-off at the free water saturation level of the OSB sheathing. A two percent driving rain load was selected as the base case above grade wall assembly was able to seasonably tolerate this level of wetting as the moisture content of the OSB sheathing rose to approximately 30%. East and southeast orientations were modelled as these directions represented the highest amount of driving rain (mm/a) as noted within the climate analysis of WUFI Pro 6.4 for Toronto, Ontario. For the interior retrofitted wall assemblies, both experienced an increased moisture content compared to the base case wall assembly (Figure 53 and 54). Replacing the interior 0.15mm. poly membrane with a smart vapour control layer allowed the wall assembly to dry at a slightly faster rate when a wetting event occurred.

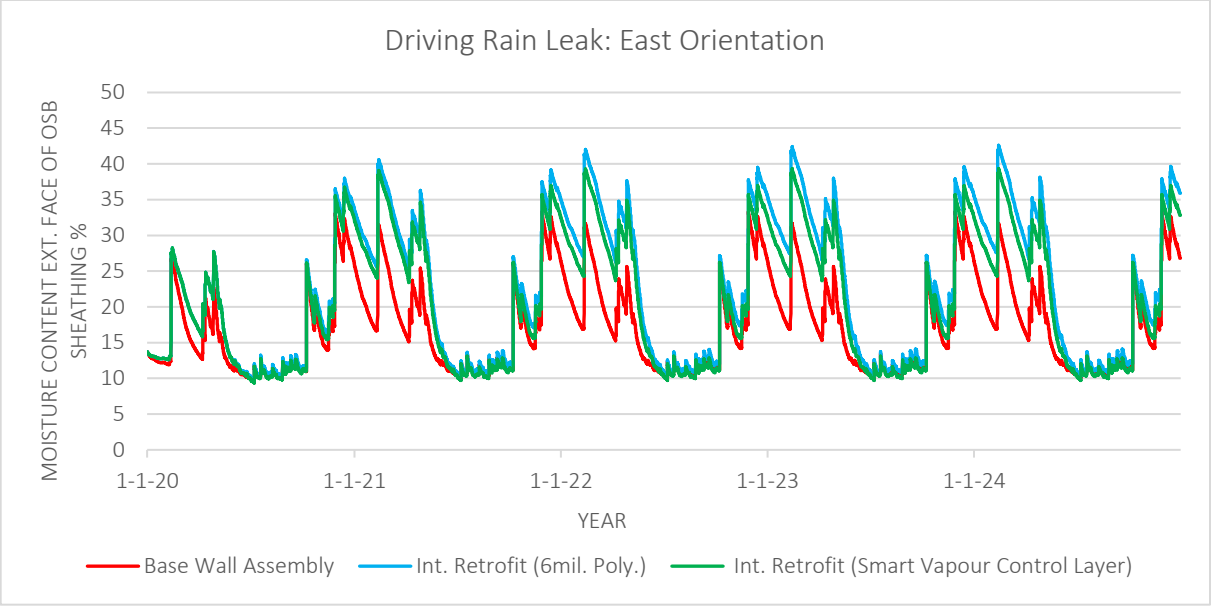


Figure 53: Exposure to a Driving Rain Leak: Percentage of Moisture Content of the Interior Face of the Exterior OSB Sheathing in the Base Case and Interior Retrofitted Above Grade Wall Assembly (East Orientation)

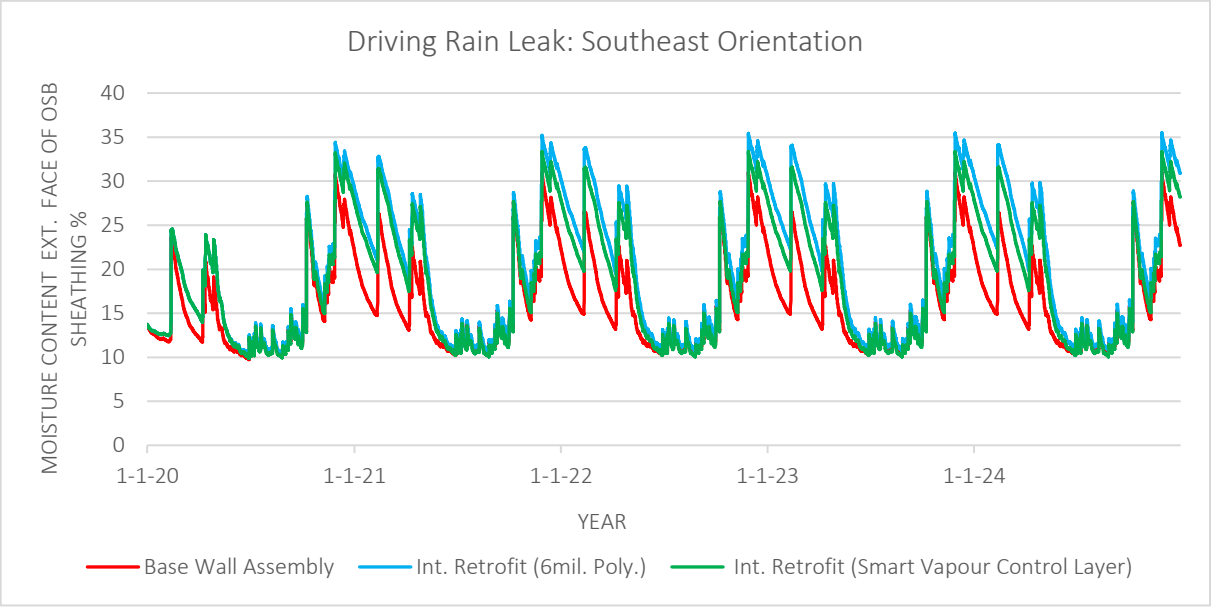


Figure 54: Exposure to a Driving Rain Leak: Percentage of Moisture Content of the Interior Face of the Exterior OSB Sheathing in the Base Case and Interior Retrofitted Above Grade Wall Assembly (Southeast Orientation)

In either the east or southeast orientation, the exterior retrofitted wall assembly with polyisocyanurate rigid insulation was not able to handle the increased moisture load from the driving rain leak. The assembly was not able to dry out due to the low permeance rating of the foam board insulation (Figure 55 and 56).

Coupling a low permeance material outboard of the stud wall with an impermeable interior membrane creates a situation where moisture can become trapped inside the wall assembly (Finch & Hanam, 2013). These results imply that it is critical to control wetting events through proper detailing of the water control layer to ensure the long-term durability of the wall assembly. In contrast, the retrofitted wall assembly with exterior mineral wool insulation was able to dry before the next wetting cycle. The mineral wool insulation allows for outward drying of the assembly when an impermeable membrane is used on the interior. As the mineral wool insulation cannot protect the assembly against an inward vapour drive the presence of a ventilated air cavity behind the cladding reduces the chance of the wall getting wet (Pressnail et al., 2003).

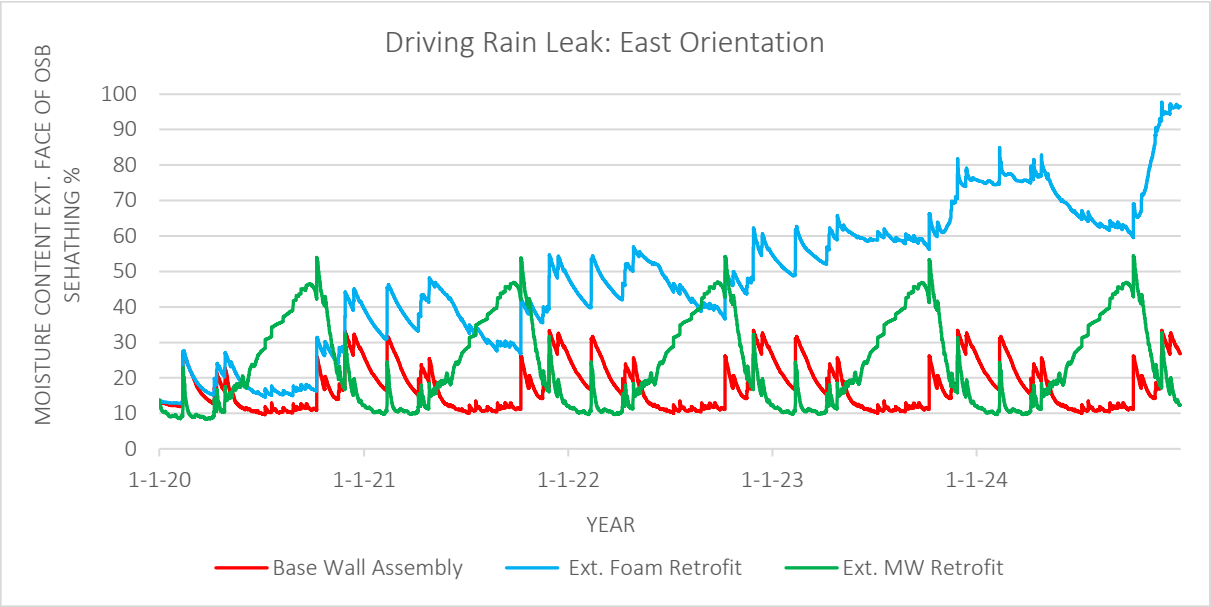


Figure 55: Exposure to a Driving Rain Leak: Percentage of Moisture Content of the Interior Face of the Exterior OSB Sheathing in the Base Case and Interior Retrofitted Above Grade Wall Assembly (East Orientation)

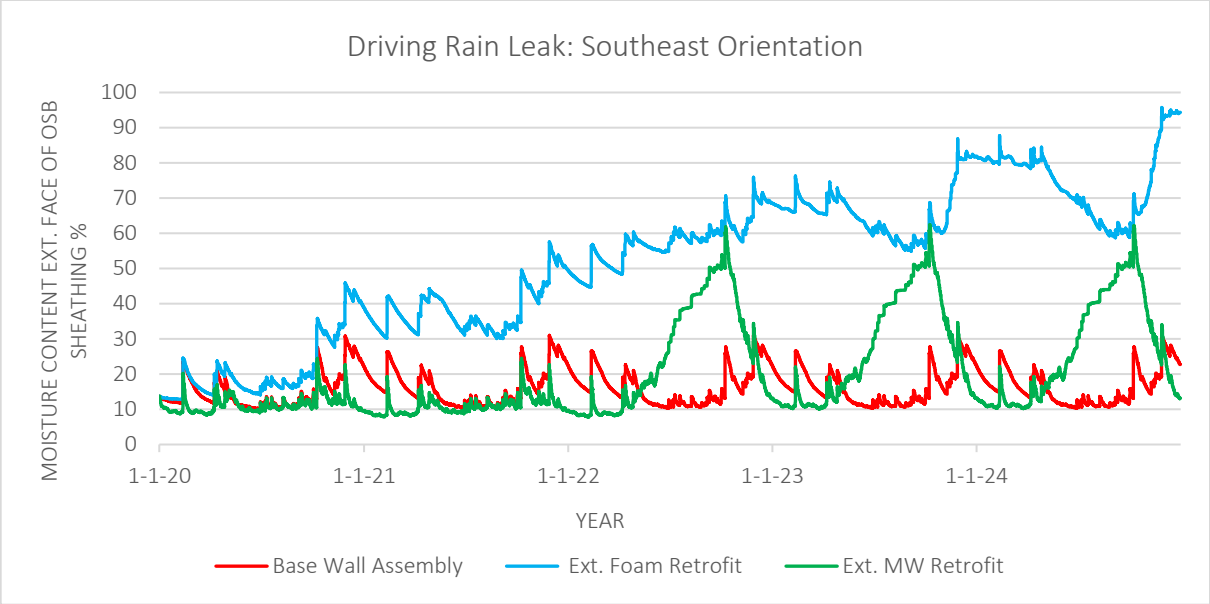


Figure 56: Exposure to a Driving Rain Leak: Percentage of Moisture Content of the Interior Face of the Exterior OSB Sheathing in the Base Case and Interior Retrofitted Above Grade Wall Assembly (Southeast Orientation)

7 CONCLUSIONS AND FUTURE WORK

7.1 Conclusion

The main objective of this research was to identify parameters to develop an archetype that would represent the GHA for an existing 1980's single detached two-storey residential house and then identify deep energy retrofits that allowed the archetype to meet the performance objectives of the CHBA NZER Renovation Pilot Program without negatively affecting the durability of the above grade wall assembly. If these objectives were met it would help give industry stakeholders confidence to undertake the implementation of deep energy retrofits in the existing residential housing stock.

The Plateau neighborhood is comprised of mainly single detached two-storey residential houses. Most of the houses range from 2000 – 3500ft^2, however, there are a few outliers beyond 3500ft^2. The houses feature 200mm concrete foundation walls that are uninsulated at the time of construction with wood framed walls clad in brick veneer. Structural wood sheathing was absent from the exterior of the wood framed walls rather a diagonal wood cross brace with exterior foam sheathing was present. Fenestrations are focused on the front and rear elevations with limited glazing on the side elevations. Many of the houses feature a one storey single or double vehicle garage offset to one of the side elevations with a bonus room

behind the garage. The additional roof area this configuration provides yields an opportunity for placement of solar PV panels.

Research indicated the approximate energy consumption of the existing single detached residential houses in the Plateau neighborhood should be approximately 183 - 194GJ/yr. Utilizing HOT2000 a calibrated baseline energy model that would represent the GHA was developed. This model was based off existing utility bill data and occupant behaviour, which gave an energy consumption value of 121GJ/yr. The GHA archetype had a substantially lower yearly energy consumption compared to the other reference cases due to the increased insulation levels in the building enclosure, the decrease in air leakage, and the efficiency of the mechanical systems was much better. One of the most impactful features of the energy modelling software is the ability to identify why and where energy is being used or lost in a house. In the development of the baseline energy model, it was revealed most of the energy usage was associated with heating (66%). HOT2000 provided clear analysis on parameters that were and were not affecting the heat loss. The three parameters that have the most impact on heat loss included air leakage (33%), above grade walls (24%), and windows (22%). Below grade walls (10%), ceilings (6%), and doors (5%), had little effect on heat loss for the house. Although this could be attributed to the lack of accuracy in calculations performed by HOT2000 and should be verified by a more advanced energy simulation software.

Since the thermal resistance of the below grade walls, ceilings, and doors have little impact on reducing the energy consumption these values were set to the minimum requirements noted in the CHBA NZER Renovation Pilot Program for the calibrated baseline energy model. Triple glazed windows were selected to achieve NZER as modelling in HOT2000 indicated a reduction of almost 50% in energy consumption compared to a double-glazed window. Ventilation is a mandatory component of the CHBA program to maintain indoor air quality, which helps to ensure good occupant health. As ventilation units do not have a 100% recovery rate of heat or cooling energy, the introduction of these units actually increased the energy consumption. Due to this factor, the highest efficiency ventilation unit was utilized for this research. Maximizing the performance of the natural gas furnace did not result in a high enough reduction in energy consumption. Therefore, an ASHP was modelled as the technology offers a significantly higher efficiency factor that resulted in a substantial reduction in energy consumption. Implementing an instantaneous water heater (tankless) into the HOT2000 energy model showed meaningful reductions in energy consumption.

The minimum allowable air change rate by the CHBA NZER Renovation Pilot Program is 1.5 at 50Pa (Canadian Home Builders Association, 2020b), while the Passive House Institutes EnerPHit program mandates a minimum ACH value of n_{50} 1.0 (Passive House Institute, 2016). To achieve the air leakage levels noted in this research the interior finishes of the exterior cladding must be removed back to the studs for the entire house. Modelling the ACH values for the two programs in HOT2000 resulted in sizeable reductions in energy consumption. The final parameter to achieve NZER performance was to determine the effective thermal resistance value of the above grade wall assembly. The minimum thermal resistance required by the CHBA NZER Renovation Pilot Program achieved NZER performance with an all-electric solution. However, due to the cost of electricity compared to natural gas in Ontario, Canada, this solution may yield a higher utility bill for the owner. An analysis should be conducted to determine the feasibility and payback period required for the integration of solar PV panels to offset the yearly utility costs. For the natural gas pathway to achieving NZER the thermal resistance of the wall assembly was increased by 20% to determine at what value is the energy budget target met (64.4GJ/yr). Table 23 presents these values and the corresponding total house package that meets the requirements to achieve NZER performance.

Table 23: Final Housing Packages to Achieve NZER for a House in the Plateau Neighborhood of East Stoney Creek

1. *Pathway to NZER with Electricity*

Ventilation	Window	Baseboard Heaters	ASHP	Hot Water	ACH @ 50Pa	Above Grade Wall Thermal Resistance (RSI)	Net Total Energy Load (GJ/yr) (Targeting 64.4GJ/yr)	Energy Reduction Required to Achieve NZER (GJ/yr)
Cailbrated Baseline Energy Model								
-	*RSI 0.45*	*AFUE 95%*	-	*0.57 EF Tank*	*5.12*	*2.90*	*121.00*	***-56.60***
vanEE ERV Gold: G2400E ECM ERV	Option 2	6 kW (100% Efficiency)	Heating COP 2.62	Conventional Tank 0.83 EF	1.5	3.08	59.26	**5.14**
					1.0	3.08	57.51	**6.89**

Ventilation	Window	Baseboard Heaters	ASHP	Hot Water	ACH @ 50Pa	Above Grade Wall Thermal Resistance (RSI)	Net Total Energy Load (GJ/yr) (Targeting 64.4GJ/yr)	Energy Reduction Required to Achieve NZER (GJ/yr)
Cailbrated Baseline Energy Model								
-	*RSI 0.45*	*AFUE 95%*	-	*0.57 EF Tank*	*5.12*	*2.90*	*121.00*	***-56.60***
vanEE ERV Gold: G2400E ECM ERV	Option 2	6 kW (100% Efficiency)	Heating COP 2.62 SEER 22.5	Instantaneous 0.94 EF	1.5	3.08	59.26	**5.14**
					1.0	3.08	57.51	**6.89**
					1.5	3.70	57.45	**6.95**
					1.0	3.70	55.72	**8.68**
					1.5	4.31	56.15	**8.25**
					1.0	4.31	54.43	**9.97**
					1.5	4.93	55.17	**9.23**
					1.0	4.93	53.46	**10.94**
					1.5	5.54	54.44	**9.96**
					1.0	5.54	52.76	**11.64**
					1.5	6.16	53.81	**10.59**
					1.0	6.16	52.08	**12.32**

2. Pathway to NZER with Natural Gas

Ventilation	Window	NG Furnace	ASHP	ACH @ 50Pa	Above Grade Wall Thermal Resistance (RSI)	Instantaneous Hot Water Net Energy Load (GJ/yr)	Energy Reduction Required to Achieve NZER (GJ/yr)
Cailbrated Baseline Energy Model							
-	*RSI 0.45*	*AFUE 95%*	-	*5.12*	*2.90*	*121 (0.57 EF Tank Water Heater)*	***-56.60***
vanEE ERV Gold: G2400E ECM ERV	Option 2	AFUE 98%	Heating COP 2.62 SEER 22.5	1.5	3.70	66.68	**-2.28**
				1.0	3.70	64.98	**-0.58**
				1.5	4.31	65.43	**-1.03**
				1.0	4.31	63.73	**0.67**
				1.5	4.93	64.45	**-0.05**
				1.0	4.93	62.76	**1.64**
				1.5	5.54	63.72	**0.68**
				1.0	5.54	62.04	**2.36**
				1.5	6.16	63.14	**1.26**
				1.0	6.16	61.47	**2.93**

Only the below grade slab is uninsulated in the GHA archetype model. Through energy modelling it was clear that the addition of insulation to this assembly resulted in a negligible reduction in the energy consumption. However, energy is just one parameter that an assembly should be measured against. Durability and comfort are the two other factors that should be considered in an evaluation. To address these two issues a model was developed using THERM to elevate the surface temperature of an uninsulated versus an insulated slab. The temperatures throughout the year of the uninsulated slab remained above the DEW point (assuming indoor conditions as noted in the analysis section). This is in part due to the depth underground the slab is located. With the temperature of the slab remaining above the DEW point, formation of condensation is not a concern. Therefore, durability of the assembly should not come into question. However, the temperature of the uninsulated slab was low enough compared to the temperature of the interior environment that it could negatively affect the comfort level of the occupants within the space. Although insulation is not required from an energy perspective, analysis concluded it may be necessary to maintain the comfort of the occupants.

One of the primary areas of concern related to durability in a highly insulated building enclosure are the above grade wall assemblies. With the considerable accumulation of thermal resistance in the assembly, the drying capability from interior heat loss has been drastically reduced. It is therefore important to analyze how the retrofitted assembly will perform if it were to become wet. Under normal operating conditions evaluated in WUFI Pro 6.4, all five of the wall assemblies performed well. Both the base wall assembly and the retrofitted wall assembly with mineral wool insulation tolerated the driving rain leak (Table 24). Although the double stud wall assembly did dry out over time, there were long periods when

the moisture content of the interior face of the OSB sheathing was above 30%. In the case of the double stud wall assembly, it would appear beneficial for drying to occur both towards the exterior and the interior. This would improve the opportunity for the assembly to dry if it were to get wet. The only assembly that failed due to the driving rain leak was the exterior retrofitted wall assembly with foam board insulation. The foam sheathing had a low permeance rating and coupled with the low permeance rating of the interior polyethylene vapour control layer, the assembly simply cannot dry if it were to become wet. This type of assembly is commonly referred to as a double vapour barrier. Before the implementation of this type of assembly, meaningful measures should be taken to ensure the assembly does not get wet with effective detailing of the water and air control layers.

Table 24: Durability Analysis of the Retrofitted Above Grade Wall Assemblies

Assembly	Operating Condition	
	Normal	Driving Rain Leak
Base Wall		
Double Stud Wall (Poly.)		
Double Stud Wall (SM)		
Exterior Foam (Low perm.)		
Exterior Mineral Wool		

Legend to Table 24

- *Green: Pass.*
- *Yellow: Proceed with caution.*
- *Red: Fail.*

7.2 Future Research

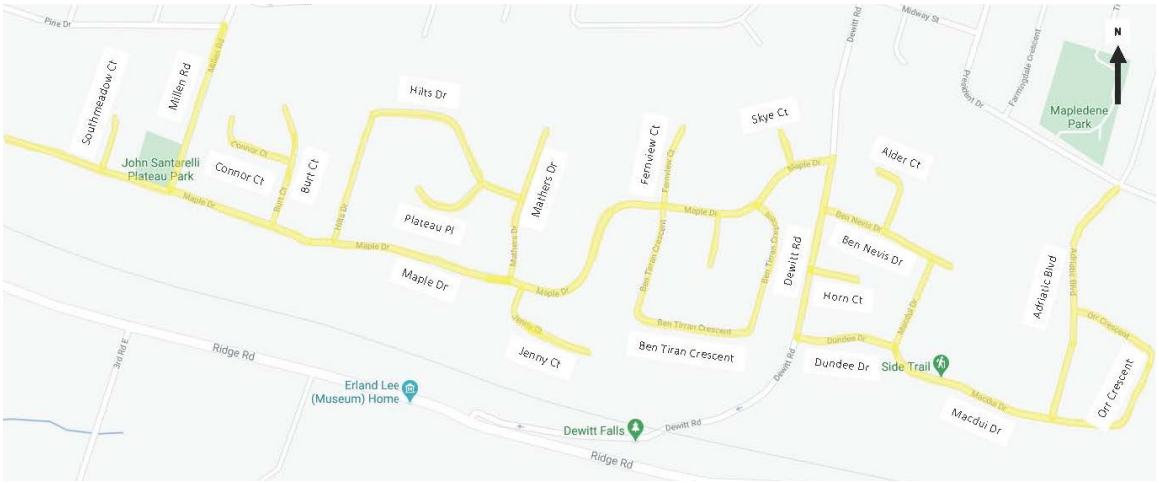
At the conclusion of this research there are additional areas or a further depth of an investigation that could be performed for several parameters. Jermyn (2014) noted, EnergyPlus modelling software yields a lower energy consumption value compared to an elevation utilizing HOT2000. The energy consumption results produced in this research should be validated with a more advanced energy simulation software such as EnergyPlus. A comparative analysis between EnergyPlus and HOT200 highlighting mechanisms that affect estimated energy consumption by device and percentage of annual heat loss or gain by building enclosure assembly would be useful to understand the ranking of the methodologies behind each program.

Implementation of a ventilation unit into the calibrated baseline energy model for the GHA archetype resulted in a significant increase in the net energy consumption. Due to this, further investigation into the accuracy of the values should be explored as HOT2000 only incorporates certain aspects of the CAN/CSA-326 Standard into the program's calculations. A comparative analysis should be conducted with a more advanced energy simulation software.

The hygrothermal modelling in this research tested a limited number of assemblies under specific parameters. For the assemblies that led to a classification of proceed with caution or ultimately failure, further investigation could be implemented to determine if alterations of material selections could be applied to achieve a pass classification. The failure mechanism could also further be quantified in terms of the maximum amount of moisture the assembly can tolerate before a failure occurs. Hygrothermal modelling could also be conducted on assemblies beyond the above grade wall such as the below grade wall assembly or the ceiling assembly to determine their performance when highly insulated.

Appendices

A1 Definition of the Plateau neighborhood of East Stoney Creek, a community within the City of Hamilton



A2 Window Inspection Data: 1980's Plateau Neighborhood

Window Inspection Data						
	Width	Height	Divider Type	No. Horizontal	No. Vertical	Material
Basement						
Window 1	762mm	355mm	None	None	None	Vinyl
Window 2	762mm	355mm	None	None	None	Vinyl
Window 3	762mm	355mm	None	None	None	Vinyl
First Floor						
Front Entrance Door 1	381mm	2082mm	None	None	None	Vinyl
Front Entrance Door 1	381mm	2082mm	None	None	None	Vinyl
Living Room 1	610mm	1727mm	Vinyl	4	1	Vinyl
Living Room 2	914mm	1727mm	Vinyl	4	2	Vinyl
Living Room 3	610mm	1727mm	Vinyl	4	1	Vinyl
Office 1	610mm	1727mm	Vinyl	4	1	Vinyl
Office 2	914mm	1727mm	Vinyl	4	2	Vinyl
Office 3	610mm	1727mm	Vinyl	4	1	Vinyl
Mud Room	838mm	914mm	None	None	None	Vinyl
Den	2057mm	1320mm	None	None	None	Vinyl
Kitchen 1	1117mm	1727mm	None	None	None	Vinyl
Kitchen 2	711mm	1727mm	None	None	None	Vinyl
Kitchen 4	838mm	914mm	None	None	None	Vinyl
Dining Room	1727mm	1320mm	None	None	None	Vinyl
Second Floor						
Ensuite	635mm	736mm	None	None	None	Vinyl
Master Bedroom	1524mm	1168mm	None	None	None	Vinyl
Bed Room 1	1143mm	1168mm	None	None	None	Vinyl
Bed Room 2	1371mm	1168mm	None	None	None	Vinyl
Bed Room 3 (1)	660mm	1168mm	None	None	None	Vinyl
Bed Room 3 (2)	1371mm	1168mm	None	None	None	Vinyl

A3 Exterior Door Inspection Data: 1980's Plateau Neighborhood

Door Inspection Data				
	Width	Height	Material	Insulated
First Floor				
Front Entrance	863mm	2082mm	Steel	Yes
Rear Entrance	863mm	2082mm	Wood	No

A4 ACH Values for the GHA Archetype Based on the Preconstruction ACH Estimate Equations *(Khemet, 2019)*

Equation Parameter	Measurement
Volume	879.1m^3
No. of Storeis	2
Year	1980
Height	5.1m
HDD	3400
Ceiling RSI	5.28
Foundation RSI	0.2
Window RSI	0.45
Wall RSI	2.9
ACH Based on: Equation 15 *ACH=135.304 - 0.005(Volume) + 1.048(Storeys) - 0.065(Year)*	4.30
ACH Based on Equation: 16 *ACH = 126.649 - 0.005(Volume) + 0.939(Height) - 0.057(Year) - 0.001(HDD) - 0.288(Ceiling RSI) - 0.218(Foundation RSI) - 3.264(Window RSI) - 0.400(Wall RSI)*	6.59

A5 Collected Utility Bill Data: 1980's Plateau Neighborhood

Study 1: Collected Utility Bills			
Year 2016/2017	**Month**	**Electricity (kWh)**	**Billing Period**
	December	763	Dec. 5 - Feb. 2
	February	712	Feb. 2 - Mar. 31
	March	695	Mar. 31 - June 5
	June	583	June 5 - July 4
	July	668	July 4 - Aug. 8
	August	600	Aug. 8 - Sept. 7
	September	437	Sept. 7 - Oct. 4
	October	439	Oct. 4 - Oct. 31
	November	258	Oct. 31 - Nov. 24
	December	662	Nov. 24 - Jan. 5
Year 2018			
	January	507	Jan. 5 - Feb. 7
	February	389	Feb. 7 - Mar. 7
	March	372	Mar. 7 - Apr. 3
	April	347	Apr. 3 - Apr. 30
	May	464	Apr. 30 - May 30
	June	617	May 30 - June 29
	July	948	June 29 - Aug. 7
	August	903	Aug. 7 - Sept. 7
	September	622	Sept. 7 - Oct. 9
	October	358	Oct. 9 - Nov. 7
	November	433	Nov. 7 - Dec. 6
	December	651	Dec. 6 - Jan. 9

Study 1: Collected Utility Bills			
Year 2016	**Month**	**Natural Gas (m^3)**	**Billing Period**
	December	525	Dec. 8 - Jan. 11
Year 2017			
	January	425	Jan. 11 - Feb. 10
	February	398	Feb. 10 - Mar. 13
	March	280	Mar. 13 - Apr. 12
	April	121	Apr. - May 12
	May	29	May 12 - June 12
	June	19	June 12 - July 12
	July	18	July 12 - Aug. 12
	August	15	Aug. 14 - Sept. 14
	September	16	Sept. 14 - Oct. 12
	October	119	Oct. 12 - Nov. 10
	November	275	Nov. 10 - Dec. 8
	December	478	Dec. 9 - Jan. 11
Year 2018			
	January	568	Dec. 8 - Jan. 11
	February	452	Jan. 11 - Feb. 12
	March	381	Feb. 12 - Mar. 13
	April	393	Mar. 13 - Apr. 11
	May	39	May 11 - June 12
	June	24	June 12 - July 12
	July	35	July 12 - Aug. 13
	August	26	Aug. 13 - Sept. 13
	September	43	Sept. 13 - Oct. 15
	October	171	Oct. 15 - Nov. 13
	November	276	Nov. 13 - Dec. 11
	December	321	Dec. 11 - Jan. 11
Year 2019			
	January	445	Jan. 11 - Feb. 12

A6 HOT2000 Baseline Energy Model Run

HOT2000
Natural Resources CANADA
Version 11.9



File: Baseline Energy Model_Mathers Dr_10 House

Weather Library: C:\HOT2000 v11.9b20154\Dat\Wth110.dir
Weather Data for: TORONTO, ONTARIO

Builder Code:

Data Entry by: Tyler Simspon
Date of entry: 2020-10-16

Company: Ryerson University

Client name: Simpson,
Street address: 10 Mathers
City: Stoney Creek **Region:** ONTARIO
Postal code: L8G 4J3 **Telephone:**

GENERAL HOUSE CHARACTERISTICS

House type:	Single Detached		
Number of storeys:	Two storeys		
Plan shape:			
Front orientation:	West		
Year House Built:	1980-89		
Wall colour:	Default	**Absorptivity:**	0.40
Roof colour:	Default	**Absorptivity:**	0.40
Soil Condition:	Normal conductivity (dry sand, loam, clay)		
Water Table Level:	Normal (7-10m/23-33ft)		
House Thermal Mass Level:	(A) Light, wood frame		
Effective mass fraction	1.000		
Occupants :	2 Adults for 65.0% of the time 1 Children for 65.0% of the time 1 Infants for 65.0% of the time		
Sensible Internal Heat Gain From Occupants:	3.12 kWh/day		

HOUSE TEMPERATURES

Heating Temperatures

Main Floor	**Daytime Setpoint:**	21.0 °C
	Nightime Setpoint:	19.0 °C
	Nightime Setback Duration:	8.0 Hours
	24 Hour Average:	20.3 °C
Basement	**Setpoint:**	19.0 °C
	TEMP. Rise from 20.3 °C:	5.5 °C

Cooling Temperature: Main Floor : 25.00 °C

Basement is- Heated: Yes **Cooled:** No **Separate T/S:** No

Fraction of internal gains released in basement : 0.150

Indoor design temperatures for equipment sizing

Heating:	21.0 °C
Cooling:	25.0 °C

WINDOW CHARACTERISTICS

Label	Location	#	Overhang Width (m)	Header Height (m)	Tilt deg	Curtain Factor	Shutter (RSI)
South							
S 1st Flr_Wall	S 1st Flr_Wall	1	0.61	2.41	90.0	1.00	0.00
Southeast							
Insert Rear Door	Rear Entrance Door	1	0.61	0.15	90.0	1.00	0.00
East							
E Ensuite 2nd Flr_Wall	E 2nd Flr_Wall	1	0.61	0.15	90.0	1.00	0.00
E Master 2nd Flr_Wall	E 2nd Flr_Wall	1	0.61	0.15	90.0	1.00	0.00
E1 1st Flr_Wall	E 1st Flr_Wall	1	0.61	2.54	90.0	1.00	0.00
E2 1st Flr_Wall	E 1st Flr_Wall	1	0.61	2.54	90.0	1.00	0.00
E3 1st Flr_Wall	E 1st Flr_Wall	1	0.61	2.54	90.0	1.00	0.00
E4 1st Flr_Wall	E 1st Flr_Wall	1	0.61	2.54	90.0	1.00	0.00
Northeast							
NE 1st Flr_Wall	NE 1st Flr_Wall	1	0.61	0.15	90.0	1.00	0.00

North							
N 2nd Flr_Wall	N 2nd Flr_Wall	1	0.61	0.15	90.0	1.00	0.00
West							
Insert Front Door	Front Door	1	0.61	2.54	90.0	1.00	0.00
Sidelight 1	Front Door	2	0.61	2.54	90.0	1.00	0.00
W 1st Flr_Wall	W 1st Flr_Wall	4	0.61	2.54	90.0	1.00	0.00
W 2nd Flr_Wall	W 2nd Flr_Wall	2	0.61	0.15	90.0	1.00	0.00
W1 1st Flr_Wall	W 1st Flr_Wall	2	0.61	2.54	90.0	1.00	0.00
W1 2nd Flr_Wall	W 2nd Flr_Wall	1	0.61	0.15	90.0	1.00	0.00

Label	Type	#	Window Width (m)	Window Height (m)	Total Area (m^2)	Window RSI	SHGC	ER*
South								
S 1st Flr_Wall	200014	1	0.84	0.91	0.77	0.336	0.5448	1.6
Southeast								
Insert Rear Door	200000	1	0.48	1.55	0.75	0.237	0.6550	-19.5
East								
E Ensuite 2nd Flr_Wall	200014	1	0.63	0.74	0.47	0.333	0.4908	-5.2
E Master 2nd Flr_Wall	200014	1	1.52	1.17	1.78	0.342	0.6134	9.3
E1 1st Flr_Wall	200014	1	1.73	1.32	2.28	0.343	0.6296	10.9
E2 1st Flr_Wall	200014	1	0.84	0.91	0.77	0.336	0.5448	1.6
E3 1st Flr_Wall	200014	1	1.12	1.73	1.93	0.342	0.6166	9.7
E4 1st Flr_Wall	200014	1	2.06	1.32	2.72	0.344	0.6380	11.8
Northeast								
NE 1st Flr_Wall	200014	1	0.71	1.73	1.23	0.338	0.5686	5.0
North								
N 2nd Flr_Wall	200014	1	1.14	1.17	1.34	0.340	0.5937	7.1
West								
Insert Front Door	200000	1	0.53	1.19	0.64	0.238	0.6557	-20.0
Sidelight 1	200000	2	0.18	1.19	0.42	0.165	0.5132	-71.8
W 1st Flr_Wall	200014	4	0.61	1.73	4.21	0.336	0.5467	5.5
W 2nd Flr_Wall	200014	2	1.37	1.17	3.20	0.341	0.6068	9.7
W1 1st Flr_Wall	200014	2	0.91	1.73	3.16	0.340	0.5979	9.0
W1 2nd Flr_Wall	200014	1	0.66	1.17	0.77	0.336	0.5361	0.9

*ER Window Energy Rating (ER 2009) estimated for actual dimensions, and Air tightness type: CSA - A1; Leakage rate = 1.86 L/s.m^2

Above grade fraction of wall area occupied by windows: 10.6 %

WINDOW CODE SCHEDULE

Name	Internal Code	Description (Glazings, Coatings, Fill, Spacer, Type, Frame)
200014	200014	Double/double with 1 coat, Clear, 13 mm Air, Metal, Hinged, Vinyl, ER* = 2.0, Eff. RSI= 0.34
200000	200000	Double/double with 1 coat, Clear, 13 mm Air, Metal, Picture, Aluminum, ER* = -1.9, Eff. RSI= 0.28

* Window Standard Energy Rating (ER 2009) estimated for assumed dimensions, and Air tightness type: CSA - A1; Leakage rate = 1.86 L/s.m^2

BUILDING PARAMETER DETAILS

CEILING COMPONENTS

	Construction Type	Code Type	Roof Slope	Heel Ht. (m)	Section Area (m^2)	R. Value (RSI)
1st Fl Den_Ceiling	Attic/gable	User specified	5.004/12	0.10	34.94	5.28
1st Fl Din. Bump Out_Ceiling	Attic/gable	User specified	5.004/12	0.10	3.54	5.28
2nd Flr_Ceiling	Attic/gable	User specified	5.004/12	0.10	85.87	5.28

MAIN WALL COMPONENTS

Label	Lintel Type	Fac. Dir	Number of Corn.	Number of Inter.	Height (m)	Perim. (m)	Area (m^2)	R. Value (RSI)
E 1st Flr_Wall Type: 1201281041	010	East	4	2	2.74	13.84	37.92	2.59
E 2nd Flr_Wall Type: 1201281041	010	East	2	2	2.74	8.99	24.63	2.72
N 1st Flr_Wall Type: 1201281041	010	South	2	1	2.74	9.55	26.17	2.92
N 2nd Flr_Wall Type: 1201281041	010	North	2	2	2.74	9.55	26.17	2.81
NE 1st Flr_Wall Type: 1201281041	010	Northeast	3	0	2.74	1.60	4.38	2.29
S 1st Flr_Wall Type: 1201281041	010	South	6	0	2.74	5.87	16.08	2.72
S 2nd Flr_Wall Type: 1201281041	010	South	2	3	2.74	9.55	26.17	2.87
S Gar. 1st Flr_Wall Type: 1201281041	010	South	2	0	2.74	4.14	11.34	> 3.05
SE 1st Flr_Wall Type: 1201281041	010	Southeast	2	0	2.74	1.67	4.58	2.25
W 1st Flr_Wall Type: 1201281041	010	West	10	2	2.74	10.29	28.19	2.25
W 2nd Flr_Wall Type: 1201281041	010	West	2	1	2.74	8.99	24.63	2.64
W Gar. 1st Flr_Wall Type: 1201281041	010	West	2	2	2.74	5.92	16.22	> 2.87

> Indicates that the component is adjacent to an enclosed unconditioned space.

WALL CODE SCHEDULE

Name	Internal Code	Description (Structure, typ/size, Spacing, Insull, 2, Int., Sheathing,

Exterior, Studs)

1201281041	1201281041	Wood frame, 38x89 mm (2x4 in), 400 mm (16 in), RSI 2.11 @ 89 mm (R 12 @ 3.5") batt, 19 mm (0.75 in) isocyanurate, 12 mm (0.5 in) gypsum board, None, Brick, 3 studs

DOORS

Label	Type	Height (m)	Width (m)	Gross Area (m^2)	R. Value (RSI)
Front Door Loc: W 1st Flr_Wall	Wood hollow core	2.08	1.63	3.38	0.37
Gar. Door Loc: W Gar. 1st Flr_Wall	Wood hollow core	2.06	0.81	1.67	> 0.53
Rear Entrance Door Loc: SE 1st Flr_Wall	Steel fibreglass core	2.08	0.86	1.80	0.29

> Indicates that the component is adjacent to an enclosed unconditioned space.

FOUNDATIONS

Foundation Name: Foundation
Foundation Type: Basement
Data Type: Library

Volume: 215.9 m^3
Opening to Main Floor: 0.00 m^2

Total Wall Height: 2.29 m
Depth Below Grade: 2.14 m

Non-Rectangular Floor Perimeter: 41.94 m
Floor Area: 94.29 m^2

Interior wall type: User specified
Exterior wall type: User specified
Number of corners : 8
Lintel type: 010
Added to slab type : N/A
Floors Above Found.: 4231080000

R-value: 0.00 RSI
R-Value: 0.00 RSI
R-Value: 0.00 RSI
R-Value: 1.19 RSI

Exposed areas for: Foundation
Exposed Perimeter: 5.99 m

Configuration: BCNN_1
- concrete walls and floor
- no insulation
- first storey brick veneer placed directly on basement's concrete walls

---

Foundation Name: Foundation Low Ceiling
Foundation Type: Basement
Data Type: Library

Volume: 73.7 m^3
Opening to Main Floor: 0.00 m^2

Total Wall Height: 2.11 m
Depth Below Grade: 1.96 m

Non-Rectangular Floor Perimeter: 24.28 m

		Floor Area:	34.94 m^2
Interior wall type:	User specified	**R-value:**	0.00 RSI
Exterior wall type:	User specified	**R-Value:**	0.00 RSI
Number of corners :	8		
Lintel type:	010		
Added to slab type :	N/A	**R-Value:**	0.00 RSI
Floors Above Found.:	4231080000	**R-Value:**	1.19 RSI

Exposed areas for: Foundation Low Ceiling
Exposed Perimeter: 5.99 m

Configuration: BCNN_1
- concrete walls and floor
- no insulation
- first storey brick veneer placed directly on basement's concrete walls

---

FOUNDATION CODE SCHEDULE

Floors Above Foundation

Name	Internal Code	Description (Structure, typ/size, Spacing, Insul1, 2, Int., Sheathing, Exterior, Drop Framing)
4231080000	4231080000	Wood frame, 38x235 mm (2x10 in), 400 mm (16 in), None, 19 mm (0.75 in) isocyanurate, None, None, None, No

Lintel Code Schedule

Name	Code	Description (Type, Material, Insulation)
010	010	Single, Steel, None

ROOF CAVITY INPUTS

Gable Ends		**Total Area:**	17.28 m^2
Sheathing Material	Plywood/Part. bd 9.5 mm (3/8 in)		0.08 RSI
Exterior Material:	Hollow metal/vinyl cladding		0.11 RSI
Sloped Roof		**Total Area:**	134.73 m^2
Sheathing Material	Plywood/Part. bd 12.7 mm (1/2 in)		0.11 RSI
Exterior Material:	Asphalt shingles		0.08 RSI
Total Cavity Volume:	85.9 m^3	**Ventilation Rate:**	0.50 ACH/hr

BUILDING ASSEMBLY DETAILS

Label	Construction Code	Nominal (RSI)	System (RSI)	Effective (RSI)
MAIN WALL COMPONENTS				
E 1st Flr_Wall	1201281041	2.84	2.70	2.59
E 2nd Flr_Wall	1201281041	2.84	2.78	2.72
N 1st Flr_Wall	1201281041	2.84	2.92	2.92
N 2nd Flr_Wall	1201281041	2.84	2.84	2.81
NE 1st Flr_Wall	1201281041	2.84	2.38	2.29
S 1st Flr_Wall	1201281041	2.84	2.75	2.72
S 2nd Flr_Wall	1201281041	2.84	2.87	2.87
S Gar. 1st Flr_Wall	1201281041	2.84	2.89	2.89
SE 1st Flr_Wall	1201281041	2.84	2.37	2.25
W 1st Flr_Wall	1201281041	2.84	2.38	2.25
W 2nd Flr_Wall	1201281041	2.84	2.74	2.64
W Gar. 1st Flr_Wall	1201281041	2.84	2.74	2.71
FLOORS ABOVE BASEMENTS				
Foundation	4231080000	0.73	1.19	1.19
Foundation Low Ceiling	4231080000	0.73	1.19	1.19

BUILDING PARAMETERS SUMMARY

ZONE 1 : Above Grade

Component	Area m^2 Gross	Area m^2 Net	Effective (RSI)	Heat Loss MJ	% Annual Heat Loss
Ceiling	124.35	124.35	5.28	7713.57	6.00
Main Walls	246.49	215.03	2.71	30250.68	23.52
Doors	6.85	5.05	0.35	5946.42	4.62
South Windows	0.77	0.77	0.34	938.96	0.73
Southeast Windows	0.75	0.75	0.24	1302.50	1.01
East Windows	9.94	9.94	0.34	11994.56	9.33
Northeast Windows	1.23	1.23	0.34	1499.87	1.17
North Windows	1.34	1.34	0.34	1619.30	1.26
West Windows	12.40	12.40	0.32	15985.20	12.43
		ZONE 1 Totals:		**77251.06**	**60.06**

INTER-ZONE Heat Transfer : Floors Above Basement

	Area m^2 Gross	Area m^2 Net	Effective (RSI)	Heat Loss MJ

	129.23	129.23	1.192	1675.02	

ZONE 2 : Basement

Component	Area m^2 Gross	Area m^2 Net	Effective (RSI)	Heat Loss MJ	% Annual Heat Loss
Walls above grade	1.80	1.80	-	2758.24	2.14
Below grade foundation	153.79	153.79	-	8963.21	6.97
		ZONE 2 Totals:		**11721.45**	**9.11**

Air Leakage and Mechanical Ventilation

	House Volume	Air Change	Heat Loss MJ	% Annual Heat Loss
	879.10 m^3	0.265 ACH	39640.508	30.82

AIR LEAKAGE AND MECHANICAL VENTILATION

Building Envelope Surface Area: 526.43 m^2

Air Leakage Test Results at 50 Pa. (0.2 in H_2O) = 5.12 ACH

Equivalent Leakage Area @ 10 Pa = 1680.66 cm2

Terrain Description			**Height** (m)
@ Weather Station :	Open flat terrain, grass	Anemometer:	10.0
@ Building site :	Parkland, bushes	Height of the highest ceiling:	5.1

Local Shielding:

Walls:	Light
Flue :	Light

Leakage Fractions-

Ceiling:	0.200
Walls:	0.650
Floors:	0.150

Normalized Leakage Area @ 10 Pa: 3.1925 cm^2/m^2

Estimated Airflow to cause a 5 Pa Pressure Difference: 267 L/s

Estimated Airflow to cause a 10 Pa Pressure Difference: 419 L/s

F326 VENTILATION REQUIREMENTS

Kitchen, Living Room, Dining Room	3 rooms @ 5.0 L/s: 15.0 L/s
Utility Room	1 rooms @ 5.0 L/s: 5.0 L/s
Bedroom	1 rooms @ 10.0 L/s: 10.0 L/s
Bedroom	1 rooms @ 5.0 L/s: 5.0 L/s
Bathroom	1 rooms @ 5.0 L/s: 5.0 L/s
Basement Rooms	10.0 L/s

SECONDARY FANS & OTHER EXHAUST APPLIANCES

	Control	**Supply (L/s)**	**Exhaust (L/s)**
Other Fans	Continuous	0.00	7.05

Dryer	Continuous	-	1.19

Dryer is vented outdoors

Rated Fan Power	5.36 Watts

NEW ERS VENTILATION DATA

Whole House Systems

Air Distribution/circulation type:	Forced air heating ductwork
Air Distribution/circulation fan power:	100.00 Watts
Operation schedule:	360.00 min/day

Supplementary Systems

System # 1 Type:	Dryer	
Manufacturer:		
Model:		
Airflow Supply Rate: 0.00 L/s	**Exhaust:** 38.00 L/s	**Fan Power:** 0.00 Watts
Operation schedule:	45.00 min/day	

System # 2 Type:	Range hood	
Manufacturer:		
Model:		
Airflow Supply Rate: 0.00 L/s	**Exhaust:** 75.00 L/s	**Fan Power:** 57.00 Watts
Operation schedule:	72.00 min/day	

System # 3 Type:	Bathroom	
Manufacturer:		
Model:		
Airflow Supply Rate: 0.00 L/s	**Exhaust:** 33.00 L/s	**Fan Power:** 25.08 Watts
Operation schedule:	72.00 min/day	

System # 4 Type:	Bathroom	
Manufacturer:		
Model:		
Airflow Supply Rate: 0.00 L/s	**Exhaust:** 33.00 L/s	**Fan Power:** 25.08 Watts
Operation schedule:	72.00 min/day	

AIR LEAKAGE AND MECHANICAL VENTILATION SUMMARY

F326 Required continous ventilation:	50.000 L/s (0.20 ACH)
Other Continuous Supply Flow Rates:	0.000 L/s (0.00 ACH)
Other Continuous Exhaust Flow Rates:	7.050 L/s (0.03 ACH)
Total house ventilation is Balanced	
Gross Air Leakage and Mechanical Ventilation Energy Load:	38653.906 MJ
Seasonal Heat Recovery Ventilator Efficiency:	0.000 %
Estimated Ventilation Electrical Load: Heating Hours:	0.000 MJ
Estimated Ventilation Electrical Load: Non-Heating Hours:	0.000 MJ
Net Air Leakage and Mechanical Ventilation Load:	39640.508 MJ

SPACE HEATING SYSTEM

PRIMARY Heating Fuel:	Natural Gas
Equipment:	Furnace/Boiler with continuous pilot
Manufacturer:	
Model:	
Calculated* Output Capacity:	15.50 kW
* Design Heat loss X 1.00 + 0.5 kW	
Pilot Light energy consumption:	25.30 MJ/day
AFUE:	96.00
Steady State Efficiency:	100.00
Fan Mode:	Auto
ECM Motor:	Yes
Low Speed Fan Power:	0 watts
High Speed Fan Power:	186 watts
Flue Diameter:	152.40 mm

AIR CONDITIONING SYSTEM

System Type:	Central single package system		
Manufacturer:			
Model:			
Capacity:	8924 Watts		
SEER	14.00	**Rated COP**	3.038
Sensible Heat Ratio:	0.76		
Indoor Fan Flow Rate:	602.14 L/s	**Fan Power (watts)**	287.88
Ventilator Flow Rate:	0.00 L/s	**Crankcase Heater Power (watts):**	60.00
Fraction of windows Openable:	0.000	**ECM Motor:**	Yes
Cooling system capacity sizing factor:	1.000		
Economizer control:	N/A	**Indoor Fan Operation:**	Auto

Air Conditioner is integrated with the Heating System

DOMESTIC WATER HEATING SYSTEM

PRIMARY Water Heating Fuel:	Natural gas
Water Heating	Induced draft fan (pilot)

Equipment:			
Energy Factor:	0.571		
Manufacturer:			
Model:			
Tank Capacity:	151.4 Litres	**Tank Blanket Insulation:**	0.0 RSI
Tank Location:	Basement		
Pilot Energy :	17.7 MJ/day	**Flue Diameter:**	76.2 mm

ANNUAL DOMESTIC WATER HEATING SUMMARY

Daily Hot Water Consumption:	308.1 Litres
Hot Water Temperature:	55.0 °C
Estimated Domestic Water Heating Load:	21052 MJ
Primary Domestic Water Heating Energy Consumption:	35774 MJ
Primary System Seasonal Efficiency:	58.8%

ANNUAL SPACE HEATING SUMMARY

Gross Space Heat Loss:	128613 MJ
Gross Space Heating Load:	126017 MJ
Usable Internal Gains:	23563 MJ
Usable Internal Gains Fraction:	18.3 %
Usable Solar Gains:	18555 MJ
Usable Solar Gains Fraction:	14.4 %
Auxilary Energy Required:	83899 MJ
Space Heating System Load:	83899 MJ
Furnace/Boiler Seasonal efficiency:	86.0 %
Furnace/Boiler Annual Energy Consumption:	97133 MJ

DESIGN SPACE HEATING AND COOLING LOADS

Design Heat Loss* at -20.0 °C (17.42 Watts / m3):	15315 Watts
Design Cooling Load* for July at (31.0 ° C):	7825 Watts

*** Please refer to notes at the end of this report.**

ANNUAL SPACE COOLING SUMMARY

Design Sensible Heat Ratio:	0.769
Estimated Annual Space Cooling Energy:	1728.04 kWh
Seasonal COP (April to October):	2.415

BASE LOADS SUMMARY

	kwh/day	Annual kWh
Interior Lighting	0.60	219.00
Appliances	6.76	2466.38
Other	9.70	3540.50
Exterior Use	0.90	328.50
HVAC Fans		
HRV/Exhaust	0.13	46.94
Space Heating	0.30	107.80
Space Cooling	0.44	162.31
Total Average Electrical Load	18.83	6871.43

Natural gas Stove:	**Location:** Main floor
Energy consumption:	5.6 MJ/Day

FAN OPERATION SUMMARY (kWh)

Hours	HRV/Exhaust Fans	Space Heating	Space Cooling
Heating	29.5	107.8	0.0
Neither	4.9	0.0	0.0
Cooling	12.6	0.0	162.3
Total	46.9	107.8	

ENERGY CONSUMPTION SUMMARY REPORT

Estimated Annual Space Heating Energy Consumption	= 97521.55 MJ	= 27089.32 kWh
Ventilator Electrical Consumption: Heating Hours	= 0.00 MJ	= 0.00 kWh
Estimated Annual DHW Heating Energy Consumption	= 35774.41 MJ	= 9937.34 kWh
ESTIMATED ANNUAL SPACE + DHW ENERGY CONSUMPTION	= 133295.95 MJ	= 37026.65 kWh

Estimated Greenhouse Gas Emissions 7.250 tonnes/year

ESTIMATED ANNUAL FUEL CONSUMPTION SUMMARY

Fuel	Space Heating	Space Cooling	DHW Heating	Baseloads	Ventilation	Total
Natural Gas (m3)	2607.0	0.0	960.2	54.6	0.0	3621.7
Electricity (kWh)	107.8	1728.0	0.0	6554.4	46.9	8437.2

ESTIMATED ANNUAL FUEL CONSUMPTION COSTS

Fuel Costs Library = Embedded

RATE	Electricity (Ottawa08)	Natural Gas (Toronto)	Oil (Ottawa08)	Propane (Ottawa08)	Wood (Sth Ont)	Total
$	908.40	928.81	0.00	0.00	0.00	1837.21

Fuel Costs Library Listing

Filename = Embedded

Record # 1	Fuel: Electricity		
Rate ID = Ottawa08	Hydro Rate Block		
Rate Block		Dollars	Charge
	kWhr	Per kWhr	($)
Minimum	0.0		9.540
1	600.0	0.0926	
2	99999.0	0.1016	
Record # 2	Fuel: Natural Gas		

Rate ID = Toronto	these are not real rates		
Rate Block		Dollars	Charge
	m3	Per m3	($)
Minimum	0.0		8.000
1	40.0	0.2500	
2	100.0	0.2400	
3	200.0	0.2300	
4	99999.0	0.2200	
Record # 3	Fuel: Oil		
Rate ID = Ottawa08	Oil Rate Block		
Rate Block		Dollars	Charge
	Litre	Per Litre	($)
Minimum	0.0		0.000
1	99999.0	1.1750	
Record # 4	Fuel: Propane		
Rate ID = Ottawa08	Propane Rate Block		
Rate Block		Dollars	Charge
	Litre	Per Litre	($)
Minimum	0.0		0.000
1	99999.0	0.7200	
Record # 5	Fuel: Wood		
Rate ID = Sth Ont	Cord Rate		
Rate Block		Dollars	Charge
	Cord	Per Cord	($)
Minimum	0.0		0.000
1	99999.0	210.0000	

MONTHLY ENERGY PROFILE

Month	Energy Load (MJ)	Internal Gains (MJ)	Solar Gains (MJ)	Aux. Energy (MJ)	HRV Eff. %
Jan	23577.4	2515.3	1646.0	19416.0	0.0
Feb	20172.8	2266.0	2271.6	15635.2	0.0
Mar	17662.8	2515.2	3274.4	11873.2	0.0
Apr	11238.8	2449.5	2971.6	5817.7	0.0
May	5709.6	2551.8	2470.5	687.3	0.0
Jun	1534.6	1322.8	211.8	0.0	0.0
Jul	53.5	53.5	0.0	0.0	0.0
Aug	458.4	457.3	1.0	0.0	0.0
Sep	3101.8	1840.3	1261.4	0.0	0.0
Oct	8864.5	2581.7	2011.1	4271.7	0.0
Nov	13739.5	2475.8	1159.6	10104.1	0.0
Dec	19903.6	2534.0	1276.0	16093.6	0.0
Ann	126017.3	23563.5	18555.0	83898.8	0.0

FOUNDATION ENERGY PROFILE

	Heat Loss (MJ)				
Month	**Crawl Space**	**Slab**	**Basement**	**Walkout**	**Total**
Jan	0.0	0.0	878.2	0.0	878.2
Feb	0.0	0.0	707.2	0.0	707.2
Mar	0.0	0.0	537.1	0.0	537.1
Apr	0.0	0.0	263.2	0.0	263.2
May	0.0	0.0	31.1	0.0	31.1
Jun	0.0	0.0	0.0	0.0	0.0
Jul	0.0	0.0	0.0	0.0	0.0
Aug	0.0	0.0	0.0	0.0	0.0
Sep	0.0	0.0	0.0	0.0	0.0
Oct	0.0	0.0	193.2	0.0	193.2
Nov	0.0	0.0	457.0	0.0	457.0
Dec	0.0	0.0	727.9	0.0	727.9
Ann	0.0	0.0	3794.8	0.0	3794.8

FOUNDATION TEMPERATURES & VENTILATION PROFILE

	Temperature (Deg °C)			Air Change Rate		Heat Loss
Month	**Crawl Space**	**Basement**	**Walkout**	**Natural**	**Total**	**(MJ)**

Jan	0.0	18.6	0.0	0.358	0.392	8146.4
Feb	0.0	18.5	0.0	0.335	0.369	6735.3
Mar	0.0	18.7	0.0	0.312	0.346	5686.0
Apr	0.0	19.3	0.0	0.272	0.305	3357.9
May	0.0	20.4	0.0	0.188	0.222	1427.5
Jun	0.0	22.0	0.0	0.145	0.179	490.4
Jul	0.0	23.2	0.0	0.125	0.159	153.9
Aug	0.0	22.8	0.0	0.112	0.146	234.7
Sep	0.0	21.4	0.0	0.148	0.182	842.2
Oct	0.0	20.2	0.0	0.203	0.237	2242.5
Nov	0.0	19.5	0.0	0.269	0.303	3987.2
Dec	0.0	18.9	0.0	0.313	0.347	6336.5
Ann	0.0	20.3	0.0	0.231	0.265	39640.5

SPACE HEATING SYSTEM PERFORMANCE

Month	Space Heating Load (MJ)	Furnace Input (MJ)	Pilot Light (MJ)	Indoor Fans (MJ)	Heat Pump Input (MJ)	Total Input (MJ)	System Cop
Jan	19416.0	19826.6	784.3	118.4	0.0	20729.3	0.937
Feb	15635.2	16043.4	708.4	85.9	0.0	16837.7	0.929
Mar	11873.2	12407.3	784.3	47.4	0.0	13239.0	0.897
Apr	5817.7	6377.1	759.0	13.5	0.0	7149.6	0.814
May	687.3	1155.4	784.3	0.3	0.0	1940.0	0.354
Jun	0.0	0.0	759.0	0.0	0.0	759.0	0.000
Jul	0.0	0.0	784.3	0.0	0.0	784.3	0.000
Aug	0.0	0.0	784.3	0.0	0.0	784.3	0.000
Sep	0.0	0.0	759.0	0.0	0.0	759.0	0.000
Oct	4271.7	4869.3	784.3	7.2	0.0	5660.8	0.755
Nov	10104.1	10651.1	759.0	34.0	0.0	11444.1	0.883
Dec	16093.6	16568.7	784.3	81.4	0.0	17434.5	0.923
Ann	83898.8	87898.9	9234.5	388.1	0.0	97521.5	0.860

AIR CONDITIONING SYSTEM PERFORMANCE

Month	Sensible Load (MJ)	Latent Load (MJ)	AirCond Energy (kWh)	Fan Energy (kWh)	Ventilator Energy (kWh)	Crankcase Heater (kWh)	Total Energy (kWh)	COP	Av.RH %

Apr	135.1	9.5	13.6	1.6	0.0	41.4	56.6	0.7	34.1
May	1006.2	81.9	102.2	12.1	0.0	30.9	145.3	2.1	35.6
Jun	2725.1	415.7	291.9	34.1	0.0	11.9	337.9	2.6	40.9
Jul	4424.5	827.1	486.5	55.9	0.0	5.4	547.9	2.7	42.7
Aug	3337.6	698.2	375.1	43.4	0.0	8.2	426.7	2.6	43.8
Sep	1058.9	221.9	121.5	14.2	0.0	25.8	161.6	2.2	43.5
Oct	65.6	15.7	7.8	0.9	0.0	43.2	52.0	0.4	44.0
Ann	12753.0	2270.2	1398.7	162.3	0.0	167.0	1728.0	2.4	41.9

MONTHLY ESTIMATED ENERGY CONSUMPTION BY DEVICE (MJ)

	Space Heating		DHW Heating		Lights &	HRV &	Air
Month	**Primary**	**Secondary**	**Primary**	**Secondary**	**Appliances**	**FANS**	**Conditioner**
Jan	20610.9	0.0	3350.4	0.0	2176.8	132.7	0.0
Feb	16751.8	0.0	3070.0	0.0	1966.1	98.9	0.0
Mar	13191.6	0.0	3350.1	0.0	2176.8	61.8	0.0
Apr	7136.1	0.0	3111.4	0.0	2106.6	33.2	198.1
May	1939.7	0.0	3028.9	0.0	2176.8	58.3	479.4
Jun	759.0	0.0	2774.0	0.0	2106.6	136.8	1093.7
Jul	784.3	0.0	2737.7	0.0	2176.8	215.6	1771.0
Aug	784.3	0.0	2690.5	0.0	2176.8	170.6	1380.0
Sep	759.0	0.0	2649.4	0.0	2106.6	65.0	530.5
Oct	5653.6	0.0	2854.4	0.0	2176.8	24.9	183.9
Nov	11410.1	0.0	2939.1	0.0	2106.6	47.9	0.0
Dec	17353.0	0.0	3218.6	0.0	2176.8	95.8	0.0
Ann	97133.5	0.0	35774.4	0.0	25629.8	1141.4	5636.6

ESTIMATED FUEL COSTS (Dollars)

Month	Electricity	Natural Gas	Oil	Propane	Wood	Total
Jan	64.50	153.90	0.00	0.00	0.00	218.40
Feb	58.64	129.36	0.00	0.00	0.00	188.00
Mar	62.68	110.09	0.00	0.00	0.00	172.77
Apr	65.40	72.89	0.00	0.00	0.00	138.30
May	75.87	41.14	0.00	0.00	0.00	117.01
Jun	93.60	32.23	0.00	0.00	0.00	125.83
Jul	116.77	32.20	0.00	0.00	0.00	148.96
Aug	104.46	31.90	0.00	0.00	0.00	136.36
Sep	75.68	31.43	0.00	0.00	0.00	107.11

Oct	66.59	62.66	0.00	0.00	0.00	129.25
Nov	60.66	97.11	0.00	0.00	0.00	157.77
Dec	63.55	133.89	0.00	0.00	0.00	197.44
Ann	908.40	928.81	0.00	0.00	0.00	1837.21

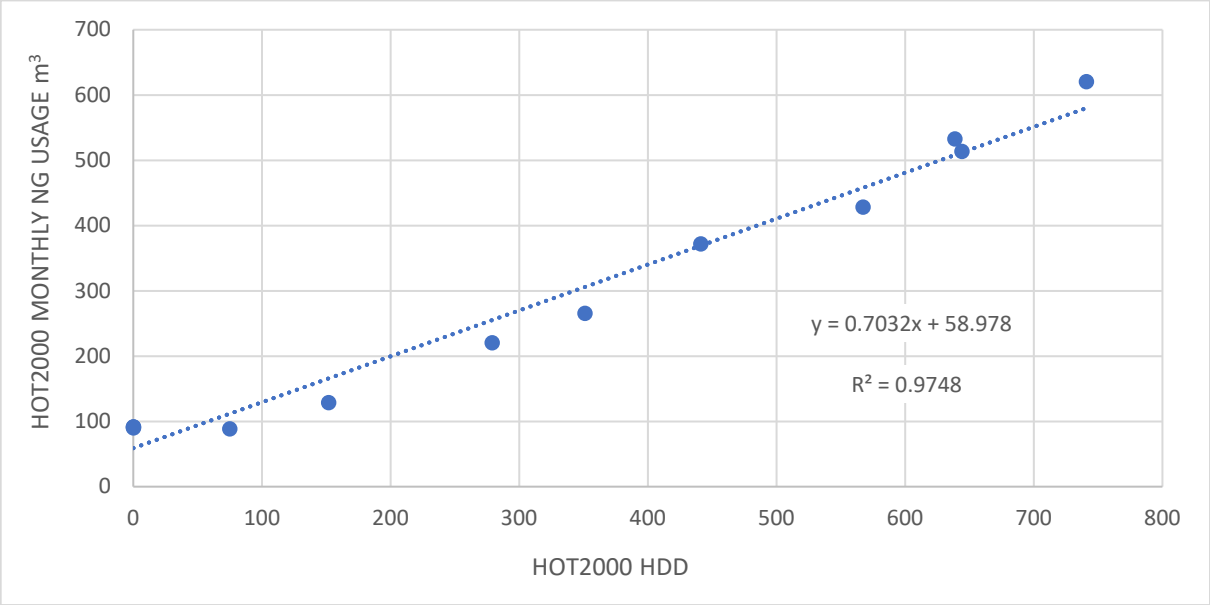
The calculated heat losses and energy consumptions are only estimates, based upon the data entered and assumptions within the program. Actual energy consumption and heat losses will be influenced by construction practices, localized weather, equipment characteristics and the lifestyle of the occupants.

A7 Calculations of Weather Normalized Energy Consumption Data: Natural Gas and Electricity

Month	Baseline HOT2000 NG Consumption (m^3)	HOT2000 Temp.	No. Days in Month	HDD HOT2000	HDD Actual 2018	HDD Actual 2017	HDD Actual Average	Calculated Normalized Weather Data NG Consumption (m^3)
Jan.	621	-5.9	31	741	678.7	569.7	*624*	**498**
Feb.	513	-5.0	28	644	511.9	481.2	*497*	**408**
Mar.	428	-0.3	31	567	539.0	545.2	*542*	**440**
April	265	6.3	30	351	432.1	291.2	*362*	**313**
May	129	13.1	31	152	145.9	219.9	*183*	**188**
June	92	18.1	30	0	34.5	43.3	*39*	**86**
July	91	21.1	31	0	0.5	2.3	*1*	**60**
Aug.	90	20.0	31	0	2.0	8.8	*5*	**63**
Sept.	88	15.5	30	75	34.0	44.9	*39*	**87**
Oct.	220	9.0	31	279	244.2	127.9	*186*	**190**
Nov.	372	3.3	30	441	450.2	384.3	*417*	**352**
Dec.	533	-2.6	31	639	517.5	644.5	*581*	**468**

Notes to Table:

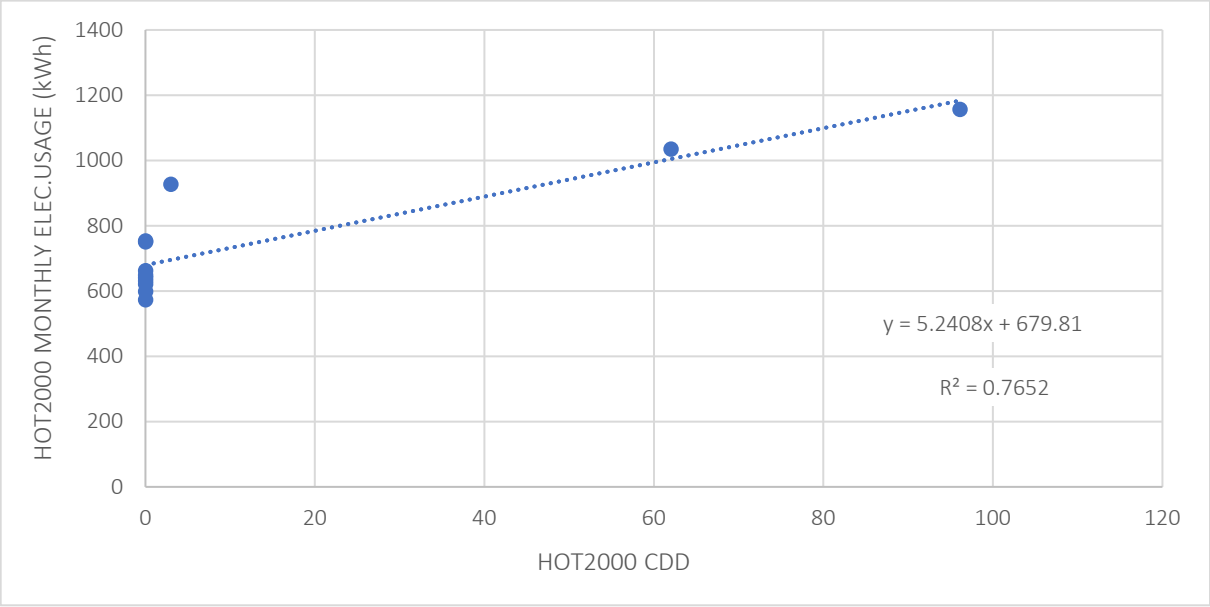
- *HDD HOT2000 calculated: (HOT2000 Temp. – 18°C) * No. of Days in Month.*
- *Source of actual HDD and CDD values from www.degreedays.net*



Month	Baseline HOT2000 Elec. Consumption (kWh)	HOT2000 Temp.	No. Days in Month	CDD HOT2000	CDD Actual 2018	CDD Actual 2017	CDD Actual Average	Calculated Normalized Weather Data Elec. Consumption (kWh)
Jan.	642	-5.9	31	0	0.0	0.0	0	**680**
Feb.	574	-5.0	28	0	0.0	0.0	0	**680**
Mar.	622	-0.3	31	0	0.0	0.0	0	**680**
April	649	6.3	30	0	0	3	1	**687**
May	754	13.1	31	0	28	17	22	**796**
June	927	18.1	30	3	56	72	64	**1014**
July	1156	21.1	31	96	162	105	133	**1378**
Aug.	1035	20.0	31	62	168	88	128	**1351**
Sept.	751	15.5	30	0	78	59	68	**1038**
Oct.	663	9.0	31	0	13	19	16	**764**
Nov.	598	3.3	30	0	0	0	0	**680**
Dec.	631	-2.6	31	0	0	0	0	**680**

Notes to Table:

- *HDD HOT2000 calculated: (HOT2000 Temp. – 18°C) * No. of Days in Month.*
- *Source of actual HDD and CDD values from www.degreedays.net*



A8 HOT2000 Calibrated Energy Model Run

HOT2000
Natural Resources CANADA
Version 11.9



File: Calibrated Energy Model_Mathers Dr_10 House

Weather Library: C:\HOT2000 v11.9b20154\Dat\Wth110.dir
Weather Data for: WINDSOR, ONTARIO

Builder Code:

Data Entry by: Tyler Simspon
Date of entry: 2020-10-16

Company: Ryerson University

Client name: Simpson,
Street address: 10 Mathers
City: Stoney Creek **Region:** ONTARIO
Postal code: L8G 4J3 **Telephone:**

GENERAL HOUSE CHARACTERISTICS

House type:	Single Detached		
Number of storeys:	Two storeys		
Plan shape:			
Front orientation:	West		
Year House Built:	1980-89		
Wall colour:	Default	**Absorptivity:**	0.40
Roof colour:	Default	**Absorptivity:**	0.40
Soil Condition:	Normal conductivity (dry sand, loam, clay)		
Water Table Level:	Normal (7-10m/23-33ft)		
House Thermal Mass Level:	(A) Light, wood frame		
Effective mass fraction	1.000		
Occupants :	2 Adults for 50.0% of the time 1 Children for 50.0% of the time 1 Infants for 50.0% of the time		
Sensible Internal Heat Gain From Occupants:	2.40 kWh/day		

HOUSE TEMPERATURES

Heating Temperatures

Main Floor	**Daytime Setpoint:**	21.0 °C
	Nightime Setpoint:	18.0 °C
	Nightime Setback Duration:	8.0 Hours
	24 Hour Average:	20.0 °C
Basement	**Setpoint:**	19.0 °C
	TEMP. Rise from 20.0 °C:	5.5 °C

Cooling Temperature: Main Floor : 26.00 °C

Basement is- Heated: Yes **Cooled:** No **Separate T/S:** No

Fraction of internal gains released in basement : 0.150

Indoor design temperatures for equipment sizing

Heating:	22.0 °C
Cooling:	26.0 °C

WINDOW CHARACTERISTICS

Label	Location	#	Overhang Width (m)	Header Height (m)	Tilt deg	Curtain Factor	Shutter (RSI)
South							
S 1st Flr_Wall	S 1st Flr_Wall	1	0.61	2.41	90.0	1.00	0.00
Southeast							
Insert Rear Door	Rear Entrance Door	1	0.61	0.15	90.0	1.00	0.00
East							
E Ensuite 2nd Flr_Wall	E 2nd Flr_Wall	1	0.61	0.15	90.0	1.00	0.00
E Master 2nd Flr_Wall	E 2nd Flr_Wall	1	0.61	0.15	90.0	1.00	0.00
E1 1st Flr_Wall	E 1st Flr_Wall	1	0.61	2.54	90.0	1.00	0.00
E2 1st Flr_Wall	E 1st Flr_Wall	1	0.61	2.54	90.0	1.00	0.00
E3 1st Flr_Wall	E 1st Flr_Wall	1	0.61	2.54	90.0	1.00	0.00
E4 1st Flr_Wall	E 1st Flr_Wall	1	0.61	2.54	90.0	1.00	0.00
Northeast							
NE 1st Flr_Wall	NE 1st Flr_Wall	1	0.61	0.15	90.0	1.00	0.00

North							
N 2nd Flr_Wall	N 2nd Flr_Wall	1	0.61	0.15	90.0	1.00	0.00
West							
Insert Front Door	Front Door	1	0.61	2.54	90.0	1.00	0.00
Sidelight 1	Front Door	2	0.61	2.54	90.0	1.00	0.00
W 1st Flr_Wall	W 1st Flr_Wall	4	0.61	2.54	90.0	1.00	0.00
W 2nd Flr_Wall	W 2nd Flr_Wall	2	0.61	0.15	90.0	1.00	0.00
W1 1st Flr_Wall	W 1st Flr_Wall	2	0.61	2.54	90.0	1.00	0.00
W1 2nd Flr_Wall	W 2nd Flr_Wall	1	0.61	0.15	90.0	1.00	0.00

Label	Type	#	Window Width (m)	Window Height (m)	Total Area (m^2)	Window RSI	SHGC	ER*
South								
S 1st Flr_Wall	200014	1	0.84	0.91	0.77	0.336	0.5448	1.6
Southeast								
Insert Rear Door	200000	1	0.48	1.55	0.75	0.237	0.6550	-19.5
East								
E Ensuite 2nd Flr_Wall	233015	1	0.63	0.74	0.47	0.373	0.4630	0.1
E Master 2nd Flr_Wall	233015	1	1.52	1.17	1.78	0.438	0.5755	21.2
E1 1st Flr_Wall	233015	1	1.73	1.32	2.28	0.449	0.5903	23.7
E2 1st Flr_Wall	233015	1	0.84	0.91	0.77	0.398	0.5126	9.8
E3 1st Flr_Wall	233015	1	1.12	1.73	1.93	0.440	0.5784	21.8
E4 1st Flr_Wall	233015	1	2.06	1.32	2.72	0.455	0.5981	25.1
Northeast								
NE 1st Flr_Wall	200014	1	0.71	1.73	1.23	0.338	0.5686	5.0
North								
N 2nd Flr_Wall	200014	1	1.14	1.17	1.34	0.340	0.5937	7.1
West								
Insert Front Door	200000	1	0.53	1.19	0.64	0.238	0.6557	-20.0
Sidelight 1	200000	2	0.18	1.19	0.42	0.165	0.5132	-71.8
W 1st Flr_Wall	233015	4	0.61	1.73	4.21	0.398	0.5143	13.8
W 2nd Flr_Wall	233015	2	1.37	1.17	3.20	0.434	0.5694	21.3
W1 1st Flr_Wall	233015	2	0.91	1.73	3.16	0.428	0.5613	20.1
W1 2nd Flr_Wall	233015	1	0.66	1.17	0.77	0.393	0.5046	8.7

*ER Window Energy Rating (ER 2009) estimated for actual dimensions, and Air tightness type: CSA - A1; Leakage rate = 1.86 L/s.m^2

Above grade fraction of wall area occupied by windows: 10.6 %

WINDOW CODE SCHEDULE

Name	Internal Code	Description (Glazings, Coatings, Fill, Spacer, Type, Frame)
200014	200014	Double/double with 1 coat, Clear, 13 mm Air, Metal, Hinged, Vinyl, ER* = 2.0, Eff. RSI= 0.34
200000	200000	Double/double with 1 coat, Clear, 13 mm Air, Metal, Picture, Aluminum, ER* = -1.9, Eff. RSI= 0.28
233015	233015	Double/double with 1 coat, Low-E .20 (hard1), 13 mm Argon, Metal, Hinged, Reinforced vinyl, ER* = 9.8, Eff. RSI= 0.39

* Window Standard Energy Rating (ER 2009) estimated for assumed dimensions, and Air tightness type: CSA - A1; Leakage rate = 1.86 L/s.m^2

BUILDING PARAMETER DETAILS

CEILING COMPONENTS

	Construction Type	Code Type	Roof Slope	Heel Ht. (m)	Section Area (m^2)	R. Value (RSI)
1st Fl Den_Ceiling	Attic/gable	User specified	5.004/12	0.10	34.94	5.28
1st Fl Din. Bump Out_Ceiling	Attic/gable	User specified	5.004/12	0.10	3.54	5.28
2nd Flr_Ceiling	Attic/gable	User specified	5.004/12	0.10	85.87	5.28

MAIN WALL COMPONENTS

Label	Lintel Type	Fac. Dir	Number of Corn.	Number of Inter.	Height (m)	Perim. (m)	Area (m^2)	R. Value (RSI)
E 1st Flr_Wall Type: 1201281041	010	East	4	2	2.74	13.84	37.92	2.59
E 2nd Flr_Wall Type: 1201281041	010	East	2	2	2.74	8.99	24.63	2.72
N 1st Flr_Wall Type: 1201281041	010	South	2	1	2.74	9.55	26.17	2.92
N 2nd Flr_Wall Type: 1201281041	010	North	2	2	2.74	9.55	26.17	2.81
NE 1st Flr_Wall Type: 1201281041	010	Northeast	3	0	2.74	1.60	4.38	2.29
S 1st Flr_Wall Type: 1201281041	010	South	6	0	2.74	5.87	16.08	2.72
S 2nd Flr_Wall Type: 1201281041	010	South	2	3	2.74	9.55	26.17	2.87
S Gar. 1st Flr_Wall Type: 1201281041	010	South	2	0	2.74	4.14	11.34	> 3.05
SE 1st Flr_Wall Type: 1201281041	010	Southeast	2	0	2.74	1.67	4.58	2.25
W 1st Flr_Wall Type: 1201281041	010	West	10	2	2.74	10.29	28.19	2.25
W 2nd Flr_Wall Type: 1201281041	010	West	2	1	2.74	8.99	24.63	2.64
W Gar. 1st Flr_Wall Type: 1201281041	010	West	2	2	2.74	5.92	16.22	> 2.87

> Indicates that the component is adjacent to an enclosed unconditioned space.

WALL CODE SCHEDULE

Name	Internal Code	Description (Structure, typ/size, Spacing, Insull, 2, Int., Sheathing,

Exterior, Studs)

1201281041	1201281041	Wood frame, 38x89 mm (2x4 in), 400 mm (16 in), RSI 2.11 @ 89 mm (R 12 @ 3.5") batt, 19 mm (0.75 in) isocyanurate, 12 mm (0.5 in) gypsum board, None, Brick, 3 studs

DOORS

Label	Type	Height (m)	Width (m)	Gross Area (m^2)	R. Value (RSI)
Front Door Loc: W 1st Flr_Wall	Wood hollow core	2.08	1.63	3.38	0.37
Gar. Door Loc: W Gar. 1st Flr_Wall	Wood hollow core	2.06	0.81	1.67	> 0.53
Rear Entrance Door Loc: SE 1st Flr_Wall	Steel fibreglass core	2.08	0.86	1.80	0.29

> Indicates that the component is adjacent to an enclosed unconditioned space.

FOUNDATIONS

Foundation Name: Foundation
Foundation Type: Basement
Data Type: Library

Volume: 215.9 m^3
Opening to Main Floor: 0.00 m^2

Total Wall Height: 2.29 m
Depth Below Grade: 2.14 m

Non-Rectangular Floor Perimeter: 41.94 m
Floor Area: 94.29 m^2

Interior wall type: User specified
Exterior wall type: User specified
Number of corners : 8
Lintel type: 010
Added to slab type : N/A
Floors Above Found.: 4231080000

R-value: 0.00 RSI
R-Value: 0.00 RSI
R-Value: 0.00 RSI
R-Value: 1.19 RSI

Exposed areas for: Foundation
Exposed Perimeter: 5.99 m

Configuration: BCNN_1
- concrete walls and floor
- no insulation
- first storey brick veneer placed directly on basement's concrete walls

---

Foundation Name: Foundation Low Ceiling
Foundation Type: Basement
Data Type: Library

Volume: 73.7 m^3
Opening to Main Floor: 0.00 m^2

Total Wall Height: 2.11 m
Depth Below Grade: 1.96 m

Non-Rectangular Floor Perimeter: 24.28 m

		Floor Area:	34.94 m^2
Interior wall type:	User specified	**R-value:**	0.00 RSI
Exterior wall type:	User specified	**R-Value:**	0.00 RSI
Number of corners :	8		
Lintel type:	010		
Added to slab type :	N/A	**R-Value:**	0.00 RSI
Floors Above Found.:	4231080000	**R-Value:**	1.19 RSI

Exposed areas for: Foundation Low Ceiling
Exposed Perimeter: 5.99 m

Configuration: BCNN_1
- concrete walls and floor
- no insulation
- first storey brick veneer placed directly on basement's concrete walls

---

FOUNDATION CODE SCHEDULE

Floors Above Foundation

Name	Internal Code	Description (Structure, typ/size, Spacing, Insul1, 2, Int., Sheathing, Exterior, Drop Framing)
4231080000	4231080000	Wood frame, 38x235 mm (2x10 in), 400 mm (16 in), None, 19 mm (0.75 in) isocyanurate, None, None, None, No

Lintel Code Schedule

Name	Code	Description (Type, Material, Insulation)
010	010	Single, Steel, None

ROOF CAVITY INPUTS

Gable Ends		**Total Area:**	17.28 m^2
Sheathing Material	Plywood/Part. bd 9.5 mm (3/8 in)		0.08 RSI
Exterior Material:	Hollow metal/vinyl cladding		0.11 RSI
Sloped Roof		**Total Area:**	134.73 m^2
Sheathing Material	Plywood/Part. bd 12.7 mm (1/2 in)		0.11 RSI
Exterior Material:	Asphalt shingles		0.08 RSI
Total Cavity Volume:	85.9 m^3	**Ventilation Rate:**	0.50 ACH/hr

BUILDING ASSEMBLY DETAILS

Label	Construction Code	Nominal (RSI)	System (RSI)	Effective (RSI)
MAIN WALL COMPONENTS				
E 1st Flr_Wall	1201281041	2.84	2.70	2.59
E 2nd Flr_Wall	1201281041	2.84	2.78	2.72
N 1st Flr_Wall	1201281041	2.84	2.92	2.92
N 2nd Flr_Wall	1201281041	2.84	2.84	2.81
NE 1st Flr_Wall	1201281041	2.84	2.38	2.29
S 1st Flr_Wall	1201281041	2.84	2.75	2.72
S 2nd Flr_Wall	1201281041	2.84	2.87	2.87
S Gar. 1st Flr_Wall	1201281041	2.84	2.89	2.89
SE 1st Flr_Wall	1201281041	2.84	2.37	2.25
W 1st Flr_Wall	1201281041	2.84	2.38	2.25
W 2nd Flr_Wall	1201281041	2.84	2.74	2.64
W Gar. 1st Flr_Wall	1201281041	2.84	2.74	2.71
FLOORS ABOVE BASEMENTS				
Foundation	4231080000	0.73	1.19	1.19
Foundation Low Ceiling	4231080000	0.73	1.19	1.19

BUILDING PARAMETERS SUMMARY

ZONE 1 : Above Grade

Component	Area m^2 Gross	Area m^2 Net	Effective (RSI)	Heat Loss MJ	% Annual Heat Loss
Ceiling	124.35	124.35	5.28	6133.92	5.65
Main Walls	246.49	215.03	2.71	25624.70	23.62
Doors	6.85	5.05	0.35	5148.47	4.75
South Windows	0.77	0.77	0.34	812.96	0.75
Southeast Windows	0.75	0.75	0.24	1127.72	1.04
East Windows	9.94	9.94	0.44	8090.88	7.46
Northeast Windows	1.23	1.23	0.34	1298.60	1.20
North Windows	1.34	1.34	0.34	1402.01	1.29
West Windows	12.40	12.40	0.38	11623.19	10.71
		ZONE 1 Totals:		**61262.46**	**56.47**

INTER-ZONE Heat Transfer : Floors Above Basement

	Area m^2 Gross	Area m^2 Net	Effective (RSI)	Heat Loss MJ

	129.23	129.23	1.192	1056.62	

ZONE 2 : Basement

Component	Area m^2 Gross	Area m^2 Net	Effective (RSI)	Heat Loss MJ	% Annual Heat Loss
Walls above grade	1.80	1.80	-	2405.61	2.22
Below grade foundation	153.79	153.79	-	9094.66	8.38
		ZONE 2 Totals:		**11500.27**	**10.60**

Air Leakage and Mechanical Ventilation

	House Volume	Air Change	Heat Loss MJ	% Annual Heat Loss
	879.10 m^3	0.271 ACH	35731.535	32.93

AIR LEAKAGE AND MECHANICAL VENTILATION

Building Envelope Surface Area: 526.43 m^2

Air Leakage Test Results at 50 Pa. (0.2 in H_2O) = 5.12 ACH

Equivalent Leakage Area @ 10 Pa = 1680.66 cm2

Terrain Description			**Height** (m)
@ Weather Station :	Open flat terrain, grass	Anemometer:	10.0
@ Building site :	Parkland, bushes	Height of the highest ceiling:	5.1

Local Shielding:

Walls:	Light
Flue :	Light

Leakage Fractions-

Ceiling:	0.200
Walls:	0.650
Floors:	0.150

Normalized Leakage Area @ 10 Pa: 3.1925 cm^2/m^2

Estimated Airflow to cause a 5 Pa Pressure Difference: 267 L/s

Estimated Airflow to cause a 10 Pa Pressure Difference: 419 L/s

F326 VENTILATION REQUIREMENTS

Kitchen, Living Room, Dining Room	3 rooms @ 5.0 L/s: 15.0 L/s
Utility Room	1 rooms @ 5.0 L/s: 5.0 L/s
Bedroom	1 rooms @ 10.0 L/s: 10.0 L/s
Bedroom	1 rooms @ 5.0 L/s: 5.0 L/s
Bathroom	1 rooms @ 5.0 L/s: 5.0 L/s
Basement Rooms	10.0 L/s

SECONDARY FANS & OTHER EXHAUST APPLIANCES

	Control	**Supply (L/s)**	**Exhaust (L/s)**
Other Fans	Continuous	0.00	1.70

Dryer	Continuous	-	0.45

Dryer is vented outdoors

Rated Fan Power	1.29 Watts

NEW ERS VENTILATION DATA

Whole House Systems

Air Distribution/circulation type:	Forced air heating ductwork
Air Distribution/circulation fan power:	100.00 Watts
Operation schedule:	360.00 min/day

Supplementary Systems

System # 1 Type:	Dryer	
Manufacturer:		
Model:		
Airflow Supply Rate: 0.00 L/s	**Exhaust:** 38.00 L/s	**Fan Power:** 0.00 Watts
Operation schedule:	17.00 min/day	

System # 2 Type:	Range hood	
Manufacturer:		
Model:		
Airflow Supply Rate: 0.00 L/s	**Exhaust:** 75.00 L/s	**Fan Power:** 57.00 Watts
Operation schedule:	15.00 min/day	

System # 3 Type:	Bathroom	
Manufacturer:		
Model:		
Airflow Supply Rate: 0.00 L/s	**Exhaust:** 33.00 L/s	**Fan Power:** 25.10 Watts
Operation schedule:	39.00 min/day	

System # 4 Type:	Bathroom	
Manufacturer:		
Model:		
Airflow Supply Rate: 0.00 L/s	**Exhaust:** 33.00 L/s	**Fan Power:** 25.10 Watts
Operation schedule:	1.00 min/day	

AIR LEAKAGE AND MECHANICAL VENTILATION SUMMARY

F326 Required continous ventilation:	50.000 L/s (0.20 ACH)
Other Continuous Supply Flow Rates:	0.000 L/s (0.00 ACH)
Other Continuous Exhaust Flow Rates:	1.698 L/s (0.01 ACH)
Total house ventilation is Balanced	
Gross Air Leakage and Mechanical Ventilation Energy Load:	34840.746 MJ
Seasonal Heat Recovery Ventilator Efficiency:	0.000 %
Estimated Ventilation Electrical Load: Heating Hours:	0.000 MJ
Estimated Ventilation Electrical Load: Non-Heating Hours:	0.000 MJ
Net Air Leakage and Mechanical Ventilation Load:	35731.535 MJ

SPACE HEATING SYSTEM

PRIMARY Heating Fuel:	Natural Gas
Equipment:	Furnace/Boiler with continuous pilot
Manufacturer:	
Model:	
Calculated* Output Capacity:	14.00 kW
* Design Heat loss X 1.00 + 0.5 kW	
Pilot Light energy consumption:	17.00 MJ/day
AFUE:	95.00
Steady State Efficiency:	100.00
Fan Mode:	Auto
ECM Motor:	Yes
Low Speed Fan Power:	0 watts
High Speed Fan Power:	168 watts
Flue Diameter:	152.40 mm

AIR CONDITIONING SYSTEM

System Type:	Central split system		
Manufacturer:			
Model:			
Capacity:	8697 Watts		
SEER	16.00	**Rated COP**	3.268
Sensible Heat Ratio:	0.76		
Indoor Fan Flow Rate:	586.86 L/s	**Fan Power (watts)**	280.58
Ventilator Flow Rate:	0.00 L/s	**Crankcase Heater Power (watts):**	60.00
Fraction of windows Openable:	0.000	**ECM Motor:**	Yes
Cooling system capacity sizing factor:	1.000		
Economizer control:	N/A	**Indoor Fan Operation:**	Auto

Air Conditioner is integrated with the Heating System

DOMESTIC WATER HEATING SYSTEM

PRIMARY Water Heating Fuel:	Natural gas
Water Heating	Induced draft fan (pilot)

Equipment:			
Energy Factor:	0.571		
Manufacturer:			
Model:			
Tank Capacity:	151.4 Litres	**Tank Blanket Insulation:**	0.0 RSI
Tank Location:	Basement		
Pilot Energy :	17.7 MJ/day	**Flue Diameter:**	76.2 mm

ANNUAL DOMESTIC WATER HEATING SUMMARY

Daily Hot Water Consumption:	87.0 Litres
Hot Water Temperature:	55.0 °C
Estimated Domestic Water Heating Load:	5943 MJ
Primary Domestic Water Heating Energy Consumption:	13759 MJ
Primary System Seasonal Efficiency:	43.2%

ANNUAL SPACE HEATING SUMMARY

Gross Space Heat Loss:	108494 MJ
Gross Space Heating Load:	106748 MJ
Usable Internal Gains:	19650 MJ
Usable Internal Gains Fraction:	18.1 %
Usable Solar Gains:	17565 MJ
Usable Solar Gains Fraction:	16.2 %
Auxilary Energy Required:	69532 MJ
Space Heating System Load:	69532 MJ
Furnace/Boiler Seasonal efficiency:	86.6 %
Furnace/Boiler Annual Energy Consumption:	79967 MJ

DESIGN SPACE HEATING AND COOLING LOADS

Design Heat Loss* at -16.0 °C (15.82 Watts / m3):	13909 Watts
Design Cooling Load* for July at (32.0 ° C):	7756 Watts

*** Please refer to notes at the end of this report.**

ANNUAL SPACE COOLING SUMMARY

Design Sensible Heat Ratio:	0.769
Estimated Annual Space Cooling Energy:	1455.85 kWh
Seasonal COP (June to September):	2.746

BASE LOADS SUMMARY

	kwh/day	Annual kWh
Interior Lighting	0.60	219.00
Appliances	6.54	2388.02
Other	7.50	2737.50
Exterior Use	0.40	146.00
HVAC Fans		
HRV/Exhaust	0.03	11.31
Space Heating	0.24	87.96
Space Cooling	0.42	152.94
Total Average Electrical Load	15.73	5742.72

Natural gas Stove:	**Location:** Main floor
Energy consumption:	5.6 MJ/Day

FAN OPERATION SUMMARY (kWh)

Hours	HRV/Exhaust Fans	Space Heating	Space Cooling
Heating	7.0	88.0	0.0
Neither	1.5	0.0	0.0
Cooling	2.8	0.0	152.9
Total	11.3	88.0	

ENERGY CONSUMPTION SUMMARY REPORT

Estimated Annual Space Heating Energy Consumption	= 80283.90 MJ	= 22301.08 kWh
Ventilator Electrical Consumption: Heating Hours	= 0.00 MJ	= 0.00 kWh
Estimated Annual DHW Heating Energy Consumption	= 13759.46 MJ	= 3822.07 kWh
ESTIMATED ANNUAL SPACE + DHW ENERGY CONSUMPTION	= 94043.36 MJ	= 26123.16 kWh

Estimated Greenhouse Gas Emissions 5.192 tonnes/year

ESTIMATED ANNUAL FUEL CONSUMPTION SUMMARY

Fuel	Space Heating	Space Cooling	DHW Heating	Baseloads	Ventilation	Total
Natural Gas (m3)	2146.3	0.0	369.3	54.6	0.0	2570.1
Electricity (kWh)	88.0	1455.9	0.0	5490.5	11.3	7045.6

ESTIMATED ANNUAL FUEL CONSUMPTION COSTS

Fuel Costs Library = Embedded

RATE	Electricity (Ottawa08)	Natural Gas (Toronto)	Oil (Ottawa08)	Propane (Ottawa08)	Wood (Sth Ont)	Total
$	774.96	691.32	0.00	0.00	0.00	1466.28

Fuel Costs Library Listing

Filename = Embedded

Record # 1	Fuel: Electricity		
Rate ID = Ottawa08	Hydro Rate Block		
Rate Block		Dollars	Charge
	kWhr	Per kWhr	($)
Minimum	0.0		9.540
1	600.0	0.0926	
2	99999.0	0.1016	
Record # 2	Fuel: Natural Gas		

Rate ID = Toronto	these are not real rates		
Rate Block		Dollars	Charge
	m3	Per m3	($)
Minimum	0.0		8.000
1	40.0	0.2500	
2	100.0	0.2400	
3	200.0	0.2300	
4	99999.0	0.2200	
Record # 3	Fuel: Oil		
Rate ID = Ottawa08	Oil Rate Block		
Rate Block		Dollars	Charge
	Litre	Per Litre	($)
Minimum	0.0		0.000
1	99999.0	1.1750	
Record # 4	Fuel: Propane		
Rate ID = Ottawa08	Propane Rate Block		
Rate Block		Dollars	Charge
	Litre	Per Litre	($)
Minimum	0.0		0.000
1	99999.0	0.7200	
Record # 5	Fuel: Wood		
Rate ID = Sth Ont	Cord Rate		
Rate Block		Dollars	Charge
	Cord	Per Cord	($)
Minimum	0.0		0.000
1	99999.0	210.0000	

MONTHLY ENERGY PROFILE

Month	Energy Load (MJ)	Internal Gains (MJ)	Solar Gains (MJ)	Aux. Energy (MJ)	HRV Eff. %
Jan	21264.2	2261.7	1935.2	17067.4	0.0
Feb	17764.8	2036.9	2490.6	13237.4	0.0
Mar	15100.9	2261.8	3094.7	9744.4	0.0
Apr	9234.3	2205.6	2943.4	4085.3	0.0
May	4135.5	2299.7	1783.0	52.8	0.0
Jun	433.9	431.3	2.5	0.0	0.0
Jul	0.0	0.0	0.0	0.0	0.0
Aug	0.0	0.0	0.0	0.0	0.0
Sep	1649.2	1307.1	342.1	0.0	0.0
Oct	6974.7	2332.2	2109.4	2533.0	0.0
Nov	12116.6	2232.9	1424.3	8459.4	0.0
Dec	18074.0	2281.2	1440.0	14352.7	0.0
Ann	106748.1	19650.4	17565.2	69532.5	0.0

FOUNDATION ENERGY PROFILE

	Heat Loss (MJ)				
Month	**Crawl Space**	**Slab**	**Basement**	**Walkout**	**Total**
Jan	0.0	0.0	919.5	0.0	919.5
Feb	0.0	0.0	713.2	0.0	713.2
Mar	0.0	0.0	525.0	0.0	525.0
Apr	0.0	0.0	220.1	0.0	220.1
May	0.0	0.0	2.8	0.0	2.8
Jun	0.0	0.0	0.0	0.0	0.0
Jul	0.0	0.0	0.0	0.0	0.0
Aug	0.0	0.0	0.0	0.0	0.0
Sep	0.0	0.0	0.0	0.0	0.0
Oct	0.0	0.0	136.5	0.0	136.5
Nov	0.0	0.0	455.7	0.0	455.7
Dec	0.0	0.0	773.2	0.0	773.2
Ann	0.0	0.0	3746.1	0.0	3746.1

FOUNDATION TEMPERATURES & VENTILATION PROFILE

	Temperature (Deg °C)			Air Change Rate		Heat Loss
Month	**Crawl Space**	**Basement**	**Walkout**	**Natural**	**Total**	**(MJ)**

Jan	0.0	18.6	0.0	0.391	0.400	7705.5
Feb	0.0	18.4	0.0	0.366	0.375	6204.9
Mar	0.0	18.6	0.0	0.345	0.354	5115.4
Apr	0.0	19.2	0.0	0.298	0.307	2893.0
May	0.0	20.5	0.0	0.223	0.232	1114.8
Jun	0.0	22.5	0.0	0.180	0.189	275.6
Jul	0.0	24.0	0.0	0.147	0.156	20.6
Aug	0.0	23.4	0.0	0.133	0.142	92.6
Sep	0.0	21.7	0.0	0.170	0.179	540.6
Oct	0.0	20.0	0.0	0.239	0.247	1900.5
Nov	0.0	19.4	0.0	0.309	0.318	3783.2
Dec	0.0	18.9	0.0	0.349	0.357	6084.8
Ann	0.0	20.4	0.0	0.262	0.271	35731.5

SPACE HEATING SYSTEM PERFORMANCE

Month	Space Heating Load (MJ)	Furnace Input (MJ)	Pilot Light (MJ)	Indoor Fans (MJ)	Heat Pump Input (MJ)	Total Input (MJ)	System Cop
Jan	17067.4	17595.2	527.0	101.3	0.0	18223.5	0.937
Feb	13237.4	13736.4	476.0	68.7	0.0	14281.1	0.927
Mar	9744.4	10322.9	527.0	36.2	0.0	10886.1	0.895
Apr	4085.3	4608.2	510.0	8.0	0.0	5126.2	0.797
May	52.8	477.1	527.0	0.0	0.0	1004.1	0.053
Jun	0.0	0.0	510.0	0.0	0.0	510.0	0.000
Jul	0.0	0.0	527.0	0.0	0.0	527.0	0.000
Aug	0.0	0.0	527.0	0.0	0.0	527.0	0.000
Sep	0.0	0.0	510.0	0.0	0.0	510.0	0.000
Oct	2533.0	3077.7	527.0	3.2	0.0	3607.8	0.702
Nov	8459.4	9035.3	510.0	27.2	0.0	9572.5	0.884
Dec	14352.7	14909.6	527.0	72.0	0.0	15508.6	0.925
Ann	69532.5	73762.2	6205.0	316.6	0.0	80283.9	0.866

AIR CONDITIONING SYSTEM PERFORMANCE

Month	Sensible Load (MJ)	Latent Load (MJ)	AirCond Energy (kWh)	Fan Energy (kWh)	Ventilator Energy (kWh)	Crankcase Heater (kWh)	Total Energy (kWh)	COP	Av.RH %

Jun	2936.3	526.2	302.6	37.0	0.0	10.3	349.9	2.7	41.3
Jul	4412.4	955.0	467.8	56.4	0.0	3.3	527.5	2.8	43.3
Aug	3290.3	779.6	355.1	43.2	0.0	7.2	405.5	2.8	44.0
Sep	1221.5	268.8	132.5	16.2	0.0	24.2	172.9	2.4	42.8
Ann	11860.5	2529.6	1257.9	152.9	0.0	45.0	1455.9	2.7	43.0

MONTHLY ESTIMATED ENERGY CONSUMPTION BY DEVICE (MJ)

	Space Heating		DHW Heating		Lights &	HRV &	Air
Month	**Primary**	**Secondary**	**Primary**	**Secondary**	**Appliances**	**FANS**	**Conditioner**
Jan	18122.2	0.0	1258.0	0.0	1851.5	104.7	0.0
Feb	14212.4	0.0	1149.5	0.0	1672.3	71.8	0.0
Mar	10849.9	0.0	1258.1	0.0	1851.5	39.7	0.0
Apr	5118.2	0.0	1178.0	0.0	1791.8	11.3	0.0
May	1004.1	0.0	1157.6	0.0	1851.5	3.5	0.0
Jun	510.0	0.0	1085.6	0.0	1791.8	136.6	1126.4
Jul	527.0	0.0	1086.2	0.0	1851.5	206.6	1695.9
Aug	527.0	0.0	1073.1	0.0	1851.5	159.1	1304.3
Sep	510.0	0.0	1051.1	0.0	1791.8	61.8	563.9
Oct	3604.7	0.0	1112.9	0.0	1851.5	6.6	0.0
Nov	9545.3	0.0	1129.5	0.0	1791.8	30.6	0.0
Dec	15436.6	0.0	1219.9	0.0	1851.5	75.5	0.0
Ann	79967.3	0.0	13759.5	0.0	21799.9	907.9	4690.5

ESTIMATED FUEL COSTS (Dollars)

Month	**Electricity**	**Natural Gas**	**Oil**	**Propane**	**Wood**	**Total**
Jan	55.42	126.85	0.00	0.00	0.00	182.27
Feb	50.39	103.03	0.00	0.00	0.00	153.42
Mar	53.74	83.91	0.00	0.00	0.00	137.66
Apr	51.62	49.30	0.00	0.00	0.00	100.92
May	52.81	23.44	0.00	0.00	0.00	76.25
Jun	85.63	19.75	0.00	0.00	0.00	105.39
Jul	105.21	19.90	0.00	0.00	0.00	125.12
Aug	92.82	19.82	0.00	0.00	0.00	112.64
Sep	67.65	19.53	0.00	0.00	0.00	87.18
Oct	52.89	39.59	0.00	0.00	0.00	92.48
Nov	52.11	75.42	0.00	0.00	0.00	127.53
Dec	54.66	110.77	0.00	0.00	0.00	165.43

Ann	774.96	691.32	0.00	0.00	0.00	1466.28

The calculated heat losses and energy consumptions are only estimates, based upon the data entered and assumptions within the program. Actual energy consumption and heat losses will be influenced by construction practices, localized weather, equipment characteristics and the lifestyle of the occupants.

A9 NRCan Solar Photovoltaic Ready Checklist

V. *PHOTOVOLTAIC (PV) READY* CHECKLIST AND BUILDER'S DECLARATION

Each of the following specifications shall be completed by the builder in accordance with Section II of the *Photovoltaic (PV) Ready Guidelines*.

1. On the Roof	Completed
Roof orientation and mounting angles: Area 1: _____ azimuth (***degrees***) _____ slope (***degrees***) or pitch (rise:run) Area 2 (as required):_____ azimuth (***degrees***) _____ slope (***degrees***) or pitch (rise:run) Area 3 (as required):_____ azimuth (***degrees***) _____ slope (***degrees***) or pitch (rise:run)	☐
Unobstructed, unshaded roof space for PV system: Area 1:_____ *m²* or *ft²* (*circle one*) Area 2 (as required):_____ *m²* or *ft²* (*circle one*) Area 3 (as required):_____ *m²* or *ft²* (*circle one*) Total Area:_____ *m²* or *ft²* (*circle one*)	☐
Roof ridge setback and access pathways have been included in the roof plan as required by the municipality	☐
Roof structure designed and constructed with Solar-Ready Trusses™ or equivalent and roof structure design will support additional loads of at least 0.17kPa or 3.5psf associated with PV system	☐
2. PV Conduit	
Minimum one PV conduit, sized 3.8 cm/1-1/2", non-combustible if required, run to the electrical panel location	☐
3. Installation and Termination of PV Conduit	
PV conduit installed entirely within the building envelope ***(except for section terminating above the roof if applicable)***	☐
PV conduit with bends/elbows greater than 45 degrees requires pull-rope installed; ***Check if pull-rope installed***	☐
Electrical panel termination workspace provided, conduit sealed and capped	☐
Check one: Attic termination workspace provided, conduit sealed and capped	☐
OR	
Roof termination workspace provided, conduit sealed, flashed and capped	☐

4. Space/Electrical Panel Rating/Network Communications	Completed
Designated wall space near electrical panel provided for PV hardware	☐
Electrical panel will accommodate a PV supply breaker rated up to _____ Amperes in net-metering configuration	☐
Wired network communications available: ***Check if network jack provided at designated PV wall space***	☐

5. Code Compliance	
Electrical Safety Code and Building Code inspections passed	☐

6. Identification of Components	
Copies of the ***PV Ready* documentation** have been included in the home-buyer's information package, filed with the local building permits office, and affixed to the designated PV wall space on-site.	☐

7. Declaration, Name & Signature

I hereby confirm that the *PV Ready* upgrades have been installed in this house according to Section II of *NRCan's Photovoltaic Ready Guidelines*

Home Address

City, Province, Postal Code

Name

Signature

Company Name

Date (yyyy-mm-dd)

A10 Composition of Above Grade Wall Assemblies for WUFI Hygrothermal Modelling

Base Wall Assembly	
Material	**Dimension and/or Unit and Attributes**
Gypsum Board (USA)	12.5mm Bulk Density: 850kg/m^3 Porosity: 0.65 m^3/m^3 Spec. Heat Capacity: 870 J/kgK Thermal Conductivity: 0.163 W/mK Water Vapour Diffusion Resistance Factor: 6
Poly (Vapour Control Layer)	4 ng/s•m^2•PA Bulk Density: 130kg/m^3 Porosity: 0.001 m^3/m^3 Spec. Heat Capacity: 2300 J/kgK Thermal Conductivity: 2.3 W/mK Water Vapour Diffusion Resistance Factor: 50000
Wood Studs (not modelled in WUFI for reference only)	38x89mm at 410mm o.c.
Glass Fiber Batt Insulation	89mm Bulk Density: 19.22kg/m^3 Porosity: 0.99 m^3/m^3 Spec. Heat Capacity: 840 J/kgK Thermal Conductivity: 0.035 W/mK Water Vapour Diffusion Resistance Factor: 1.3
Oriented Strand Board (OSB)	11mm Bulk Density: 553kg/m^3 Porosity: 0.64 m^3/m^3 Spec. Heat Capacity: 1400 J/kgK Thermal Conductivity: 0.12 W/mK Water Vapour Diffusion Resistance Factor: 134

Asphalt Impregnated Paper (30 min)	0.22mm Bulk Density: 200kg/m^3 Porosity: 0.001 m^3/m^3 Spec. Heat Capacity: 1500 J/kgK Thermal Conductivity: 2.3 W/mK Water Vapour Diffusion Resistance Factor: 472
Polyisocyanurate Rigid Foam Insulation	19mm Bulk Density: 32.5kg/m^3 Porosity: 0.99 m^3/m^3 Spec. Heat Capacity: 1470 J/kgK Thermal Conductivity: 0.024 W/mK Water Vapour Diffusion Resistance Factor: 72
Air Cavity	5mm Bulk Density: 1.3kg/m^3 Porosity: 0.999 m^3/m^3 Spec. Heat Capacity: 1000 J/kgK Thermal Conductivity: 0.047 W/mK Water Vapour Diffusion Resistance Factor: 79
Air Cavity	20mm Bulk Density: 1.3kg/m^3 Porosity: 0.999 m^3/m^3 Spec. Heat Capacity: 1000 J/kgK Thermal Conductivity: 0.013 W/mK Water Vapour Diffusion Resistance Factor: 56
Red Matt Clay Brick	89mm Bulk Density: 1935kg/m^3 Porosity: 0.217 m^3/m^3 Spec. Heat Capacity: 800 J/kgK Thermal Conductivity: 0.495 W/mK Water Vapour Diffusion Resistance Factor: 137.8

Interior Retrofitted Wall Assembly (Double Stud)	
Material	Dimension and/or Unit
Gypsum Board (USA)	12.5mm Bulk Density: 850kg/m^3 Porosity: 0.65 m^3/m^3 Spec. Heat Capacity: 870 J/kgK Thermal Conductivity: 0.163 W/mK Water Vapour Diffusion Resistance Factor: 6
Option 1: Poly (Vapour Control Layer)	4 ng/s•m^2•PA Bulk Density: 130kg/m^3 Porosity: 0.001 m^3/m^3 Spec. Heat Capacity: 2300 J/kgK Thermal Conductivity: 2.3 W/mK Water Vapour Diffusion Resistance Factor: 50000
Option 2: Vara Plus by Partel *(Smart Vapour Membrane)*	1mm WUFI (actual 0.32mm) Bulk Density: 113kg/m^3 Porosity: 0.001 m^3/m^3 Spec. Heat Capacity: 1810 J/kgK Thermal Conductivity: 0.27 W/mK Water Vapour Diffusion Resistance Factor: 67800 Sd: 0.4 – 30 Permeance: 6.87 – 478.88ng/s•m^2•PA
Wood Studs (not modelled in WUFI for reference only)	38x89mm at 410mm o.c.
Glass Fiber Batt Insulation	89mm Bulk Density: 19.22kg/m^3 Porosity: 0.99 m^3/m^3 Spec. Heat Capacity: 840 J/kgK Thermal Conductivity: 0.035 W/mK Water Vapour Diffusion Resistance Factor: 1.3

Mineral Wood Semi-Rigid Insulation	25mm Bulk Density: 128kg/m^3 Porosity: 0.954 m^3/m^3 Spec. Heat Capacity: 850 J/kgK Thermal Conductivity: 0.0322 W/mK Water Vapour Diffusion Resistance Factor: 1.3
Wood Studs (not modelled in WUFI for reference only)	38x89mm at 410mm o.c.
Glass Fiber Batt Insulation	89mm Bulk Density: 19.22kg/m^3 Porosity: 0.99 m^3/m^3 Spec. Heat Capacity: 840 J/kgK Thermal Conductivity: 0.035 W/mK Water Vapour Diffusion Resistance Factor: 1.3
Oriented Strand Board (OSB)	11mm Bulk Density: 553kg/m^3 Porosity: 0.64 m^3/m^3 Spec. Heat Capacity: 1400 J/kgK Thermal Conductivity: 0.12 W/mK Water Vapour Diffusion Resistance Factor: 134
Asphalt Impregnated Paper (30 min)	0.22mm Bulk Density: 200kg/m^3 Porosity: 0.001 m^3/m^3 Spec. Heat Capacity: 1500 J/kgK Thermal Conductivity: 2.3 W/mK Water Vapour Diffusion Resistance Factor: 472
Polyisocyanurate Rigid Foam Insulation	19mm Bulk Density: 32.5kg/m^3 Porosity: 0.99 m^3/m^3 Spec. Heat Capacity: 1470 J/kgK Thermal Conductivity: 0.024 W/mK

	Water Vapour Diffusion Resistance Factor: 72
Air Cavity	5mm Bulk Density: 1.3kg/m^3 Porosity: 0.999 m^3/m^3 Spec. Heat Capacity: 1000 J/kgK Thermal Conductivity: 0.047 W/mK Water Vapour Diffusion Resistance Factor: 79
Air Cavity	20mm Bulk Density: 1.3kg/m^3 Porosity: 0.999 m^3/m^3 Spec. Heat Capacity: 1000 J/kgK Thermal Conductivity: 0.013 W/mK Water Vapour Diffusion Resistance Factor: 56
Red Matt Clay Brick	89mm Bulk Density: 1935kg/m^3 Porosity: 0.217 m^3/m^3 Spec. Heat Capacity: 800 J/kgK Thermal Conductivity: 0.495 W/mK Water Vapour Diffusion Resistance Factor: 137.8

Exterior Retrofitted Wall Assembly	
Material	**Dimension and/or Unit**
Gypsum Board (USA)	12.5mm Bulk Density: 850kg/m^3 Porosity: 0.65 m^3/m^3 Spec. Heat Capacity: 870 J/kgK Thermal Conductivity: 0.163 W/mK Water Vapour Diffusion Resistance Factor: 6
Poly (Vapour Control Layer)	4 ng/s•m^2•PA

	Bulk Density: 130kg/m^3 Porosity: 0.001 m^3/m^3 Spec. Heat Capacity: 2300 J/kgK Thermal Conductivity: 2.3 W/mK Water Vapour Diffusion Resistance Factor: 50000
Wood Studs (not modelled in WUFI for reference only)	38x89mm at 410mm o.c.
Glass Fiber Batt Insulation	89mm Bulk Density: 19.22kg/m^3 Porosity: 0.99 m^3/m^3 Spec. Heat Capacity: 840 J/kgK Thermal Conductivity: 0.035 W/mK Water Vapour Diffusion Resistance Factor: 1.3
Oriented Strand Board (OSB)	11mm Bulk Density: 553kg/m^3 Porosity: 0.64 m^3/m^3 Spec. Heat Capacity: 1400 J/kgK Thermal Conductivity: 0.12 W/mK Water Vapour Diffusion Resistance Factor: 134
Asphalt Impregnated Paper (30 min)	0.22mm Bulk Density: 200kg/m^3 Porosity: 0.001 m^3/m^3 Spec. Heat Capacity: 1500 J/kgK Thermal Conductivity: 2.3 W/mK Water Vapour Diffusion Resistance Factor: 472
Option 1: Polyisocyanurate Rigid Foam Insulation	102mm Bulk Density: 32.5kg/m^3 Porosity: 0.99 m^3/m^3 Spec. Heat Capacity: 1470 J/kgK Thermal Conductivity: 0.024 W/mK Water Vapour Diffusion Resistance Factor: 72

Option 2: Mineral Wood Semi-rigid Insulation	152mm Bulk Density: 73kg/m^3 Porosity: 0.95 m^3/m^3 Spec. Heat Capacity: 850 J/kgK Thermal Conductivity: 0.0322 W/mK Water Vapour Diffusion Resistance Factor: 1.2
Air Cavity	5mm Bulk Density: 1.3kg/m^3 Porosity: 0.999 m^3/m^3 Spec. Heat Capacity: 1000 J/kgK Thermal Conductivity: 0.047 W/mK Water Vapour Diffusion Resistance Factor: 79
Air Cavity	20mm Bulk Density: 1.3kg/m^3 Porosity: 0.999 m^3/m^3 Spec. Heat Capacity: 1000 J/kgK Thermal Conductivity: 0.013 W/mK Water Vapour Diffusion Resistance Factor: 56
Red Matt Clay Brick	89mm Bulk Density: 1935kg/m^3 Porosity: 0.217 m^3/m^3 Spec. Heat Capacity: 800 J/kgK Thermal Conductivity: 0.495 W/mK Water Vapour Diffusion Resistance Factor: 137.8

Reference List

Ali, U., Shamsi, M. H., Hoare, C., Mangina, E., & O'Donnell, J. (2019). A data-driven approach for multi-scale building archetypes development. *Energy and Buildings*, *202*. https://doi.org/10.1016/j.enbuild.2019.109364

Beausoleil-Morrison, Ian; Mitalas, G. (1997). Basesimp : a Residential-Foundation Heat-Loss Algorithm for Incorporating Into Whole-Building Energy-Analysis Programs. In *Building simulation 1997*.

Beausoleil-Morrison, I. (2021). *Fundamentals of Building Performance Simulation*. New York, NY: Routledge.

Beheshti, S., Sahebalam, A., & Nidoy, E. (2019). Structure dependent weather normalization. *Energy Science and Engineering*, *7*(2), 338–353. https://doi.org/10.1002/ese3.272

Ben, H., & Steemers, K. (2020). Modelling energy retrofit using household archetypes. *Energy and Buildings*, *224*, 110224. https://doi.org/10.1016/j.enbuild.2020.110224

Berkeley Labs. (2020). THERM 7.7.10.

Biaou, A. L., & Bernier, M. (2005). Domestic hot water heating in zero net energy homes. *IBPSA 2005 - International Building Performance Simulation Association 2005*, 63–70.

BizEE. (2020). Degree Days Weather Data for Energy Saving. Retrieved from https://www.degreedays.net/

Blaszak, K. M. (2010). Towards Sustainability: Prioritizing Retrofit Options for Toronto's Single-family Homes. In *Ryerson University*.

Canadian Home Builders Association. (2020a). *Canadian Home Builder's Association Net Zero Home Labelling Program - Version 1.1 Administrative Requirements* (Issue February).

Canadian Home Builders Association. (2020b). *Canadian Home Builders' Association: Net Zero Renovation Pilot Program* (Issue February).

Canmet Energy: Natural Resources Canada. (2018). *PhotoVoltaic Ready Guidelines: Vol. Version 1.* https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/canmetenergy/files/pubs/17-259_Photovoltaic-EN_accessible.pdf

Carll, C. G., & Highley, T. L. (1999). Decay of Wood and Wood-Based Products above Ground in Buildings. *Journal of Testing and Evaluation*, *27*(2), 150–158. https://doi.org/10.1520/jte12054j

Demirezen, G., Ekrami, N., & Fung, A. S. (2019). Monitoring and evaluation of nearly-zero energy house (NZEH) with hybrid HVAC for cold climate-Canada. *IOP Conference Series: Materials Science and Engineering*, *609*(6), 6. https://doi.org/10.1088/1757-899X/609/6/062001

Denver, J. (2014). *Deep energy retrofits: Toronto's urban single family housing stock. | Digital Repository* [Ryerson University]. https://digital.library.ryerson.ca/islandora/object/RULA%3A3485

Fazio, P., Derome, D., Gerbasi, D., Athienitis, A., & Depani, S. (2000). Large-Scale Testing of Two Flat Roof Assemblies Insulated with Cellulose. *Journal of Architectural Engineering*, *6*(1), 13.

Finch, G., & Hanam, B. (2013). *Net Zero Building Enclosure Retrofits for Houses : An Analysis of Retrofit Strategies*.

Foroushani, S. (2021). Uncertainty in building energy simulation and its implications for the british columbia energy step code. *ESim 2021*, *September 2020*, 9.

Fraunhofer IBP, (2020). WUFI Pro 6.4.

Hakkaki-Fard, A., Aidoun, Z., & Ouzzane, M. (2015). Improving cold climate air-source heat pump performance with refrigerant mixtures. *Applied Thermal Engineering*, *78*, 695–703. https://doi.org/10.1016/j.applthermaleng.2014.11.036

Hanam, B. (2010). *Development of an Open Source Hourly Building Energy Modeling Software Tool*. University of Waterloo.

Hubler, D., Tupper, K., & Greensfelder, E. (2010). Pulling the levers on existing buildings: A simple method for calibrating hourly energy models. *ASHRAE Transactions*, *116*(PART 2), 261–268.

Khemet, B. (2019). *Towards a Methodological Approach to Builder Specific, Preconstruction Airtightness Estimates for Light-Framed, Detached, Low-rise Residential Buildings in Canada* (Issue December). University of Toronto.

Kisilewicz, T. (2007). Computer simulation in solar architecture design. *Architectural Engineering and Design*

Management, *3*(2), 106–123. https://doi.org/10.1080/17452007.2007.9684635

Lawrence, C. (2020). A Surrogate Modelling Methodology to Predict Energy Use for Multiple Single-Family Century Home Archetypes in Toronto. *Thesis Ryerson University*.

Li, H. X., Ma, Z., Liu, H., Wang, J., Al-Hussein, M., & Mills, A. (2020). Exploring and verifying BIM-based energy simulation for building operations. *Engineering, Construction and Architectural Management*, *27*(8), 1679–1702. https://doi.org/10.1108/ECAM-06-2019-0314

Loomis, H., & Pettit, B. (2015). *Measure Guideline: Deep Energy Enclosure Retrofit (DEER) for Double Stud Walls*.

Lstiburek, J., Ueno, K., & Musunuru, S. (2016). *Strategy Guideline : Modeling Enclosure Design in Above-Grade Walls* (Issue February).

Matutinovic, L. (2014). Using Calibrated Energy Models to Help Understand , Manage and Improve Existing Building Energy Performance. *ESIM 2014 - Biannual Conference of IBPSA-Canada*, *Necb 2011*.

Melius, J., Margolis, R., & Ong, S. (2013). Estimating Rooftop Suitability for PV : A Review of Methods , Patents , and Validation Techniques. In *NREL Technical Report* (Issue December). www.nrel.gov/publications

National Renewable Energy Laboraotory. (2020). PVWatts Calculator. Retrieved from https://pvwatts.nrel.gov/pvwatts.php

Natural Resources Canada_CanmetENERGY. (2006). *THE URBAN ARCHETYPES PROJECT Community Case Study : The City of Coquitlam*. https://doi.org/978-1-100-11951-9

Natural Resources Canada. (2020). HOT2000 v11.10.

Natural Resources Canada. (2019). *Net Zero Energy and Net Zero Energy Ready Housing*. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/pdf/Net Zero Energy Pilot Lessons Learned FINAL EN.pdf

NRCan Local Energy Efficiency Partnerships (LEEP) Team. (2015). *Zoning Decision Guide for Builders*.

NRCan Local Energy Efficiency Partnerships (LEEP) Team. (2017). *Master Planning & Decision Guide for*

Natural Gas Mechanical Systems. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/pdf/Final_NG_Mechanicals Decision Guide_E_rev.pdf

Ontario Provincial Government. (2016). *Ontario's Five Year Climate Change Action Plan 2016 - 2020*. http://www.applications.ene.gov.on.ca/ccap/products/CCAP_ENGLISH.pdf

Parekh, A. (2000). *Comparison of Thermal Performance of Lightweight Steel-Framing and Wood Stud Walls Natural Resources Canada*.

Passive House Institute. (2016). Criteria for the Passive House, EnerPHit and PHI Low Energy Building Standard. In *Passive House Institute*. https://passiv.de/downloads/03_building_criteria_en.pdf

Pressnail, K., Timusk, J., Kan, L., Dong, B., & Kan, V. (2003). In Search of a Wall for All Seasons : Controlling Sun-Driven Moisture. *9th Canadian Conference on Building Science and Technology*, 157–170.

Raftery, P., Keane, M., & O'Donnell, J. (2011). Calibrating whole building energy models: An evidence-based methodology. *Energy and Buildings*, *43*(9), 2356–2364. https://doi.org/10.1016/j.enbuild.2011.05.020

Schumacher, C., & Lepage, R. (2012). Moisture Control for Dense- Packed Roof Assemblies in Cold Climates: Final Measure Guideline. In *Building America Report 1308*.

Skarupa, C. (2020). Building Energy Surrogate Modelling Methodology for a Detached Single-Family Century Home Archetype in Toronto, ON. *Thesis Ryerson University.*

Statistics Canada. (2017). *Dwellings in Canada (Census in Brief)* (Issue 98). https://www12.statcan.gc.ca/census-recensement/2016/as-sa/98-200-x/2016005/98-200-x2016005-eng.pdf

Straube, J., & Burnett, E. (2005). *Building Science for Building Enclosures*. Building Science Press.

Straube, J., & Smegal, J. (2009). Building America Special Research Project : High-R Walls Case Study Analysis. *Building Science*, 68.

Tokarik, M. (2015). *A Multi-objective Optimization Analysis of Passive Energy Conservation Measures in a*

Toronto House. Ryerson.

Toronto and Region Conservation and Ryerson University. (2011). *The Archetype Sustainable Houses: Overview of Design and Monitoring Systems*.

Ueno, K. (2015). *Monitoring of Double Stud Wall Moisture Conditions in the Northeast*. http://www.osti.gov/scitech/servlets/purl/1176755

Ueno, Kohta. (2007). *Hygrothermal Behavior of Interior Basement Insulation*. University of Waterloo.

Viitanen, H., & Ojanen, T. (2007). Improved Model to Predict Mold Growth in Building Materials. *Buildings X*, 1–8.

Vithusan, V. (2021). Adapting Passive House to Toronto's Existing Housing Stock Through Deep Energy Retrofits. *MRP Ryerson University.*

Wu, W., Skye, H. M., & Domanski, P. A. (2018). Selecting HVAC systems to achieve comfortable and cost-effective residential net-zero energy buildings. *Applied Energy*, *212*(October 2017), 577–591. https://doi.org/10.1016/j.apenergy.2017.12.046

Yoon, J., Lee, E. J., & Claridge, D. E. (2003). Calibration procedure for energy performance simulation of a commercial building. *Journal of Solar Energy Engineering, Transactions of the ASME*, *125*(3), 251–257. https://doi.org/10.1115/1.1564076

Zirnhelt, H. E. (2013). *Using Calibrated Simulation to Quantify the Energy Savings From Residential Passive Solar Design in Canada* [Ryerson]. http://digital.library.ryerson.ca/islandora/object/RULA:1952