A COMPARISON OF BUILDING ENVELOPE PERFORMANCE LEVELS BETWEEN ONTARIO, DENMARK, GERMANY AND THE PASSIVE HOUSE STANDARD, IN THE LOW-RISE, RESIDENTAL CONTEXT

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Major Research Project

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Author's Declaration Page

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Abstract:

This research compared and analyzed where the Ontario Building Code rates in the low-rise, residential sector in terms of its:

- Current and past building envelope regulation requirements,
- ‘Typical’ building envelope connection details,
- Current building envelopes regulation requirements in energy consumption and
- ‘Typical’ building envelopes energy consumption

in comparison to Denmark, Germany and the Passive House Standard. This was analyzed to see how Ontario compared against other world renowned energy efficient regulations and where or if there was room for improvement. For this, HOT2000 and THERM were utilized on all four of the reference standards, where both of these programs were managed in a way to compare the results of ‘typical’ building envelopes and the current regulation from each of the standards. These results were then able to provide a whole home’s heating and air conditioning energy use in the Greater Toronto Area climate. Overall, the results illustrated Ontario homes consume the most energy for both typically constructed homes and homes utilizing the minimum requirements. In addition to this, Ontario also had the least performing building envelope connection details. In total, the Passive House performs at the highest level followed by Germany, Denmark and then Ontario.

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- Oliver Grimshaw of Hanse Haus, contributed typical drawings and details for a German 2009 EnEv compliant home and also answered a series of questions.

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1 Introduction:

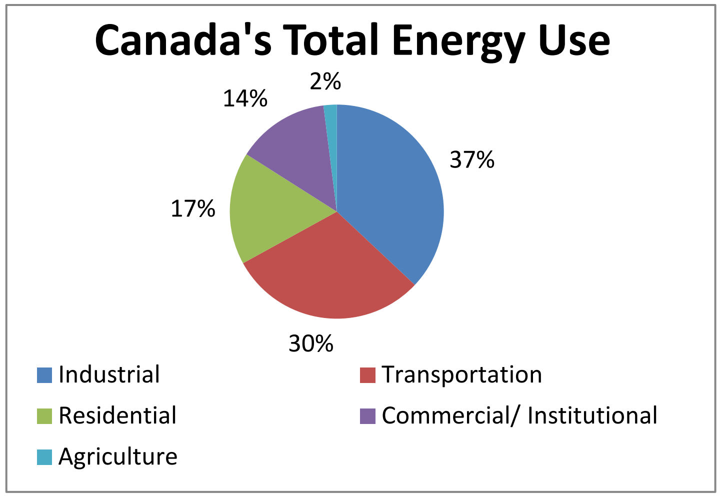

Figure 1: Canada's Total Energy Use

(Natural Resources of Canada 2010)

Currently in Canada, one of the major energy consumers is the residential sector. Out of Canada's total energy use it represents approximately 17 %, (Figure 1) (Natural Resources of Canada 2010). Overall, 63 % of this is due to the heating demand required for homes in the Canadian climate. While the remaining 37 %, breaks down as follows; 2 % cooling, 17 % hot water, 4 % lighting and 14 % appliances (Natural Resources of Canada 2010). Therefore, the energy used by the residential sector is directly connected to the standards that have been put in place through the building code over the past seven decades. The province of Ontario will be utilized in this research along with its Building Code Regulations as a representation of Canada. The purpose of using this province is because it represents a large fraction of Canada's population and because Ontario's building code is the most energy efficient in the country (Lio & Associates 2010). With a growing population, the need for energy increases and incorporating energy efficient standards for all sectors combats this issue. Specifically examining the low-rise residential sector of Ontario, there has been a trend towards instilling the construction of new energy efficient homes as of January 1st 2012 (Ontario Ministry of Municipal Affairs and Housing 2012).

1.1 Objective of this Major Research Project:

The objective of this Major Research Project is to determine where the Ontario building codes building envelope performance level rates for newly constructed, low-rise. residential homes in comparison to other high performing regulations such as Denmark, Germany and the Passive House Standard. To compare the overall performance levels of these building envelopes against one another, the following comparisons and analysis are made:

- Current and past building envelope regulation requirements,
- 'Typical' building envelope connection details,
- Current building envelope regulation requirements in energy consumption and
- 'Typical' building envelope energy consumption.

This analysis allows Ontario to know how it's building envelope rates against other world renowned energy efficient countries and standards, as well as where or if there are specific improvements that can be made. This is important because of Ontario acknowledging that it is heavily invested in energy efficiency and conservation (Ontario Ministry of Municpial Affairs and Housing 2012).

2 Literature Review:

In Ontario, the recent focus of the low-rise, residential construction industry has been directed towards energy efficient new construction (Ontario Ministry of Municipal Affairs and Housing 2012). Raising the question from the author of where Ontario rates in comparison to other energy efficient countries and regulations such as Germany, Denmark and the Passive House Standard. To gain an overall understanding of the present, however, an analysis of the history was a vital to see the growth or trends that have occurred throughout time for each location's requirements.

Papers published by researchers and each respective country's government are beneficial to this research. The document prepared by Lio & Associates on behalf of the Ontario Ministry of Municipal Affairs and Housing for the new 2012 Ontario Building Code, supplement standard 12, was discussed in depth. Then all the compliance packages were simulated utilizing HOT2000 and a base model home called 2009 MMAH Archetype. The results that were found to be of importance, related to compliance package J. The author found that approximately 78 928 Mj (21 924 kWh) were consumed by domestic hot water tanks and space heating per year, while also attaining a Energuide 80.2 level (Lio & Associates 2010). For present day results, this is good information to compare against the findings from the simulations conducted in this research. Although there will be some disparities, such as the wall area, volume and potentially the window to wall area, the results of this study should be similar to the authors results when they are converted to an Energuide rating. The other downfalls to this study were there was no history, as it was all information related to the past 6 years (2006) and there was no detailed information about the home (floor plans) to show the layout of the home to draw further comparisons.

In 2006, the Office of Energy Efficiency of Natural Resources Canada disclosed residential energy use from pre-1945 until 2004 and the air leakage trends for houses from the same time period. These graphs could be utilized as tools to show the influence that the building envelope has played throughout history in dropping the amount of energy consumed by newly constructed dwellings. Another downfall to these graphs was that they were in GJ and not kWh/m^2 which may possibly hinder a comparison against the other countries or standards because the units not being able to be converted. This will justify the impact that the building envelope has had and it can be generally assumed that from 1975 to 2004 the results shown would be very similar to Ontario's. The majority of the document deals with retrofitting older homes and making them more energy efficient as opposed to new construction. It does, however, understand and state the significance of constructing energy efficient homes during the design stage because it was more economical.

In another study found that residential sector represents 17 % of the country's consumption (Natural Resources of Canada 2010). Within this 17 %, the findings were the following: space heating 63 %, water heating 17 %, appliances 14 %, lighting 4 % and cooling 2 % (Natural Resources of Canada 2010). Although the results were based off of Canada as a whole and not only Ontario, it can be assumed that Ontario would be fairly close to these percentages because Ontario represented a large fraction of these findings. Another issue with these percentages was it represented all types of homes including new, old and renovated. However, it was important to understand where the residential sector was expending its energy within the Canadian market. Overall, these studies were not tailored towards this paper so the interpretations of their findings must be used loosely. More specifically, the percentages stated by the Natural Resources Canada publication will be used to compare against the other countries' home energy use.

Togeby, Kjaerbye and Larsen explored the energy consumption by Danish single-family homes. As a whole, heating homes in Denmark was calculated to consume 25 % of the country's energy demand from a total of 2 7350 000 homes (Togeby, Kjaerbye, & Larsen 2011). In addition to this, the U-values for the exterior walls, ceiling, floor and windows from Denmark's first building code in 1961 until 2008 were stated. There was also a table showing the mean energy consumption for space heating and hot water tanks for most of the building regulations put in place by Denmark. The 2008 and 2010 building regulations energy use, however, was missing. In order to obtain this data, two natural gas companies metered 34 700 homes with more than 150 000 observations taken (Togeby, Kjaerbye, & Larsen 2011). The mean energy consumption for each construction period was lower than the reference that dealt with the building regulations and was calculated with U-values in the building regulations among other requirements. Explanations as to why this occurred include, possible renovations completed on the older dwellings. Although, this was just an assumption made by the authors.

Dr. Rasmussen conducted a detailed study that reviewed the tightening of thermal insulation of building envelopes on new buildings through Denmark's building regulations from 1961 to 2008. However, this review's main objective was to show the significance of retrofitting Denmark's buildings constructed between 1850 and 1920. Rasmussen discussed the history stating that there were no thermal insulation requirements prior to 1961 and that the first edition of Denmark's Building regulations was not concerned with a building's energy consumption. He also declared that in 2010, 2015 and 2020 there will be a 25 % reduction in energy consumption enforced from each of the regulation's predecessor (Rasmussen 2010). As previously mentioned, Rasmussen focussed on existing buildings and design building sections that could be installed to thermally insulate the historical buildings of Denmark. The building regulations thermal insulation of building envelopes table was very weak as it only covers a few of the main components of the building envelope.

Germany, the third country included in this study, continues to be one of the countries that had made great strides towards energy efficient buildings (Blok, Boermans, Hermelink, & Schimschar 2011). Germany saw great potential in saving energy through energy efficient buildings. In fact, since 1977 there have been five updates to the 'Energy Saving Ordinance' with seven available editions (Blok, Boermans, Hermelink, & Schimschar 2011). From 1977 till present day, space heating (with auxiliary equipment) and domestic hot water heating decreased from; 300 kWh/m^2.a to about 65 kWh/m^2.a (Blok, Boermans, Hermelink, & Schimschar 2011). This information will be useful when comparing the energy consumption of heating against other standards within this research. German policy stipulated that by 2020, all new construction must consume nearly zero energy or in other words qualify as a Passive House. For homes that were more efficient than the current EnEV, subsidies were also available; this system was called the KfW standard (Blok, Boermans, Hermelink, & Schimschar 2011). This study was relevant in a variety of different areas as it discussed the KfW standard and how it works. Also included within this paper was the direct impact these policy updates had in heating energy consumption to further justify the effect increasing the EnEV has had on German homes.

A document prepared by the International Passive House Association was created for developers, contractors and clients to help provide useful information on Passive homes. It goes into detail about the requirements of a Passive House and why these types of homes are different from conventional homes. The main concept was to utilize very little energy, while also keeping the occupants comfortable (International Passive House Association 2010). This was completed by having large amounts of insulation throughout the building envelope, extremely high performing windows and frames, no thermal bridging, an airtight building and a very good ventilation system equipped with a heat recovery ventilator. By implementing all of these attributes, the house would use less than 15 kWh per m^2 per year of heating (International Passive House Association 2010). Other requirements are: windows must be less than 0.85 w/m^2k, there must be no more than 0.6 air changes per hour and, the primary energy requirement has to be less than 120 kWh per m^2 per year and less than 10 w/m^2 heating load (International Passive House Association 2010). What was missing in this document was the lack of building envelope section's, additionally, it was more of a marketing paper as the writer was trying to sell the idea of the Passive House concept to the reader. As for the relevance to the research, everything that has been stated was found to be useful in explaining the requirements of the Passive House.

Many of the studies that have been discussed were helpful in correlating background information that can be utilized in the history portions of this paper and act as supporting content for the building regulations from each location. However, in terms of satisfying the main objective of this paper the above studies were by no means fruitful. In the end, since there has been no research conducted similar to this study, the author will have to rely on professionals within the industry to accomplish the main goal and a majority of the information will have to be primary due to the uniqueness of this topic.

3 Methodology:

The following tasks were conducted on the proposed research:

1) Collect past and current building code regulations for each of the locations/standards to compare them against one another.
2) Gather papers or studies to gain background information on the standards being discussed to see if there were any studies conducted similar to this one.
3) Simulated/calculated building envelope sections with the simulation program THERM to determine their performance.
4) Simulated/calculated whole home energy use for each ‘typical’ building envelope and minimum requirements from each standard to determine heating and cooling energy consumption.
5) Analyzed, discussed and compared results.
6) Drew final conclusions to determine where Ontario rates in terms of their building envelope sections, current and past regulation requirements, and ‘typical’ and minimum requirements for building envelope energy consumption.

As the basis of the research, both current and past regulations/standards were collected to determine where Ontario stood in comparison to the other regulations. Literature was also continually gathered that was found to be similar to this research. Throughout the entire research procedure no studies were found that strived to complete the same objectives as this MRP. After these steps were completed, a ‘typical’ suburban 2012 OBC compliant home’s drawing was collected from Brookfield Homes’ Architectural Manager Daniel Lacroix and a ‘typical’ urban designed home courtesy of Russell Richman Consulting. For the purpose of this paper a ‘typical’ home represents what is on average currently being built in the residential market. The information from Brookfield Homes, included such specifics as to what compliance package was being used, the HVAC equipment brands, and the building envelope assembly sections breakdown and the urban and suburban homes were modeled with these specifics.

To be able to complete a proper comparison a Danish, Passive House and German building envelope assembly/sections also had to be collected. Overall the ‘typical’ homes information was collected from Dr. Jørgen Munch-Andersen of Danish Timber Information for Denmark, Oliver Grimshaw of Hanse House for Germany and Mark

Yanowitz of Verdeco Designs for the Passive House. The minimum requirements simulations consisted of the regulations requirements or in the case of the Passive House the Verdeco Designed Passive House. This was done, because of the Passive House requirements being dependent on energy consumption requirements, as opposed to insulation values for the building envelope.

HOT2000 was utilized to determine each of the homes total heating and cooling energy use. To ensure an accurate and fair comparison, the suburban and urban homes were simulated in a Toronto climate and all had the same orientation, layout and used the 2012 OBC HVAC equipment. The only difference was the building envelopes that were placed on top of these homes. In addition, a list of assumptions had to be made in order for the simulations (HOT2000 and THERM) to work adequately. As for thermal bridging, only the thermal bridges that HOT2000 takes into consideration were possible. Therefore the thermal bridges that were included were the stud spacing, corner connections, window/door framing, top/bottom plates, joists, floor to wall connections, basement wall to ground floor connection and basement wall to basement slab connection.

Each one of these specific ‘typical’ building envelope connection details were then created in THERM in an average Toronto climate. With everything normalized and assumptions completed, each of the standards building envelope connections were simulated in THERM and compared against one another in terms of their U-values. The results provided from the THERM simulations demonstrated the effects of thermal bridging on each of the different assemblies from all locations/standards on a building envelope connection basis. A variety of challenges occurred due to the simulation program’s downfalls, which the author highlighted within the assumptions. Once those phases were accomplished, the results were analyzed and compared against one another, to determine how the 2012 OBC building envelope rates in terms of their ‘typical’ building envelope connections in addition to their heating and cooling energy use for ‘typical’ and minimum requirements against Denmark, Germany and the Passive House Standard.

4 Energy Efficiency Standards:

Worldwide there are a variety of standards that govern how newly-built residential units are to be constructed in their respective climates, in order to reduce the amount of energy consumed by the dwelling. Today, both government and the general public alike, stand together to meet this common goal, which ultimately will slow down the progress of global warming. The energy efficiency history, that will be reviewed is from Ontario (Canada), Denmark, and Germany along with a well-known low-energy home standard, the Passive House. Denmark and Germany were selected because they are ranked in the top ten list of worldwide energy efficient countries (Denmark No. 2, Germany No. 9) (Zumbrun 2008). While the Passive House, is known as one of the most energy efficient homes in the world (International Passive House Association 2010).

5 A Comparison of Past and Current Regulations:

Table 1: Past Regulation Requirements Comparison

Past Regulation Requirements Comparison										
Building Envelope Component	**OBC 1997**	**BR 1998**	**EnEV 1995**	**OBC 2006**	**BR 2008**	**EnEV 2004**	**OBC 2012**	**BR 2010**	**EnEV 2009**	**Passive House**
Walls (RSI)	3.3	5.0	2.0	3.3	5.0	2.2	3.9	6.7	3.6	6.7
Basement Walls (RSI	2.1	3.3	2.0	2.1	5.0	2.0	2.1	6.7	2.9	6.7
Roof (RSI)	5.4	5.0	3.3	7.0	6.7	3.3	8.8	10.0	5.0	6.7
Basement Slab (RSI)	0.0	5.0	2.0	0.0	6.7	2.0	0.0	10.0	2.9	6.7
ACH	0.0	0.0	0.0	0.0	2.1	1.5	2.5	2.1	1.5	0.6
Windows (U-value	3.3	1.8	1.8	2.0	1.5	1.7	1.8	1.4	1.3	0.8
Doors (U-value)	1.4	1.8	1.8	1.4	1.5	1.7	1.4	1.4	1.8	0.8

As per Table 1, the past regulations for the last three editions were highlighted, where:

- The OBC was Ontario (Ontario Ministry of Municpial Affairs and Housing 2012), (Ministry of Municipal Affairs and Housing 1997), (Ministry Municipal Affairs and Housing 2006).
- The BR was Denmark (The Danish Ministry of Economic and Business Affairs 2010), (The Danish Ministry of Economic and Business Affairs 1998), (The Danish Ministry of Economic and Business Affairs 1998).
- The EnEV was Germany (Verordnung über energiesparenden Wärmeschutz und energiesparende Anlagentechnik bei Gebäuden 2009), (Verordnung über energiesparenden Wärmeschutz und energiesparende Anlagentechnik bei Gebäuden 2001,) (Verordnung über energiesparenden Wärmeschutz und energiesparende Anlagentechnik bei Gebäuden 2004).
- The Passive House was in Germany (International Passive House Association 2010).

When reviewing Table 1, it must be noted that both Ontario and the Passive House were representing insulation values and that the Passive House values were minimum requirements in a German climate. Germany and Denmark's results represented the entire assembly from exterior to interior and Denmark also included wood framing spacing thermal bridges. As a whole, the Passive House and Denmark on average had higher building envelope requirements. While Ontario and Germany were on average similar for the most current regulation. However, for the last two editions prior to 2012, Ontario averaged higher building envelope requirements.

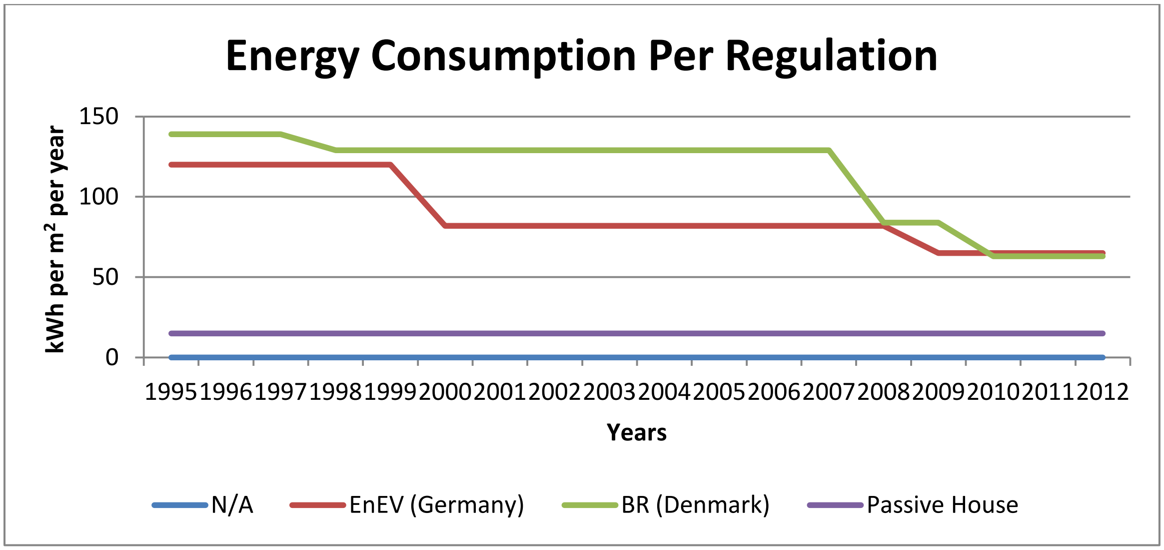

Figure 2: Energy Consumption Per Regulation

Figure 2 represents the following energy consuming components of a home:

- BR (Denmark): Space heating with auxiliary equipment and hot water tank (Togeby, Kjaerbye, & Larsen 2011).
- Passive House: Space heating without auxiliary equipment (International Passive House Association 2010).
- EnEV- Energy Saving Ordinance (Germany): Space heating with auxiliary equipment (Schettler-Kohler & Kunkel 2010).

Figure 2 illustrated, the average energy consumption for their respective requirements. Overall:

- Ontario represented 'N/A' and had no minimum requirements in energy consumption, other than the 2012 OBC where an Energuide 80 rating must be met. However, from a report completed by NRC the energy consumption over this time period had decreased due to the high performing building envelope requirements (Natural Resources Canada 2006).

- Passive House minimum requirements stayed consistent and were less than 15 kWh m^2 per year for space heating without auxiliary equipment (International Passive House Association 2010).
- BR Denmark regulations reduced over the past 17 years from 139 to 63 kWh per m^2 per year due to the building envelope regulations increasing over time (Togeby, Kjaerbye, & Larsen 2011).
- EnEV Germany regulations also reduced over the past 17 years from 120 to 65 kWh per m^2 per year because of their building envelope regulations improving (Blok, Boermans, Hermelink, & Schimschar 2011).

Table 2: Current Regulations Minimum Requirements

Current Regulations Minimum Requirements				
Building Envelope Components	**Ontario (OBC 2012 Compliance Package J)**	**Germany (EnEV 2009)**	**Denmark (Building Regulation 2010)**	**Passive House**
Walls (RSI)	3.9	3.6	6.7	>6.7
Basement walls (RSI)	2.1	2.9	6.7	>6.7
Roof/ceiling (RSI)	8.8	5	10	>6.7
Basement Slab (RSI)	0	2.9	10	>6.7
Air Changes per Hour (ACH)	2.5	1.5	1.9/2.1	<0.6
Windows (U-value)	1.8	1.3	1.4	<0.8
Door (U-Value)	1.4	1.8	1.4	<0.8
Energy Frame (kWh m^2 per year)	Energuide 80	65	52.5 +(1650/A)	<15

In Table 2, the main elements of each of the building envelope regulations can be seen. In summary:

- Both Germany and Ontario has similar RSI values for the main building envelope components (RSI) with Germany being a little higher in some cases and Ontario in the others.

- Denmark and the Passive House are significantly higher in terms of their RSI values when compared to Ontario.
- Germany and Ontario are very similar on average in terms of their requirements.
- Ontario showed the least performing Window U-values and is also rated second last for its doors.
- Germany, Denmark and the Passive House air changes per hour (ACH) are tested through the means of a blower door test and must be met, while for Ontario's compliance package J no blower door test is conducted to ensure the 2.5 ACH is met.
- In terms of overall energy consumption:
    - Ontario is governed by Energuide 80 which includes heating, auxiliary equipment for heating and domestic hot water (Lio & Associate 2010).
    - Germany energy consumption is calculated through simulation programs and on average 65 kWh/m^2 per year is the maximum amount of energy consumption for heating, auxilary equipment and domestic hot water (Blok, Boermans, Hermelink, & Schimschar 2011).
    - Denmark energy consumption is calculated by using 52.5 + (1650/A), where A is the heated floor area. The final result of this calculation represented heating, cooling, domestic hot water and electricity to run fans, pumps and other equipment or heating, cooling and ventilation (Rose 2012).
    - The Passive House consisted of a maximum heating demand of 15 kWh per m^2 per year for heating exluding auxiliary equipment.
- Thermal bridging:
    - In Ontario, for thermal bridges where wood framing is less than 0.90 (m^2K/W) RSI on an above grade wall, at least 25 % of the required insulation value must be met (Ministry of Municipal Affairs and Housing 2012).

- Denmark is concerned with joints or connections such as around windows and foundations because other thermal bridges such as the stud spacing and corners are already included in their RSI values (Rose 2012). In order to determine if an assembly met the thermal bridging (joints) requirements, the following calculation must be completed (Rose 2012):

U-value of corner (with studs)* length= Heat loss W/mk (1)

U-value of wall (without studs) *length =heat loss W/mk (2)

Thermal bridge:

Heat loss (1) –Heat loss (2)= W/mk

- For Germany, 0.05 w/m^2k is the amount of thermal bridging allowed and is added onto the EnEV 2009 minimum requirements for the building envelope or the thermal bridge is done with their simulation programs (Verordnung über energiesparenden Wärmeschutz und energiesparende Anlagentechnik bei Gebäuden 2009).
- Passive House aims towards virtually thermal bridge free construction, so that they do not have to take it into consideration (International Passive House Association 2010).

A common expected trend was found where the energy consumption reduced over time because of the building regulations became more strict over the past 17 years. Over this time period, Ontario generally had the worst requirements other than Germany, where on average they are very similar for the most current regulations. Ontario, however was better than Germany in the editions prior to this one. For more in depth information about these regulations including additional history refer to Appendix G, H, I and J.

6 Simulation Information:

In order to determine the relative performance of all four locations/standards in terms of their building envelope performance level, each of the most current requirements and 'typical' building envelopes were simulated using the program HOT2000 for two model homes, one urban and one suburban. The drawings supplied from Brookfield Homes (suburban) and Russell Richman Consulting Ltd. (urban) were incorporated with all four locations/standards building envelopes.

For the current requirements the following was simulated:

- 2012 Ontario Building Code (Brookfield Homes)
- EnEV 2009 (Energy Saving Ordinance for Germany)
- Building Regulations 2010 (Denmark)
- Passive House from Boston by Verdeco Design

Meanwhile for the 'typical' homes the following was simulated:

- Broookfield Homes Design (Ontario)
- Hanse Haus (Germany)
- Danish timber information (Denmark)
- Verdeco Design (Passive House from Boston)

The purpose behind simulating current requirements and 'typical' homes for these standards was because Germany and Denmark designed dwellings that performed better than their regulations. Whereas Ontario homes were designed to simply meet their regulation and the Passive House was dependent on the maximum heating/cooling demand, which meant the building envelope varied depending on the climate. Also, all simulated homes used wood framing, to ensure equal and accurate comparisons were completed in terms of basic design and materials, even thought in Demark and Germany a majority of their dwellings are constructed from concrete. In addition, for Ontario advanced framing was not used; instead a standard approached wood framing system represented what was 'typically' constructed in the Ontario construction industry.

Overall, each building envelope followed their respective requirements, yet were simulated in a Toronto climate. Again, the HVAC used in all of the homes was from the 2012 OBC compliance package J and, in addition the same layout, orientation and dimensions were used. By keeping these specific aspects of the homes the same for all the simulations, the performance of the building envelopes were able to be compared to support the goal of this research.

For the specific building envelope sections, THERM was used to quantify the heat loss through these sections. However, only 'typical' building envelope sections were simulated because Denmark and Germany do not have building envelope sections for their current minimum requirements. These Homes were simulated in a Toronto climate with the exterior assembly consisting of brick and an air space on the exterior followed by the remaining portion of the 'typical' building envelope section from each of the regulations.

6.1 Simulation Programs:

6.1.1 HOT2000:

HOT2000 is Canada's best residential energy analysis simulation program and has been verified by the International Energy Agency BESTEST, who tested its energy simulation accuracy (Natural Resources Canada 2011). The most current program's capabilities include, forecasting energy consumption for homes for a variety of energy types such as gas, electric, propane, oil and wood. It calculates this, through the building envelope's thermal resistance of, air infiltration through both temperature and wind, solar heat gain, annual fuel efficiency of heating, air conditioning, and domestic hot water, lighting, and ventilation efficiency.

6.1.2 THERM:

THERM was used to model 2-D heat transfer taking into consideration thermal bridging in the component of the building envelope that was being simulated (Lawrence Berkeley National Laboratory 2012). It allowed the evaluator to determine the performance level of a specific portion of the envelope while also being able to identify the potential for condensation, moisture damage and possible structural problems in the future due to moisture (Lawrence Berkeley National Laboratory 2012). Developed by Lawrence Berkley National Laboratory, this software has been widely used by all professionals in the industry who are interested in the heat transfer (heat loss) of designed structures.

6.1.3 The Models:

6.1.3.1 Suburbs:

The front view of the home can be seen in Figure 3. For the rest of the drawings and construction notes, reference Appendix B. This home located in Brantford, Ontario is part of the 'Grand Valley Trails' phase 2 from Brookfield Homes and represents a new 2012 OBC compliant dwelling.

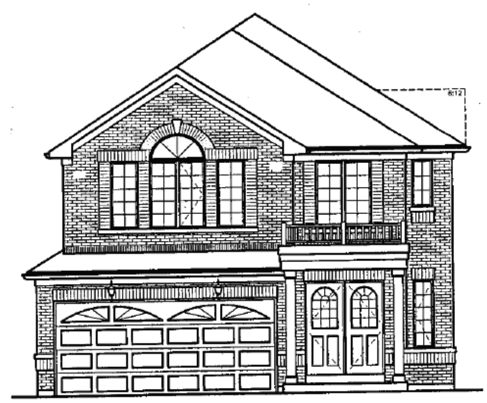

Figure 3: Brookfield Homes Model Drawing

Courtesy of Brookfield homes and Architectural Manager Daniel Lacroix (Brookfield Homes 2009)

Some details of this home include (Brookfield Homes 2012):

- Floor area 211.4 m^2 above grade.
- Basement floor area 90.4 m^2.
- Basement included one large room with a furnace, hot water tank and heat recovery ventilator.
- First floor (ground floor) included a kitchen, a great room, living room, water closet, a laundry room and a garage.
- Second floor consisted of a master bedroom, a master en-suite, walk-in closet, three additional bedrooms, one water closet and a computer nook.
- There were also two front doors, 22 windows and one set of patio doors.

6.1.3.2 Urban:

In Figure 4, a typical Toronto home can be viewed. For other drawings, reference Appendix B. This home represents a newly constructed Toronto home utilizing the 2012 OBC requirements and is courtesy of Russell Richman Consulting. Some details of this home include (Russell Richman Consulting Limited 2010):

Figure 4: Urban Example home

Courtesy of Russel Richman (Russell Richman Consulting Limited 2010)

- Floor area 166 m^2 above grade.
- Basement floor areas 53.5 m^2.
- Basement included a hot water tank, furnace and heat recover ventilator. It also had a recreation room, water closet and mechanical room.
- First Floor (ground floor) had a kitchen, dining room and living room.
- Second floor included two bedrooms, two bathrooms and a laundry room. While the third floor, had two additional bedrooms and a bathroom.
- There were also two doors (one each front and back) and 17 windows.

6.2 Urban Versus Suburban:

Comparing the urban home against the suburban home there are more distinct differences other than the floor areas. As per Table 3, the primary issues are:

- The urban home has:
  - more window surface area,
  - a greater amount of above grade wall area and
  - a higher volume to floor area ratio.

In the instances where the suburban home did have more building envelope areas such as:

- the below grade wall area,
- ceiling and
- basement slab

the below grade areas do not contend with exterior temperatures and instead only deal with ground temperatures that have little temperature variance . Thus there is less heat loss than the above grade wall areas. The ceiling has the most amount of insulation in the homes’ however, where the above grade wall met the roof, the roof’s perimeter is less than four meters apart when comparing the urban versus the suburban home. Even though the suburban home in some building envelope locations has more area than the urban home, the impact would be minimal in comparison, due to where these areas were located on the building envelope. The urban home meanwhile has more building envelope area in locations where either more heat loss could occur, or less insulation is utilized, such as the windows and above grade walls. The ratio of heated floor area to volume is also greater which meant that more energy will have to be used by the HVAC to heat and cool the home. Last but not least, other factors influencing the energy consumption can potentially be the building site terrain such as where the urban home is in the city and the suburban home is in the suburbs. Also, the urban home is considered to be in a very heavy shielded area due to neighbouring buildings where the suburbs are considered heavy shielded. To view details of these homes go to Appendix B.

Table 3: Small House Penalty

Building Envelope Areas	Suburb Home	Urban Home
Above grade wall area	275.75 m^2	334.4 m^2
Below grade wall area	98 m^2	62 m^2
Basement slab area	95 m^2	53.5 m^2
Ceiling area	127.75 m^2	88.5 m^2
Window area	30.35 m^2	31.44 m^2
Volume	776 m^3	613.3 m^3
Volume to Floor Area Ratio	2.57 m^3 per m^2	2.79 m^3 per m^2

6.3 HOT2000 and Energuide Assumptions & Inputs:

All locations Assumptions:

- The house was oriented along the north-south direction with the front facing south.
- Brick cladding for all cases.
- Layout of the windows/doors and the geometry of the home.
- The floor over the garage has been excluded/removed because it is very rare for a floor to be placed over a garage in Germany and Denmark. Thus the author does not want to skew the results with created assemblies that do not exist for Germany and Denmark. Overall, HOT2000 does not model a home based on the exact drawings and instead only worries about volume and the exterior components of the building. In the end, the exposed floor represents less than a 1.5 % difference for all simulations; with it being done this way, it had the smallest impact on the home's energy use.
- The exterior elements consisted of 90 mm brick, 25 mm air space and 6 mm plywood. This was done so an even comparison could be made.
- The walk-out basement for the urban home was not considered as the suburban home does not have one.
- Solar heat gain coefficients vary on layout, dimensions and orientation of the home, thus it was difficult to represent for Germany and Denmark.
- Urban homes were assumed to have a hip roof as oppose to a flat roof to ensure similar insulation levels to the suburban homes. Even though it was known by the author that this might go beyond height restrictions in the urban area.
- Bathroom/Kitchen exhaust fans for (all homes). HOT2000 procedures required ventilation fans to run only 5 % of the time, due to intermittent operation (Natural Resources Canada, 2010). Minimum of 24 l/s per kitchen/water closet per 2006 OBC. In total, there are four rooms, so 96 l/s fans are required. Input into HOT2000 4.8 l/s. Using three clever bathroom fans (ME070), (three fans x 60 watts=180 watts) and a Zephyr ES1-E30AB Kitchen Range hood another 36.3 watts was added. Total Watts equals 226.3 watts (Home Ventilating Institute 2012). For the urban home, another fan must be added for the fourth bathroom.
- Building site: urban- city centre, suburban- suburban, forest.
- Shielding: urban- very heavy, suburban- heavy.
- Flue shielding: urban- light, suburban- none.

Mechanical Equipment Assumptions and Inputs for All Locations:

- All HVAC (heating ventilation and air conditioning) and DHW (domestic hot water) was what identical to those installed in Brookfield Homes' 2012 OBC compliant house.

- Hot water tank- Giant Brand, model # UG40-38TFPDV-N2U, energy factor of 0.67. Assume 17.7 MJ/per day as per HOT2000. Flue was connected to furnace (Giant 2012).
- Gas furnace- Carrier model 59SC5A-60-14, 95.5 % annual fuel utilization efficiency, 50 mm flue and 372 watt blower (Carrier 2012). Assume 25.3 Mj/day for the pilot light as per HOT2000.
- Heat Recovery Ventilator- VanEE 60H, 76 % efficiency (Vanee N.D.). Inputs have been taken from the equipment specifications data sheet (Vanee).
- Air conditioner- Carrier model 24ABB330, 13.00 SEER, as per OBC supplementary 10 in 2006 and has not changed in the 2012 SB 12 (Carrier 2009). Crankcase heater is 180 watts as per Totaline HVAC dealer. As per HOT2000 the calculation method was used for the air conditioner as it was strongly recommended by HOT2000. Insulating blanket of 0.5 RSI as per supplier.
- See Appendix C for HVAC specifications.

2006 OBC Mechanical Equipment Assumptions and Inputs*:*

- Hepa 2000 Ventilator- 231 watts for 2006 OBC Home (Home Ventilating Institute 2012).
- Gas furnace- Carrier model 58MCB-60-12 with 92.1 % annual fuel utilization, 76 mm flue and blower 246 watts was used (Carrier 2010).
- See Appendix C for HVAC specifications.

German Home Assumptions and Inputs:

- Two bottom plates installed with the German Building envelope because there was no radiant flooring (Grimshaw 2012).
- HOT2000 only allowed one type of floor and since Germany has a ground floor constructed out of concrete as per section 9.2 and a second floor constructed from wood joists as per 11.1. These floors were constructed in HOT2000 and then the sum RSI was divided by two for an average, which was input into the German simulations (1.06 RSI).
- German Hanse house wood framing could not be completed to fully represent the framing adequately. The stud thicknesses were increased from 50 mm (300 mm spacing) to 57.5 (302 mm spacing) to make up for all of the framing elements in the above grade walls for the suburbs by calculation specifically utilizing the suburban dimensions. The same was done for the urban home where 55.5 (302 mm spacing) was inputted for framing width. By doing this, all framing has been represented accurately.
- Germany basement slab was not able to be insulated where the footing is due to constraints with HOT2000.

Passive House Assumptions and Inputs:

- Urban Passive House was assumed to use a 38 x 140 mm inside layer of walls for the ground floor and 2nd floor. The 38 x 89 mm inside layer was used on the 3rd floor.

- Air spaces are used from HOT2000 for basement wall.

Denmark House Assumptions and Inputs:

- Air changes per hour for suburban home: 1.5 L/s per m^2. To convert to ACH 1 liter = 0.001 m^3 1.5*0.001= 0.0015 *60 (to minutes) *60 (to hours) =5.4 m^3 per m^2. 5.4 * 301.8 m^2 (floor area)= 1,629.72/ 776 (volume of house)=2.1 ACH.
- Air changes per hour for urban home: 1.5 L/s per m^2. To convert to ACH 1 liter = 0.001 m^3 1.5*0.001= 0.0015 *60 (to minutes) *60 (to hours) =5.4 m^3 per m^2. 5.4 * 219.5 m^2 (floor area)= 1,185.3/ 613.3 (volume of house)=1.93 ACH.
- Danish Minimum Requirements home include thermal bridging for joints (windows and basement slab to basement wall)

Energuide Assumptions:

- As a method for comparison, the Energuide standard conditions and operating conditions were used. These conditions were the following (Natural Resources Canada 2005):
  - Four occupants in the home for 50 % of the time (two adults, two children).
  - 21 ^{0}C for the main floors and 19 ^{0}C for basements.
  - 225 litres of hot water consumed by occupants per day.
  - Lighting and appliances account for a total of 24 kWh per day.
  - A minimum ventilation of at least __ using the following equation (0.3ACH*1000/3600*volume of home). The minimum OBC requirements were used as they were the higher requirements.
  - These assumptions could be made because the OBC supplementary 12 states that the electricity and home usage can be assumed (Ministry of Municipal Affairs and Housing 2012).
- Toronto has 3956 Heating Degree Days (American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc 2009).
- Denmark: Koebenhavn 3653 (Copenhagen is representing Denmark) (American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc 2009).
- Germany: Berlin/Dahlem Germany 3390 HDD (American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc 2009) and the soil temperature is 10.1 ^{0}C (Canadian Geothermal Coalition 2012).
- Energuide calculations can be found in (Appendix D)

Ontario Assumptions and Inputs:

- The windows that were used by the builder and window supplied did not meet compliance package J in HOT2000. Thus different window designs were used to meet the U-values. For example, Jeld-Wen’s website stated that a window that has a vinyl frame, double glazed, low E, argon filled (9 mm) window with a metal spacer is 1.76 W/ m^2K (Jeld-Wen windows and doors, 2009). Modeling this same window in HOT2000, the U-value can range from 2.42 W/m^{2}K for a window 610 mm x 762 mm to 2 W/ m^{2}K for a window 1220 x 1575 mm. Therefore, the window inputs in HOT2000 had to be inputted with triple glazed windows to meet minimum U-value requirements. In Ontario's case, for a 1220 x 1575 mm window a U-value of 1.78 W/ m^{2}K is derived by HOT2000 and for a 610 mm x 72 mm 1.67 W/ m^{2}K. Since HOT2000 only understands the overall U-value in its calculations, it was assumed that this was not going to cause any issues in the final results.

7 Ontario:

7.1 Typical Building Envelope Layout-2012 & 2006 OBC:

In Table 4 below, a 'typical' 2012 and 2006 OBC compliant home's building envelope layout can be viewed from Brookfield Homes (Brookfield Homes 2012). For every building envelope section the layout is described from the exterior to the interior.

Table 4: Case A/B- 2012 & 2006 OBC Building Envelope Layout

2012 OBC Building Envelope Layout (Case A/B-2012)	2006 OBC Building Envelope Layout (Case A/B-2012)
Basement Wall	**Basement Wall**
• 200 mm 15 MPA Concrete wall • RSI 2.11 insulation from top of wall to 200 mm above finished floor of basement • 38 mm x 89 mm wood studs spacing at 610 mm O.C (due to it not being structural) • Vapour retarder • 12.7 mm drywall	• 200 mm 15 MPA Concrete wall • RSI 2.11 insulation from top of wall to 380 mm above finished floor of basement • 38 mm x 89 mm wood studs spaced at 610 mm O.C • Vapour retarder • 12.7 mm drywall
Above Grade walls	**Above Grade walls**
• 90 mm face brick or 100 mm Stone • 25 mm air space • Wall sheathing membrane • 6 mm exterior plywood • 38 mm x 140 mm wood studs spacing at 610 mm O.C • RSI 3.87 insulation • Vapour retarder • 12.7 mm drywall	• 90 mm face brick or 100 mm Stone • 25 mm air space • Wall sheathing membrane • mm exterior plywood • 38 mm x 140 mm wood studs spaced at 610 mm O.C • RSI 3.34 insulation • Vapour retarder • 12.7 mm drywall
OR	**OR**

• 90 mm face brick or 100 mm stone • 25 mm air space • 38 mm RSI 1.41 rigid insulation • 38 x 89 mm wood studs spacing at 400 mm O.C • RSI 2.46 insulation • Vapour retarder • 12.7 mm drywall	• 90 mm face brick or 100 mm stone • 25 mm air space • 19 mm RSI 0.70 rigid insulation • 38 x 89 mm wood studs spaced at 400 mm O.C • RSI 2.64 insulation • Vapour retarder • 12.7 drywall
Ceiling	**Ceiling**
• 38 mm x 140 mm ceilings joists spaced 610 mm O.C, 38 x 140 mm jack trusses spaced 610 mm O.C • RSI 8.8 insulation • Vapour retarder • 12.7 mm Drywall	• 38 mm x 140 mm ceilings joists spaced at 610 mm O.C, 38 x 140 mm jack trusses spaced 610 mm O.C • RSI 7 insulation • Vapour retarder • 12.7 Drywall
Windows	**Windows**
• U-value maximum of 1.8 W/m^2K	• U-value maximum of 2 W/m^2K
Doors	**Doors**
• 0.7 RSI	• 0.7 RSI
Basement Slab	**Basement Slab**
• 100 mm course granular material • Vapour retarder • 75 mm 15 MPA concrete slab	• 100 mm course granular material • Vapour retarder • 75 mm, 15 MPA concrete slab
Floor Assemblies	**Floor Assemblies**
• 12.7 mm drywall • 38 mm x 235 mm floor joists spaced spacing at 610 mm O.C • 22.5 mm tongue and grove subfloor	• 12.7 mm drywall • 38 mm x 235 mm floor joists spaced at 610 mm O.C • 22.5 mm tongue and grove subfloor

7.2 Typical Building Envelope Sections: 2006 & 2012 OBC:

2012 OBC 38 x 89 mm (Case A-2012):

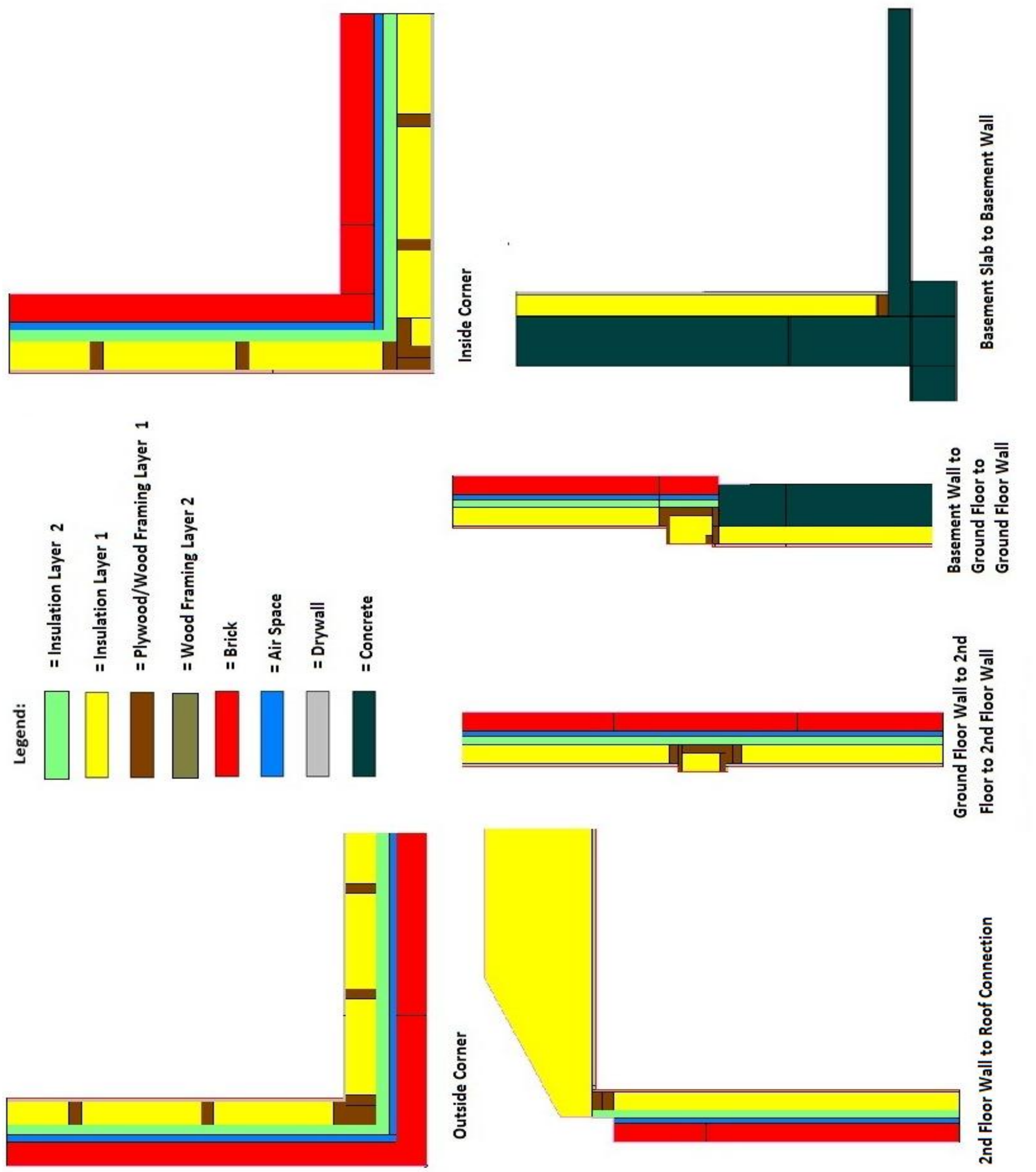

Figure 5: Case A-2012 Building Envelope Sections

(Brookfield Homes 2012)

In Figure 5, typical connection details are viewed for an Ontario 2012 OBC 38 x 89 mm home (Brookfield Homes 2012). Joining Figure 5 with the building envelope layout from Table 4, an understanding of how the building envelope is constructed can be gained. Overall, the 2012 and 2006 OBC are very similar in terms of their construction. For example, the 2006 OBC utilized 38 x 89 mm wood framing that had a decrease in RSI and thickness of its insulation layer 2 (refer to Table 4) (Brookfield Homes 2012). While for the 2012 and 2006 OBC homes that utilized 38 x 140 mm wood framing, insulation layer 2 is removed and the thickness of the insulation and wood framing increases to a 38 x 140 mm stud. As for the building envelope system, the home consists of (Brookfield Homes 2012):

- Two layers of insulation, one on the exterior that is rigid and an interior layer where the wood framing is.
- A basement wall with interior layer of insulation with 38 x 89 wood framing for both 2006 and 2012.
- A basement slab with no insulation for both 2006 and 2012.

In order to determine how the 2012 OBC and 2006 building envelope connections performed, simulations were conducted in THERM on these connection details in the section below called ‘Ontario 2012 & 2006 Building Envelope Sections Performance’.

7.3 Ontario Simulation Results:

7.3.1 Ontario 2012 & 2006 Building Envelope Sections Performance:

In this section, the building envelope from Figure 5 is simulated in the program THERM in a Toronto Climate. For a more in-depth breakdown refer to Table 4. Case A- represents 38 x 89 mm wood framing; Case B- represents 38 x 140 mm wood framing.
In Table 5 and 6 below, three columns can be seen and they stand for the following:

- Case A/B- Total U-value of the building envelope sections of Figure 5 (using total length of building envelope connection).
- Case A/B Whole Assembly- Total U-value of clear wall building envelope sections of Figure 5 (using total length of building envelope connection and no wood framing).

- Case A/B Thermal Bridge- The difference between 'Case A/B' and 'Case A/B Whole Assembly'.

2012:

Table 5: Case A-2012/2006 Building Envelope Connection U-value

U-Value (W/m²K)

Building Envelope Connection	Case A-2012	Case A-2012 Whole Assembly	Case A-2012 Thermal Bridge	Case A-2006	Case A-2006 Whole Assembly	Case A-2006 Thermal Bridge
Inside Corner	0.212	0.194	0.018	0.253	0.221	0.032
Outside Corner	0.260	0.229	0.031	0.304	0.259	0.045
Basement Slab to Basement Wall	0.557	0.552	0.005	0.557	0.552	0.005
Basement Wall to Ground Floor to Ground Floor Wall	0.295	0.275	0.020	0.311	0.288	0.023
Ground Floor Wall to 2nd Floor to 2nd Floor Wall	0.227	0.211	0.016	0.268	0.237	0.031
2nd Floor Wall to Roof Connection	0.198	0.189	0.009	0.226	0.213	0.013

2006:

Table 6: Case B-2012/2006 Building Envelope Connection U-value

U-Value (W/m²K)

Building Envelope Connection	Case B-2012	Case B-2012 Whole Assembly	Case B-2012 Thermal Bridge	Case B-2006	Case B-2006 Whole Assembly	Case B-Thermal Bridge
Inside Corner	0.218	0.191	0.027	0.241	0.216	0.025
Outside Corner	0.262	0.228	0.035	0.290	0.259	0.032
Basement Slab to Basement Wall	0.557	0.552	0.005	0.557	0.552	0.005
Basement Wall to Ground Floor to Ground Floor Wall	0.305	0.281	0.024	0.319	0.296	0.023
Ground Floor Wall to 2nd Floor to 2nd Floor Wall	0.236	0.207	0.030	0.264	0.234	0.030
2nd Floor Wall to Roof Connection	0.203	0.187	0.016	0.225	0.210	0.015

As per these Tables, the following can be taken away from these findings:

- Case A-2012 has the lowest total U-value and least amount of thermal bridges overall.
- Case A-2012 and Case B-2012 have very similar whole assembly U-values.
- Case A/B-2012 has the lower total U-values and whole assembly U-values than Case A/B-2006.
- Case B 2006- has a lower total U-value and very slightly lower whole assembly U-value than Case A-2006.

In total, Case A-2012 is the best performing and will be used to represent Ontario. To view the infrared illustrations of these building envelope sections see Appendix K and for the assumptions see Appendix F.

7.3.2 Energy Consumption Results for Ontario 2012 OBC Versus 2006 OBC:

By incorporating the building envelope layout from Table 4 into the HOT2000 program, two sets of results are calculated, one for an urban home and the other for a suburban home. In total eight simulations were completed with the help of the assumptions made in section 6.3. For the purpose of these simulations Case A represents 38 x 89 mm wood framing and Case B represents 38 x 140 mm wood framing. Both the 2012 and 2006 Ontario homes are homes that were just recently constructed by Brookfield Homes and are representation of a 'typical' home and a home meeting current minimum requirements in Ontario. These homes, therefore, signify that Ontario builders only construct their homes to the most current OBC.

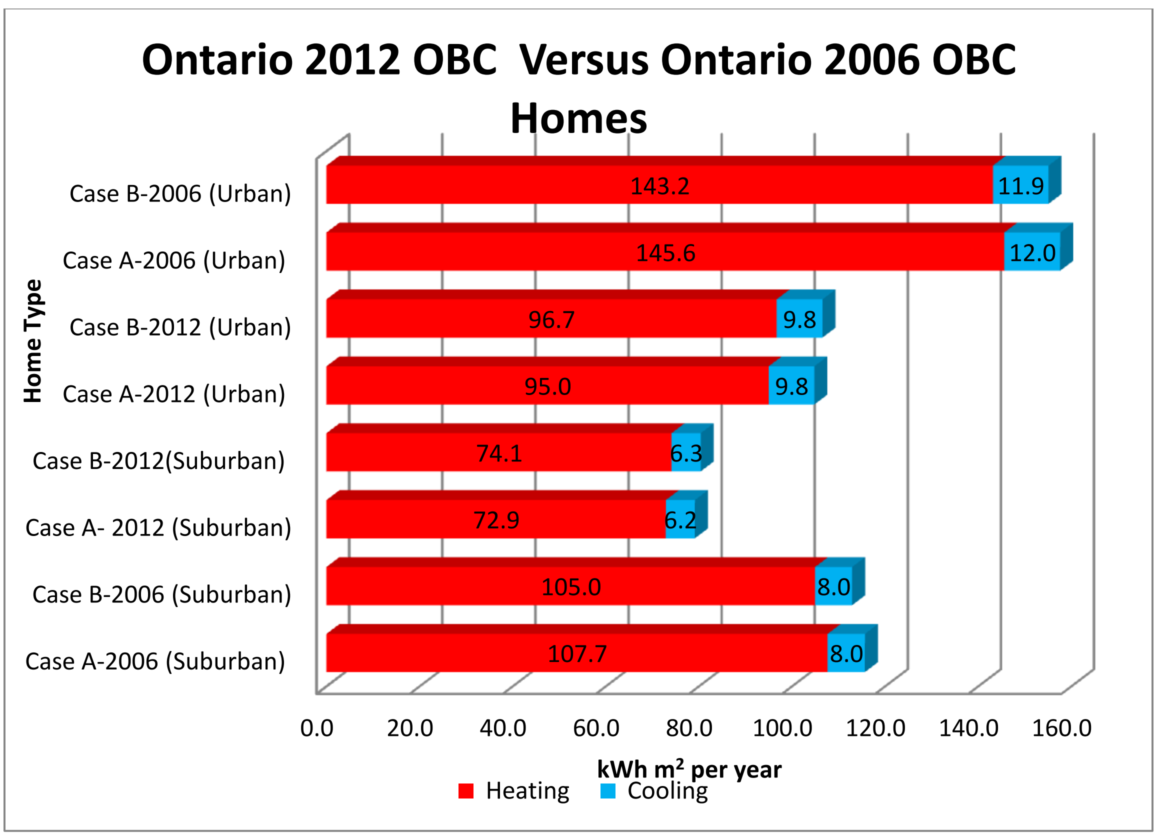

Figure 6: Ontario 2012 OBC Versus Ontario 2006 OBC Homes

In general, the results in Figure 6 did provide a graphical representation that shows the energy consumption for heating and cooling (including auxiliary equipment) for the 2006 OBC and 2012 OBC in the Greater Toronto Area, for an urban and suburban home. The following can be stated:

- Case A-2012 (suburban) consumes 32 % less heating energy than Case A-2006 (suburban) and 23% less cooling energy.
- Case B- 2012 (suburban) consumes 30 % less energy than Case B-2006 (suburban) and 21 % less cooling energy.
- Case A- 2012 (urban) consumes 35 % less heating energy than Case A-2006 (urban) and 18 % less cooling energy.
- Case B- 2012 (urban) consumes 33 % less heating energy than Case B-2006 (urban) and 18 % less cooling energy.

Moreover, as per Figure 6, it is evident that the urban home consumes more energy in heating and cooling than the suburban home, despite the suburban home has more floor area at 301.8 m^2 to the urban home's 219.5 m^2 and consists of the same HVAC equipment plus building envelopes. The 'small house penalty' comes into effect. For more information on this topic refer to section 6.2. To view details of these homes go to Appendix B. To view details about the HOT2000 calculated RSI values used in this simulation go to Appendix O, or a HOT2000 simulation example go to Appendix E. Interestingly, in comparison to a study by Lio and Associates utilizing compliance package J, Case A- 2012 shows an Energuide rating of 80.1 (Table 7) in this research, while in the Lio and Associate study an Energuide rating of 80.2 is calculated (Lio & Associates 2010). Thus this proves the accuracy of these simulations.

Table 7: Case A/B-2012 and Case A/B 2006 Energuide Ratings

Type of Home	Energuide Rating
Case A-2006 (Suburban)	74.5
Case B-2006 (Suburban)	74.9
Case A -2012 (Suburban)	80.1
Case B-2012 (Suburban)	79.9
Case A-2006 (Urban)	72.4
Case B-2006 (Urban)	72.7
Case A-2012 (Urban)	78.9
Case B-2012 (Urban)	78.6

For Energuide calculations, see Appendix D.

8 Denmark:

8.1 Denmark Building Envelope layout:

In Table 8, a ‘typical’ Denmark 2010 Building Regulation wood framing compliant home’s building envelope layout from Danish Timber Information can be viewed. For every building envelope section the layout is described from the exterior to the interior (Danish Timber Information 2008).

Table 8: Typical Denmark Building Envelope Layout

Denmark Building Envelope Layout
Basement Wall
• 100 mm extruded insulation (2.63 RSI) courtesy of Jorgen Rose • 490 mm LECA blocks (1.75 RSI) (0.25 w/mk) (Laterlite 2007) (with 155x 490 mm concrete footing) • Plaster finish
Above Grade walls
• 90 mm brick • 25 mm air space • 9 mm wind barrier or drywall etc. • 45 x 195 mm wood studs spaced at 600 mm O.C • RSI 5.73 (195 mm) • Vapour retarder • 45 x 45 mm wood studs spaced 600 mm O.C • RSI 1.32 (45 mm) • 12.7 mm drywall • 12.7 mm drywall
Ceiling
• 45x 150 mm wood joists spaced at 1200 mm O.C • RSI 11.76 (400 mm) • Vapour retarder • 25 x25 mm furring strips spaced 400 mm O.C • 12.7 mm drywall • 12.7 mm drywall
Windows
• U-value maximum of 1.4 W/m^2K
Doors
• 1.4 W/m^2k
Basement Slab

• 150 mm expanded clay aggregate (1.79 RSI) • 200 mm EPS insulation (5.26 RSI) • 100 mm concrete slab (0.05 RSI)
Floor Assemblies
• 12.7 mm drywall • 12.7 mm drywall • 25 x 25 mm furring strips spaced 400 mm O.C • Acoustical insulation throughout entire floor • 38 x 235 mm joists spaced 600 mm O.C • 18.5 mm plywood

8.2 Typical Denmark Building Envelope Sections:

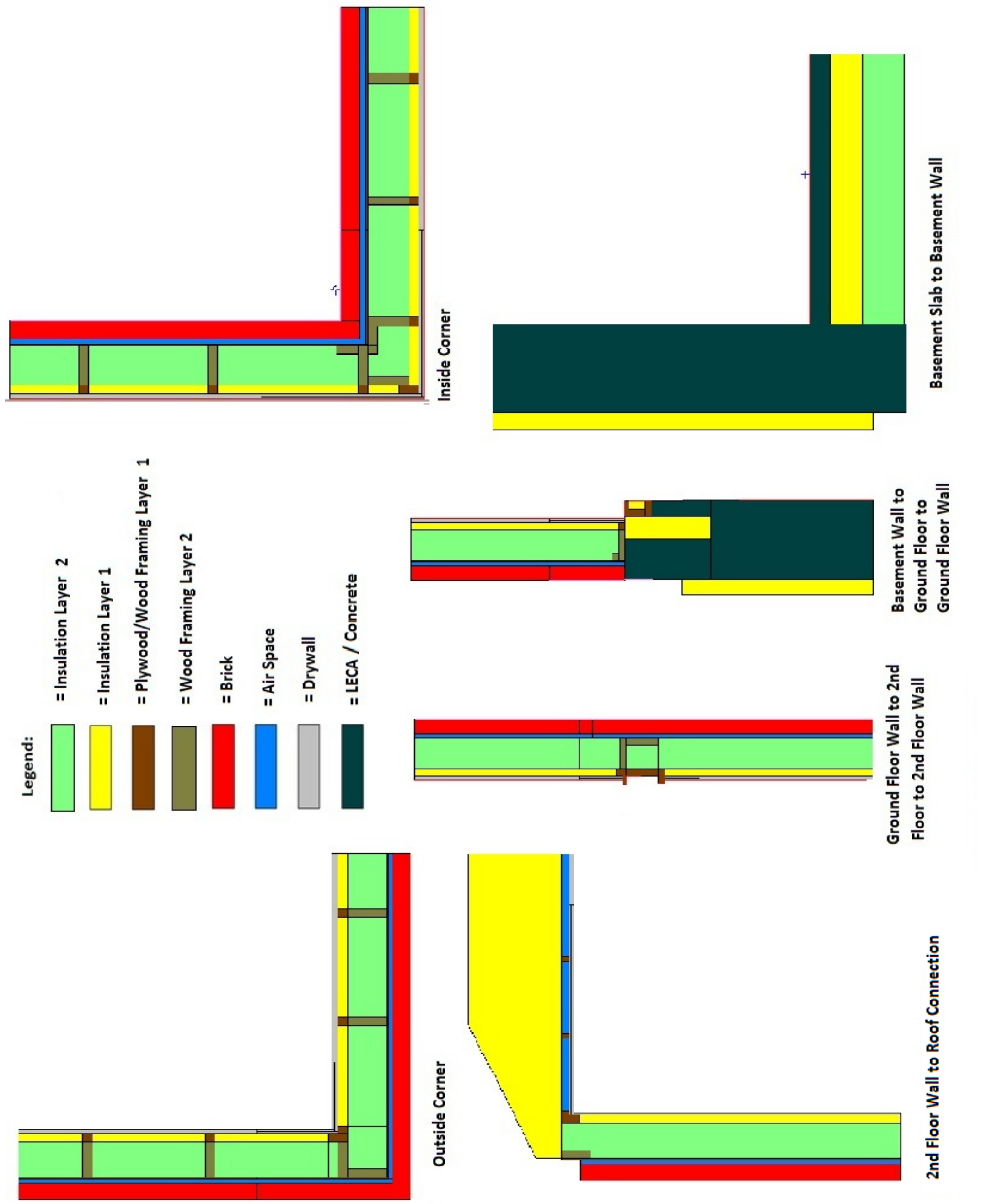

Figure 7: Typical Danish Building Envelope

(Danish Timber Information 2008)

When comparing Table 8 with Figure 7, a 'typical' Danish homes wood framing building envelope is better understood. Within the Danish building envelope system (Danish Timber Information 2008):

- A double layer of insulation is placed within the wall in addition to a double studded system.
- The basement wall is constructed out of light-weight clay aggregate (LECA) with an added layer of exterior rigid insulation.
- The basement slab is made from concrete with rigid insulation below the slab.

To determine how a Danish low-rise residential home performed, simulations in THERM were conducted on these building envelope connections in the section below.

8.3 Denmark Versus Ontario Simulation Results:

8.3.1 Denmark Versus Ontario Building Envelope Sections Performance:

Here, Danish building envelope sections from Figure 7 are simulated in the program THERM in a Toronto Climate and compared again Case A-2012. For a more in-depth breakdown refer to Table 8.

In Table 9 below, three columns can be seen and they stand for the following:

- Case A/ Typical Danish Building Envelope- Total U-value of the building envelope sections of Figure 7 (using total length of building envelope connection).
- Case A/ Typical Danish Building Envelope Whole Assembly- Total U-value of clear wall building envelope sections of Figure 7 (using total length of building envelope connection and no wood framing).
- Case A/ Typical Danish Building Envelope Thermal Bridge- The difference between the total U-value and the whole assembly.

Table 9: Typical Danish Building Envelope Connection U-value

U-Value (W/m^2K)

Building Envelope Connection	Case A-2012	Case A-2012 Whole Assembly	Case A-2012 Thermal Bridge	Typical Danish Building Envelope	Typical Danish Building Envelope Whole Assembly	Typical Danish Building Envelope Thermal Bridge
Inside Corner	0.212	0.194	0.018	0.136	0.112	0.023
Outside Corner	0.260	0.229	0.031	0.159	0.134	0.025
Basement Slab to Basement Wall	0.557	0.552	0.005	0.1786	0.1786	0.000
Basement Wall to Ground Floor to Ground Floor Wall	0.295	0.275	0.020	0.157	0.151	0.006
Ground Floor Wall to 2nd Floor to 2nd Floor Wall	0.227	0.211	0.016	0.130	0.126	0.003
2nd Floor Wall to Roof Connection	0.198	0.189	0.009	0.116	0.112	0.003

In Table 9, the following is observed:

- Typical Danish Building Envelopes and their whole assembly have a lower U-value than Case A-2012.
- Typical Danish Building Envelopes have less thermal bridging than Case A-2012 except for the inside corner where Denmark utilizes more wood framing.

To view the infrared illustrations of these building envelope sections see Appendix L and for the assumptions see Appendix F.

8.3.2 Denmark's Energy Frame Versus Ontario's:

In Figure 8, a Danish home's energy consumption for heating, cooling, domestic hot water and electricity for fans and pumps for heating, cooling and ventilation in comparison to that of Ontario is discovered. As a whole, four distinct results/simulations have been completed (to view the HOT2000 calculated RSI values see Appendix O):

- A Danish energy frame, which is the calculation 52.5 + (1650/heated floor area) and represents what the energy consumption, would be if these homes were built in Denmark (The Danish Ministry of Economic and Business Affairs 2010).
- A Danish minimum requirement, which is utilizing the building envelope RSI values required (including thermal bridging for joints) in the current 2010 building regulations from Denmark that typically meet the Danish energy frame (The Danish Ministry of Economic and Business Affairs 2010). To view what the minimum requirements are see Appendix H under 'extensions'.
- A 'typical' Danish building envelope, which is a current wood framing building envelope that is being built in Denmark as per Danish Timber Information and the building envelope layout in Table 8 (Danish Timber Information 2008).
- Case A-2012 (Suburban) is the best performing simulated home for Ontario, using 38x89 mm wood framing and is designed using compliance package J (OBC 2012) from Brookfield Homes (Brookfield Homes 2012). This home is representing a typically built home in Ontario under current regulation requirements.

Overall, the Danish minimum requirements, the 'typical' Danish building envelope and Case A-2012 for wood framing were simulated in a Toronto climate using the urban and suburban homes and both have the same orientation, layout, 2012 OBC HVAC equipment and dimensions. In addition, some assumptions are also required, which can be found in section 6.3.

In summary, as per Figure 8, the following comparison results are found:

- The 'typical' Danish building envelope and Danish minimum requirements expend very similar energy consumption for both the urban and suburban homes. In fact it was less than a 1 % difference.
- The urban 'typical' Danish building envelope consumes 76 % more than the urban Danish energy frame.
- The suburban 'typical' Danish building envelope consumes 37 % more than the suburban Danish energy frame.
- The Case A- 2012 (urban) home consumes 125 % more than the urban Danish energy frame and 28 % more than the 'typical' Danish building envelope and Danish minimum requirements.
- The Case-A 2012 (suburban) home consumes 74 % more than the suburban Danish energy frame and 27 % more than the 'typical' Danish building envelope and Danish minimum requirements.

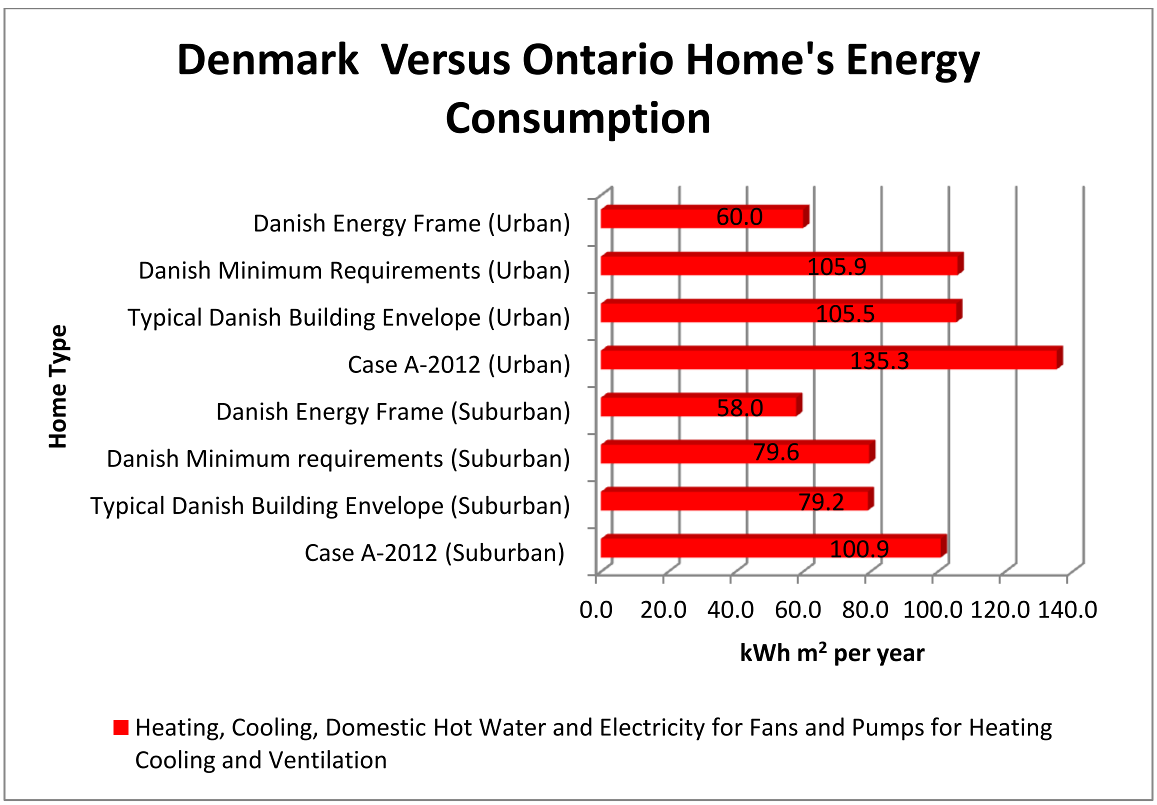

Figure 8: Denmark Versus Ontario Home's Energy Consumption

The reasoning behind the ‘typical’ Danish building envelopes and Danish minimum requirements consuming more energy, when in fact they should be consuming less energy than the Danish energy frame is because:

- Toronto’s total heating degree days (HDD) is 3956, while Copenhagen is 3653 HDD, which for the purpose of this report will represent Denmark (American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc 2009).
- Danish homes having an HRV with at least 80% efficiency with a specific fan power of less than 1000 j/m^3 to Ontario’s 67 % efficient HRV (Rose 2012).
- The furnaces must have an efficiency of at least 96 % to Ontario’s 95.5 % efficient gas furnace (Rose 2012).
- Domestic hot water tanks, have requirements in the amount of hot water they can use 250 l/m^2 per year, while in Ontario there is no such maximum (Rose 2012).

When taking into consideration all of these features it is understandable that these variances are found between the energy frames and the ‘typical’ Danish building envelope and Danish minimum requirements. As for the large difference between that of the suburban and urban home this can be credited to the ‘small house penalty’ as per section 6.2. As for Ontario, in addition to the features that were just discussed creating the differences between the Danish ‘typical’ and minimum requirements to the energy frame, there is also the building envelope disparity between the Danish and Ontario Homes. In total, what can be drawn away from this finding is that Denmark’s building envelope performs at a higher level than that of Ontario’s, due to Denmark using more insulation. For Energuide ratings of these dwellings view Table 10, with the calculation in Appendix D.

Table 10: Denmark Versus Case A-2012 Energuide Rating

Denmark Versus Case A-2012	**Energuide Rating**
Case A-2012 (Suburban)	80.1
Typical Danish Building Envelope (Suburban)	83.6
Danish Minimum requirements (Suburban)	83.5
Case A-2012 (Urban)	78.9
Typical Danish Building Envelope (Urban)	82.7
Danish Minimum Requirements (Urban)	82.6

9 Germany:

9.1 Typical Germany Building Envelope Layout:

In Table 11, a ‘typical’ German home’s wood framing building envelope performing 30 % or 45 % better than the EnEV 2009 can be viewed. In Germany, homes are designed and constructed to perform better than their requirements because of the cost of energy and tax breaks available, so it is very rare that a home simply meetings the 2009 EnEV is built (Grimshaw 2012). For every building envelope section, the layout is described from the exterior to the interior and is courtesy of Hanse Haus (Hanse House 2010).

Table 11: Typical German Building Envelope Layout

Germany Building Envelope Layout
Basement Wall (Glathaar 2012)
• 15 mm HDPE drainage sheet • 40 mm XPS insulation, 1 RSI • 2 mm coat bitumen (vapour retarder) • 80 mm external prefabricated concrete shell • 120 mm insulation (foamed in the factory), 3.87 RSI • 115 mm in-situ concrete (filled in after installation of the wall panels on site) • 70 mm internal prefabricated concrete shell • No interior finishes on average home
Above Grade walls (Hanse House 2010)
• 90 mm brick • 25 mm air space • 150 mm insulation expanded polystyrene with Neopor additive, 4.69 RSI • 8 mm OSB • 125 mm insulation mineral fibre quilt, 3.29 RSI • (125 mm x 50 mm studs spaced 300 mm O.C) Average as per Oliver Grimshaw (Grimshaw 2012) • 8 mm OSB • vapour retarder • 12.7 mm Drywall
Ceiling (Hanse House 2010)
• 240 mm x 70 mm joists spaced 625 mm O.C, RSI 6.31 mineral fibre quilt • Vapour retarder • 80 mm x 30 mm stripping spaced 300 mm O.C (spaces are air gaps) • 12.7 mm drywall
Ground Floor (Glatthaar Fertigeller 2008)

• 70 mm internal prefabricated concrete shell • 130 mm Concrete ground floor slab
Windows (Grimshaw 2012)
• U-value maximum of 1 W/m^{2}K
Doors (Grimshaw, 2012)
• 1 W/m^{2}K
Basement Slab (Glathaar 2012)
• 140 mm thick XPS insulation, 3.59 RSI • mm 2 coat bitumen (vapour retarder) • 250 mm waterproof concrete
2nd Floor Assembly (Hanse House 2010)
• 12.7 mm drywall • 30 mm x 80 mm stripping spaced 300 O.C (spaces are air gaps) • 100 mm mineral fibre quilt acting as acoustical insulation, 2.61 RSI • 240 mm joists spaced 625 O.C • 18 mm OSB

9.2 Typical Germany Building Envelope Connections:

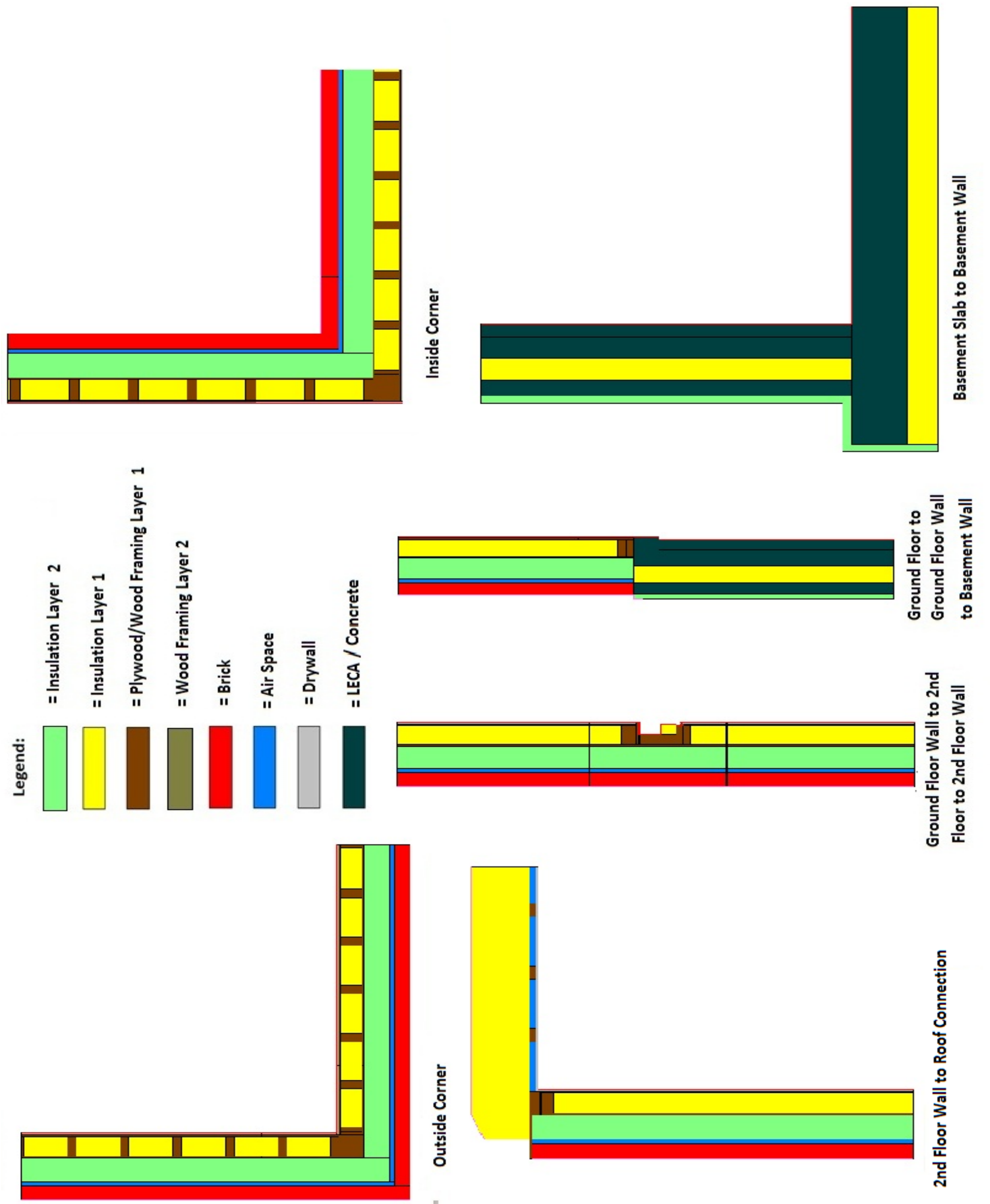

Figure 9: Typical German Building Envelope Connections

(Hanse House 2010)

By combining Table 11 with Figure 9, a ‘typical’ German home’s wood framing building envelope by Hanse Haus can be viewed. Within this system (Hanse House 2010):

- A double layer of insulation is used, with an interior layer that consists of wood framing and insulation in between the studs.
- The basement has two layers of pre-cast concrete are on the exterior and interior, which sandwiches a layer of rigid insulation and layer of concrete (Glathaar 2012). In addition, an extra layer of insulation on the exterior of the basement is also installed.
- For the basement slab, extruded polystyrene is placed under the slab and connects to the exterior layer of basement wall insulation.

In order to determine how these ‘typical’ German low-rise residential homes performed, simulations in THERM were conducted and can be found in the section below.

9.3 German Simulation Results:

9.3.1 Germany Versus Ontario Building Sections Performance:

Here, ‘typical’ German building envelope sections from Figure 9 are simulated in the program THERM in a Toronto Climate against Ontario’s Case A-2012. For a more in-depth breakdown refer to Table 11.

In Table 11 three columns can be seen and they stand for the following:

- Case A/ Typical German Building Envelope- Total U-value of the building envelope sections of Figure 9 (using total length of building envelope connection).
- Case A/ Typical German Envelope Whole Assembly- Total U-value of clear wall building envelope sections of Figure 9 (using total length of building envelope connection and no wood framing).
- Case A/ Typical German Building Envelope Thermal Bridge- The difference between the total U-value and the whole assembly.

Table 12: Typical German Building Envelope Connections U-value

U-Value (W/m^2K)

Building Envelope Section	Case A-2012	Case A-2012 Whole Assembly	Case A-2012 Thermal Bridge	Typical German Building Envelope	Typical German Building Envelope Whole Assembly	Typical German Building Envelope Thermal Bridge
Inside Corner	0.212	0.194	0.018	0.108	0.099	0.009
Outside Corner	0.260	0.229	0.031	0.133	0.119	0.013
Basement Slab to Basement Wall	0.557	0.552	0.005	0.236	0.236	0.000
Basement Wall to Ground Floor to Ground Floor Wall	0.295	0.275	0.020	0.153	0.152	0.000
Ground Floor Wall to 2nd Floor to 2nd Floor Wall	0.227	0.211	0.016	0.113	0.108	0.004
2nd Floor Wall to Roof Connection	0.198	0.189	0.009	0.132	0.128	0.004

In Table 12, the following is found:

- Typical German Building Envelopes and their whole assembly have a lower U-value than Case A-2012.
- Typical German Building Envelopes have less thermal bridging than Case A-2012.

To view the infrared illustrations of these building envelope sections see Appendix M and for the assumptions see Appendix F.

9.3.2 German Heating Demand Versus Ontario:

In Figure 10, a German home's energy consumption for heating, domestic hot water and auxiliary equipment for heating in comparison to Ontario is viewable. As a whole, four distinct results/simulations have been completed (to view HOT2000 calculated RSI values for these simulations see Appendix O):

- German heating demand, 65 kWh/m^2 per year which on average is the amount of energy a German home is to consume as per the EnEV 2009 (Energy Saving Ordinance) in Germany (Blok, Boermans, Hermelink, & Schimschar 2011).
- German minimum requirement uses the building envelope RSI values (including thermal bridging) in the current 2009 EnEV. This typically meets the maximum German heating demand required (Verordnung über energiesparenden Wärmeschutz und energiesparende Anlagentechnik bei Gebäuden 2009). To view what the minimum requirements are see Appendix I.
- A 'typical' German building envelope, using wood framing and is built by Hanse Haus and consumes 30 % less (KfW 70) than the EnEV 2009. For the building envelope layout of this home see Table 11 (Hanse House 2010).
- Case A-2012 (Suburban) which is the best performing simulated home for Ontario, uses 38 x 89 mm wood framing and is designed using compliance package J (OBC 2012) from Brookfield Homes. (Brookfield Homes 2012) This home is representing a 'typical' home built in Ontario current regulation requirements.

Overall, the German minimum requirements, 'typical' German building envelope and Case A-2012 for wood framing were simulated in a Toronto climate using the urban and suburban homes and both have the same orientation, layout, 2012 OBC HVAC equipment and dimensions. In addition, some assumptions are also required, which can be found in 6.3.

In summary, as per Figure 10 the following comparison results are found:

- Urban:
    - The 'typical' German building envelope consumes 30 % less energy than the German minimum requirements.
    - The 'typical' German building envelope consumes 33 % less energy than Case A-2012.
    - The German minimum requirements, consumes 5 % less energy than Case A-2012.
    - The 'typical' German building envelope consumes 26 % more energy than the German heating demand.
    - The German minimum requirements consume 80 % more energy than the German heating demand.
    - Case A-2012 consumes 90 % more energy than the German heating demand.
- Suburban:
    - The 'typical' German building envelope consumes 29 % less energy than the German minimum requirements.
    - The 'typical' German building envelope consumes 31 % less energy than Case A-2012.
    - The German minimum requirements, consumes 3 % less energy than Case A-2012.
    - The 'typical' German building envelope consumes 2 % less energy than German heating demand.
    - The German minimum requirements consume 39 % more energy than the German heating demand.
    - Case A-2012 consumes 44 % more energy than the German heating demand.

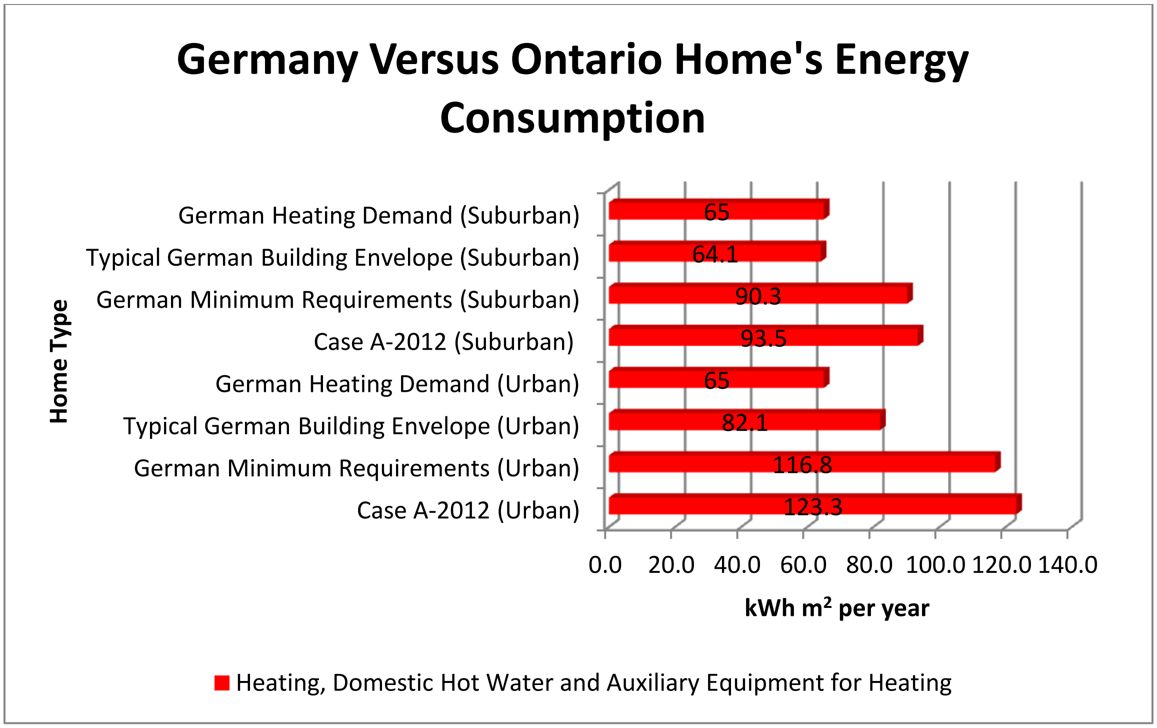

Figure 10: Germany Versus Ontario Home's Energy Use

In justifying why the 'typical' German building envelopes and the German's minimum requirements consuming more energy, when in fact they should be consuming less energy than the German heating demand is due to:

- Germany having fewer heating degree- days than Toronto (3956 to Germany's 3390 in Berlin/Dahlem) (American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc 2009).
- The Hanse Haus relies on heated flooring and a HRV minimum efficiency of 85 % to the 2012 OBC's 95.5 % efficient gas furnace and 67 % HRV (Grimshaw 2012).
- In Germany, the maximum amount of energy consumption for hot water is 12.5 kWh/m^2 per year and in the simulations that are represented in the bar graph above, a consumption of 20.5 kWh/m^2 per year for the suburban home and 28.2 kWh/m^2 per year for the urban home is calculated (Verordnung über energiesparenden Wärmeschutz und energiesparende Anlagentechnik bei Gebäuden 2009).

- The actual orientation and layout of the homes, which could greatly affect solar heat gain.

Taking everything into consideration, it was easier to understand why there is such a large differential between the German heating demand and a 'typical' German building envelope and the German's minimum requirements. As for the large difference between that of the suburban and urban home this can be credited to the 'small house penalty' as per section 6.2. In general, Germany's building envelope performs at a higher level than that of Ontario's because of the fact that Germany uses more insulation. For Energuide ratings of these dwellings see Table 13, with the calculation in Appendix D.

Table 13: Germany Versus Case A-2012 Energuide Rating

Germany Versus Case A-2012	Energuide Rating
German Minimum Requirements (Suburban)	80.6
German Minimum Requirements (Urban)	79.7
Typical German Building Envelope (Urban)	84
Typical German Building Envelope (Suburban)	84.8
Case A-2012 (Urban)	80.1
Case A-2012 (Suburban)	78.9

10 Passive House:

10.1 Building Envelope Layout:

In Table 14 below, a ‘typical’ Passive House building envelope is shown. Courtesy of Mark Yanowitz of Verdeco Design, this building envelope was Passive House Certified in 2011 (Yanowitz, Beaton House- Verdeco Designs 2009). This building envelope is thought to be a good representation of a Passive House building envelope because Boston’s heating degree days are similar to Toronto’s (3726 to 3956) (American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc 2009). In addition, it is assumed that this home can be certified in a Toronto climate. For every building envelope section below, the layout is described from the exterior to the interior.

Table 14: Passive House Building Envelope Layout

Passive House Building Envelope Layout
Basement Wall
• 254 mm concrete wall • 66.675 EPS on either side of 254 mm concrete wall (ICF forms) • RSI of 0.69 per 25.4 mm of EPS as per technical supervisor from NuDura (manufacturer) (Nudura 2010) • Vapour retarder • Air space • RSI 3.4 of dense pack insulation • 38 x 140 mm wood studs spaced 400 mm O.C • 12.7 mm drywall • Note the home has 254 mm concrete wall below grade and 152.4 mm of concrete wall above grade for the basement. However, the 254 mm concrete wall will be used in the whole house simulations. Also, there will be no walk-out.
Above Grade Walls (Ground Floor)
• 90 mm face brick or 100 mm Stone • 25 mm air space • 11 mm Zip system wall sheathing (similar to OSB) • RSI 8.63 of dense packed cellulose • 356 mm TJI studs 210 series spaced 600 mm O.C • 11 mm OSB sheathing (sealed and caulked) • RSI 3.4 of dense packed cellulose • 38 x 140 mm wood studs spaced 600 mm O.C • 12.7 mm drywall

Above Grade Walls (2nd Floor)
• 90 mm face brick or 100 mm stone • 25 mm air space • 7/16" (11 mm) Zip system wall sheathing (similar to wood sheathing) • RSI 8.63 of dense packed cellulose • 356 mm TJI studs 210 series spaced 600 mm O.C • 11 mm OSB sheathing (sealed and caulked) • RSI 2.17 of dense packed insulation • 38 x 89 mm wood studs spacing 600 mm O.C • 12.7 mm drywall
Ceiling
• 38 mm x 89 mm ceilings joists (truss framing) spaced 600 mm O.C • RSI 22.23 insulation (please note the heel height was increased to 600 mm and 750 mm of insulation was installed as oppose to what the drawing says as per Mark Yanowitz) • 11 mm OSB sheathing (sealed and caulked) • 12.7 mm drywall
Windows
• North, East, West: 0.74 w/m^2k COG, SHGC 0.55 • South: 0.91 w/m^2k COG, SHGC 0.64
Doors
• 0.74 w/m^2k SHGC 0.61 Window Frame 1.15 w/m^2k
Basement Slab
• 254 mm (RSI 8.8 of EPS rigid insulation) (Owens Corning 2004) • Vapour retarder • 102 mm concrete slab
Floor Assemblies
• 12.7 mm Drywall • 280 mm TJI joists spaced 400 mm O.C • 19 mm tongue and grove plywood

10.2 Passive House Building Envelope Connections:

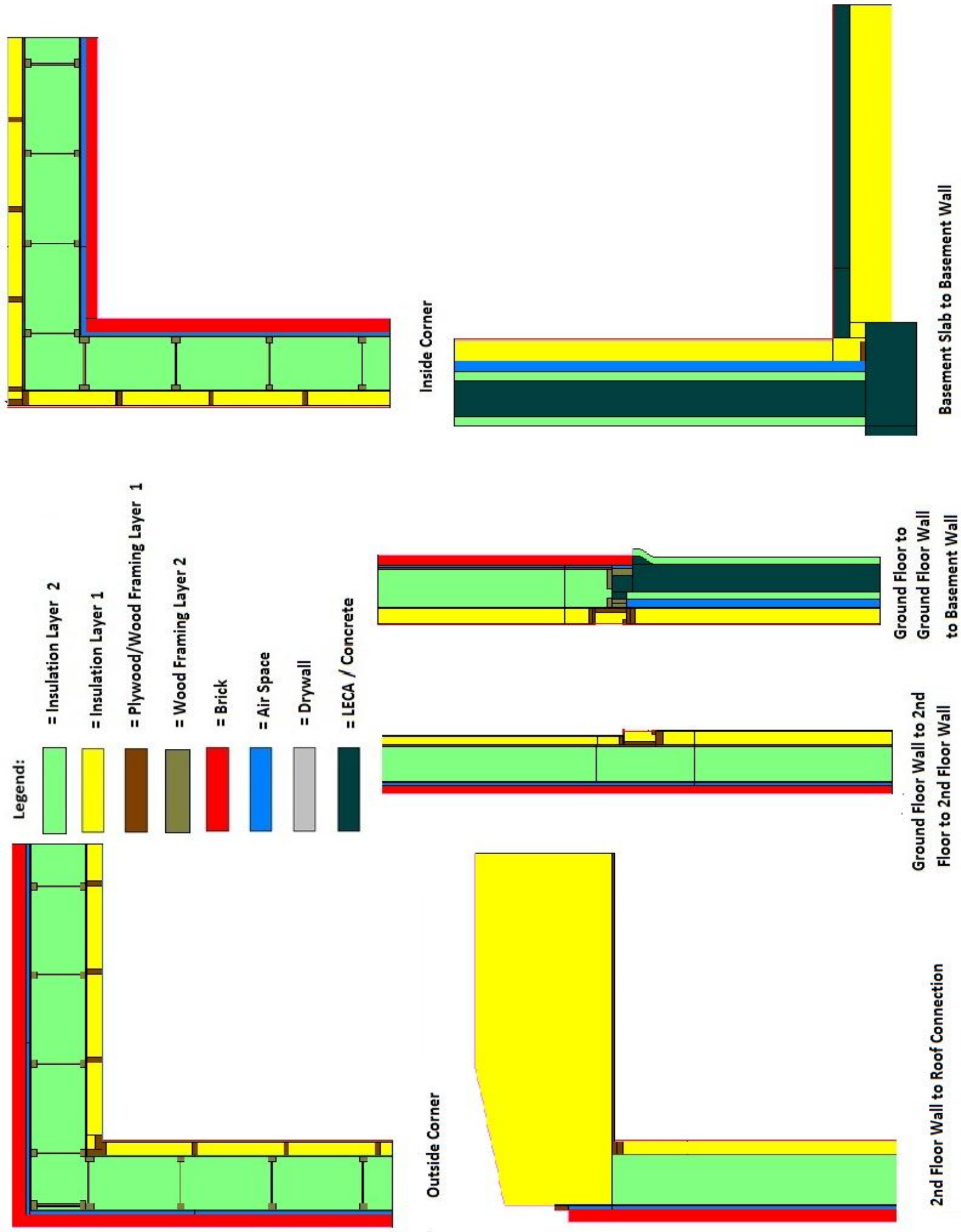

Figure 11: Typical Passive House Building Envelope Connections

(Yanowitz, Beaton House- Verdeco Designs 2009)

By merging Table 14 with Figure 11, a Passive House wood framing building envelope by Verdeco Design can be viewed. Within this system (Yanowitz, Beaton House-Verdeco Designs 2009):

- Two layers of insulation are used, with both layers that consist of wood framing to support specific loads of the home. For the ground floor, the interior layer installed 38 x 140 mm studs and for the 2^{nd} floor 38 x 89 mm studs.
- The basement includes insulated concrete forms that are used with a wood framed interior layer.
- Beneath the basement slab a large layer of rigid insulation. Insulation is placed between the footing, slab and basement wall to create a thermal break.

In order to determine how the Passive House performed, simulations in THERM were conducted and can be found in the section below.

10.3 Passive House Simulation Results:

10.3.1 Passive House Building Sections Performance:

The Passive House building envelope sections from Figure 11 are simulated in the program THERM in a Toronto Climate are compared against Ontario's Case A-2012. For a more in-depth breakdown see Table 14.

In Table 14, three columns can be seen and they stand for the following:

- Case A/ Passive House Building Envelope- Total U-value of the building envelope sections of Figure 11 (using total length of building envelope connection).
- Case A/ Passive House Building Envelope Whole Assembly- Total U-value of clear wall building envelope sections of Figure 11 (using total length of building envelope connection and no wood framing).
- Case A/ Passive House Building Envelope Thermal Bridge- The difference between the total U-value and the whole assembly.

Table 15: Typical Passive House Building Envelope Connections U-value

U-Value (W/m^2K)

Building Envelope Section	Case A-2012	Case A-2012 Whole Assembly	Case A-2012 Thermal Bridge	Passive House	Passive House Building Envelope Whole Assembly	Passive House Building Envelope Thermal Bridge
Inside Corner Ground Floor	0.212	0.194	0.018	0.0693	0.0650	0.0043
Inside Corner 2nd Floor	0.212	0.194	0.018	0.0773	0.0728	0.0045
Outside Corner Ground Floor	0.260	0.229	0.031	0.0888	0.0817	0.0071
Outside Corner 2nd Floor	0.260	0.229	0.031	0.0966	0.0895	0.0071
Basement Slab to Basement Wall	0.557	0.552	0.005	0.1013	0.1005	0.0008
Basement Wall to Ground Floor to Ground Floor Wall	0.295	0.275	0.020	0.0962	0.0884	0.0078
Ground Floor Wall to 2nd Floor to 2nd Floor Wall	0.227	0.211	0.016	0.0811	0.0801	0.0010
2nd Floor Wall to Roof Connection	0.198	0.189	0.009	0.0719	0.0711	0.0008

In Table 15, the following is discovered:

- Passive House Building Envelopes and their whole assembly have a lower U-value than Case A-2012.
- Passive House Building Envelopes have less thermal bridging than Case A-2012.

To view the infrared illustrations of these building envelope sections see Appendix N and for the assumptions see Appendix F.

10.3.2 Passive House Maximum Heating Demand Versus Ontario:

In Figure 12, the Passive House consumption for heating and cooling (excluding auxiliary equipment) comparison against Ontario is viewable. As a whole, three distinct results/simulations have been completed (to view HOT2000 calculated RSI values for these simulations see Appendix O):

- A Passive House’s heating demand maximum requirements, which is the maximum amount of heating and cooling allowed for a Passive House (International Passive House Association 2010).
- A Passive House’s building envelope, which is the building envelope that is used by the certified Passive House in Boston designed by Mark Yanowitz of Verdeco Design. For the building envelope layout of this home see Table 14 (Yanowitz, Beaton House- Verdeco Designs 2009).
- Case A-2012 (Suburban) which is the best performing simulated home, using 38 x 89 mm wood framing and is designed using compliance package J (OBC 2012) from Brookfield Homes (Brookfield Homes 2012). This home is representing a ‘typical’ home built in Ontario under current regulation requirements.

Overall, the Passive House building envelope and Case A-2012 is simulated in a Toronto climate using the urban and suburban homes and both have the same orientation, layout, 2012 OBC HVAC equipment and dimensions. Thus, the simulated Passive House will not meet the Passive House maximum heating demand requirement because of the 2012 OBC HVAC equipment. In addition, some assumptions are also required, which can be found in section 6.3 In summary, as per Figure 12, the following comparison results are found:

- Urban:
  - The Passive House consumes 90 % more than the Passive House heating demand maximum requirements and 51 % less energy than the Passive House heating demand cooling maximum requirements.
  - Case A-2012 consumes 458 % more than the Passive House heating demand maximum requirements and 51 % less than the Passive House heating demand cooling maximum requirements.
  - Case A-2012 consumes 193 % more than the Passive House heating and the same in cooling.
- Suburban:
  - The Passive House consumes 69 % more than the Passive House heating demand maximum requirements and 73 % less than the Passive House heating demand cooling maximum requirements.
  - Case A-2012 consumes 340 % more than the Passive House heating demand maximum requirements and 69 % less than the Passive House heating demand cooling maximum requirements.
  - Case A-2012 consumes 161 % more than the Passive House heating and 17 % more in cooling.

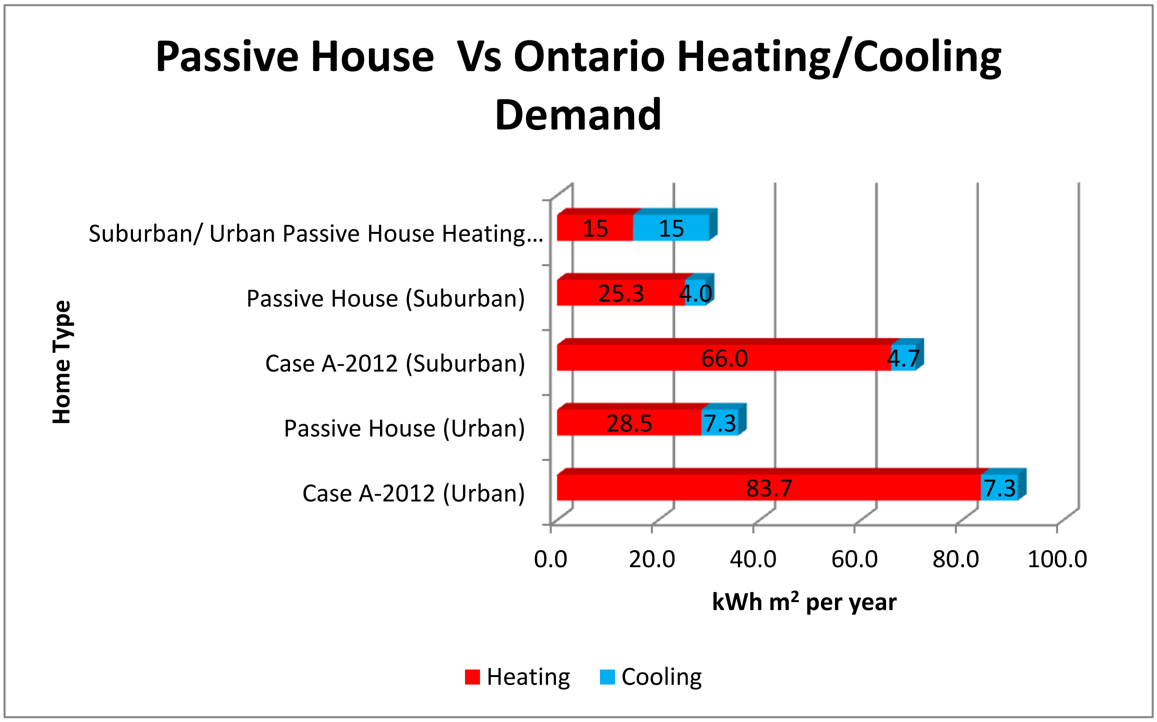

Figure 12: Passive House Versus Ontario Heating/ Cooling Demand

Installing a certified Passive House's building envelope, did reduce energy consumption for heating and cooling in comparison to Ontario's. However, the simulated Passive House in Figure 12, is unable to meet the heating and cooling demand maximum requirements of a certified Passive House because:

- The heating degree day difference between Toronto and Boston requires more energy to be used.
- The Passive House in Figure 12 is using 2012 OBC HVAC equipment as opposed to the certified Passive House heating and cooling equipment.
- The Passive House tends to have a site-specific layout and is designed for its surrounding environment.

These factors combined, with the unknown assumptions of the internal heat gain explain why the suburban and urban Passive Homes consume more energy for heating then that of a certified Passive House. However, a Passive House building envelope on an Ontario home did consume less energy than that of Case A-2012. For Energuide ratings of these dwellings see Table 16, with the calculation in Appendix D.

Table 16: Passive House Versus Case A- 2012 Energuide Rating

Passive House Versus Case A-2012	Energuide Rating
Passive House (Suburban)	87
Passive House (Urban)	86.3
Case A-2012 (Urban)	78.9
Case A-2012 (Suburban)	80.1

11 Conclusions:

The main objective of this research is to determine where the building envelope performance level is for the Ontario Building Code for newly constructed, low-rise, residential homes in comparison to other high-performing regulations such as Denmark, Germany and the Passive House Standard. To compare the overall performance levels of these building envelopes against one another, the following comparisons and analysis are made:

- Current and past building envelope regulation requirements,
- 'Typical' building envelope connection details,
- Current building envelope regulation requirements energy consumption and
- 'Typical' building envelope energy consumption.

11.1 Comparison of Current and Past Regulations:

By comparing the 2012 OBC to the German EnEV 2009, Denmark Building Regulation 2010 and the Passive House Standard, it is evident that Ontario and Germany currently are very similar in their building envelope component's RSI values with each component being a little higher in some cases for each of the locations. Yet when comparing them in air changes per hour and window U-values, Germany fairs better. In the past editions of building regulations for these two locations the roles reverse with Germany having poorer building envelope requirements on average. With that said, Germany has a slight advantage in having a better building envelope currently, but did not have that advantage in the past. In comparison, Denmark and the Passive House Standard, are above and beyond Ontario's current and past Building Code requirements.

11.2 Comparison of 'Typical' Building Envelope Connections:

By analyzing the 'typical' building envelope connection details from Germany, Denmark and the Passive House versus Ontario, the following rankings on average are determined (from best to worst):

- Total U-value Building Envelope (using total length of building envelope connection):
  - Passive House,
  - Germany,
  - Denmark,
  - Ontario.
- Building Envelope Whole Assembly- (Total U-value of clear wall building envelope sections (using total length of building envelope connection and no wood framing):
  - Passive House,
  - German/ Denmark (tied),
  - Ontario.
- Building Envelope Thermal Bridge- The difference between the total U-value and the whole assembly:
  - Passive House,
  - Germany,
  - Denmark,
  - Ontario.

Ultimately, in every facet Ontario ranks last, which means that the details reviewed in this research demonstrate that Ontario's building envelope connections need to be designed in such a way that reduces thermal bridging and heat loss.

11.3 Comparison of 'Typical' and Current Regulation Minimum Requirements Building Envelope Energy Use Versus Ontario:

Comparing Germany, Denmark and the Passive House Standard versus the 2012 OBC illustrates where Ontario rates in terms of heating and cooling consumption for both a 'typical' and minimum requirement urban and suburban home. These homes are all simulated in a Toronto climate using the following:

- Same orientation,
- Layout,
- 2012 OBC HVAC equipment.

For these homes, the following building envelope components are calculated by HOT2000 simulations. To view the RSI values see Appendix O:

Typical:

For the 'typical' home the following is used:

- A 'typical' Danish building envelope, which is a current wood framing building envelope, built in Denmark as per Danish Timber Information and the building envelope layout from Table 8 (Danish Timber Information 2008).
- A 'typical' German building envelope, which is a current wood framing building envelope built by Hanse Haus in Germany and consumes 30 % less (KfW 70) than the EnEV 2009. For the building envelope layout of this home see Table 11 (Hanse House 2010).
- A Passive House building envelope, which is the building envelope that is used by Mark Yanowitz Design's certified Passive House in Boston. For the building envelope layout of this home see Table 14 (Yanowitz, Beaton House- Verdeco Designs 2009).
- Case A-2012 (Suburban) which is the best performing simulated home for Ontario, using 38x89 mm wood framing, designed using compliance package J (OBC 2012) by Brookfield Homes (Brookfield Homes 2012). This home is representing a 'typical' home built in Ontario.

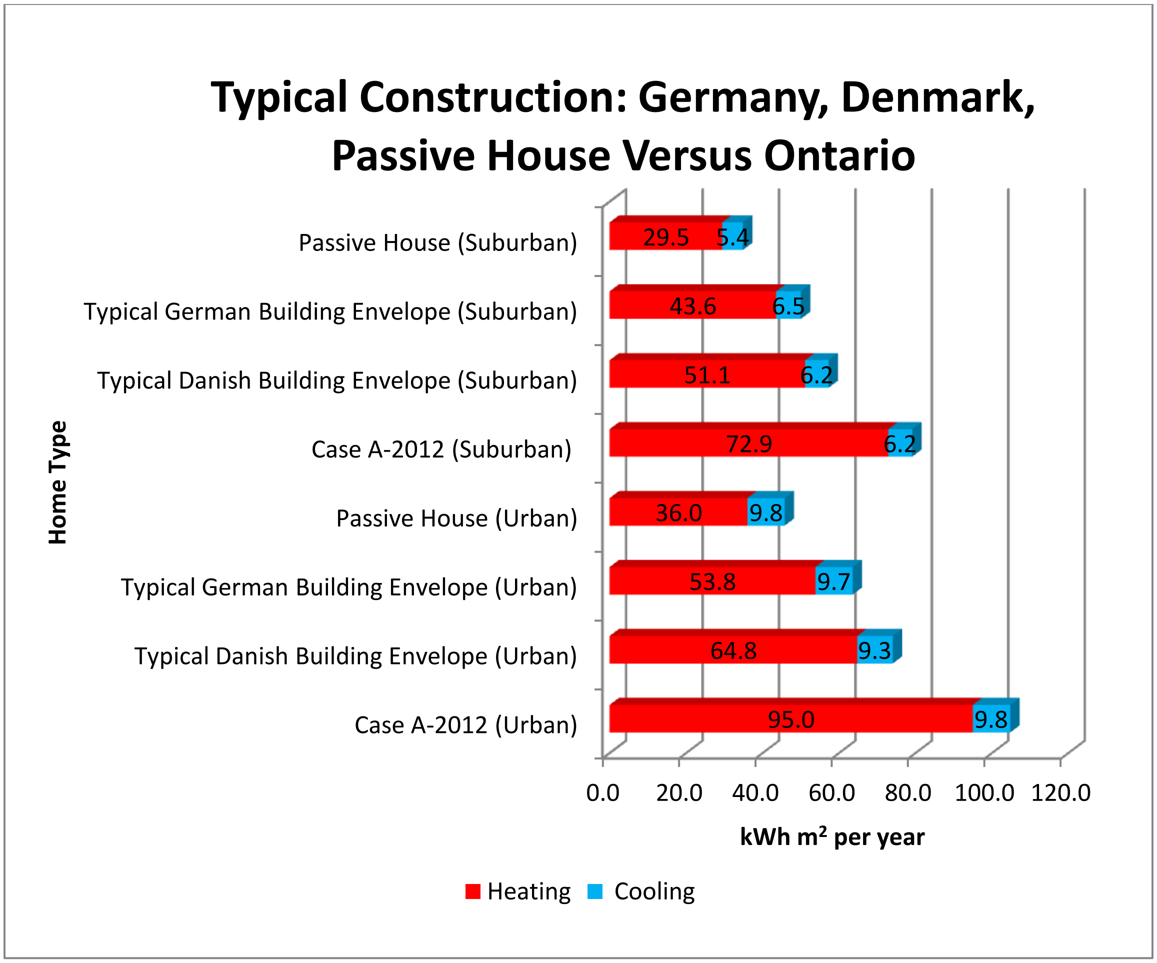

Figure 13: Typical Construction: Germany, Denmark, Passive House Versus Ontario

For the urban and suburban homes (Figure 13), the percentage difference for heating and cooling (including auxiliary fans) in comparison to Case A-2012 (Ontario), is the following:

- Suburban homes:
  - Passive House consumes 56 % less,
  - Germany at 37 % less,
  - Denmark at 2 % less.
- Urban homes:
  - Passive House consumes 56 % less,
  - Germany at 39 % less,
  - Denmark 29 % less.

Current Regulation Minimum Requirements:

For the minimum requirement homes the following is being used:

- A Danish minimum requirement, which uses the building envelope RSI values required (including thermal bridging for joints) in the current 2010 building regulations from Denmark that typically meet the Danish energy frame (The Danish Ministry of Economic and Business Affairs 2010). To view what the minimum requirements are see Appendix H and look under 'extensions'.
- A German minimum requirement uses the building envelope RSI values required (including thermal bridging) in the current 2009 EnEV from Germany, that typically meets the maximum German heating demand required (Verordnung über energiesparenden Wärmeschutz und energiesparende Anlagentechnik bei Gebäuden 2009). To view what the minimum requirements are see Appendix I.
- A Passive House building envelope, which is the building envelope used by the certified Passive House in Boston designed by Mark Yanowitz of Verdeco Design. For the building envelope layout of this home see Table 14 (Yanowitz, Beaton House- Verdeco Designs 2009). In this case, this design is being considered as the minimum requirements for a Passive House because no minimum requirements for Passive Homes exist, as they are dependent on heating/cooling/primary energy consumption.
- Case A-2012 (Suburban) which is the best performing simulated home for Ontario, using 38 x 89 mm wood framing, designed using compliance package J (OBC 2012) building envelope, is the worst one of the four. This home is designed by Brookfield homes and represents a 'typical' home in Ontario built using minimum requirements (Brookfield Homes 2009).

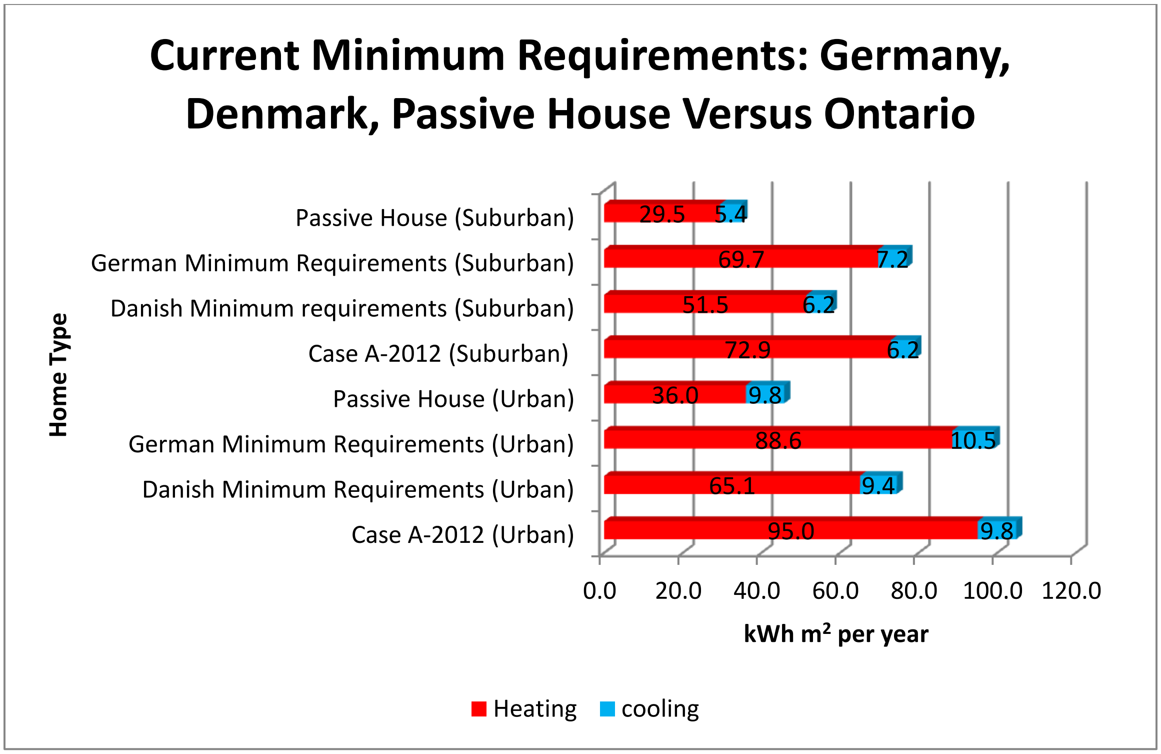

Figure 14: Current Regulation Minimum Requirements: Germany, Denmark, Passive House Versus Ontario

The minimum requirements (Figure 14), show slightly different results. In this case, combined heating and cooling (including auxiliary fans) combined in comparison to Case A- 2012 (Ontario), is the following:

- Suburban homes:
    - Passive House consumes 56 % less,
    - Denmark consumes 27 % less,
    - Germany consumes 3 % less.
- Urban homes:
    - Passive House 56 % less,
    - Denmark consumes 29 % less,
    - Germany consumes 5 % less.

Based on this information, the main observation derived is how the 2012 Ontario Building Code building envelope rates from a heating and cooling energy consumption perspective in comparison to energy efficient countries like Denmark, Germany and the

Passive House Standard. Both sets of results conclude that Ontario consumes more heating and cooling (combined) energy than Denmark and the Passive House Standard for both ‘typical’ and current regulation minimum requirements. However, when Ontario is compared against Germany, the current regulation minimum requirements are very similar, yet for ‘typical’ homes the Germans build on average to a higher level. Overall, improvements are still required in the low-rise, residential sector as far as the building envelope is concerned even though the 2012 Ontario homes have improved since 2006.

11.4 Final Thoughts:

In conclusion, Ontario now knows where it rates in terms of its building envelope in comparison to other world renowned energy efficient countries and standards on four separate levels. With that being said, the Ontario building envelope shows that it needs to be improved by:

- Increasing the insulation RSI,
- Reducing thermal bridges (heat loss) at connections (b,etter designs)
- Reducing ACH and performing blower door tests and
- Reducing windows U-values.

This can only occur if the Ontario low-rise, residential sector makes the following changes:

- Ontario Government increases the building envelope insulation levels and puts in place thermal bridging requirements for connections.
- Ontario Government creates an energy frame stating the maximum amount of energy that can be used for heating, cooling, domestic hot water, etc.
- Ontario home builders, construct homes that are beyond the Ontario Building Code Standards similar to Denmark, Germany and the Passive House.

Some other important points that can be taken away from this research are:

- Ontario homes Case A-2012 and Case B-2012 show minimal differences in heating and cooling energy consumption. This demonstrates that in order to reduce the impact of thermal bridging, a greater amount of exterior rigid insulation is required.
- The suburban/urban typology changes the base energy consumption, but changing the building envelope follows a linear pattern that is similar in both an urban/suburban context.
- The importance of the building envelope, as an imperative system within a home that requires a great detail of attention, as it has been proven to have an immense effect on a home's energy use.

Finally, as much as Ontario states that they are heavily invested in energy efficiency and conservation, this research finds otherwise (Ontario Ministry of Municpial Affairs and Housing 2012).

12 Further Research:

The research complete up to this point is a respectable beginning in seeing where Ontario rates in comparison to Denmark, Germany and the Passive House Standard. However, looking into the future, the following research can be conducted on this topic:

- More simulations with future codes and standards,
- Utilize other simulation program(s)
    - Each simulation program has benefits and drawbacks; some are better at solar heat gain, thermal mass, etc.
- Simulate more building envelope assemblies with different designs by having the support of the German, Danish and Canadian governments/institutions.
- Normalize results according to heating degree days.
- Use WUFI to simulate and see if there is a potential for condensation or mould problems in these building envelope assemblies in a Toronto climate.

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Appendices:

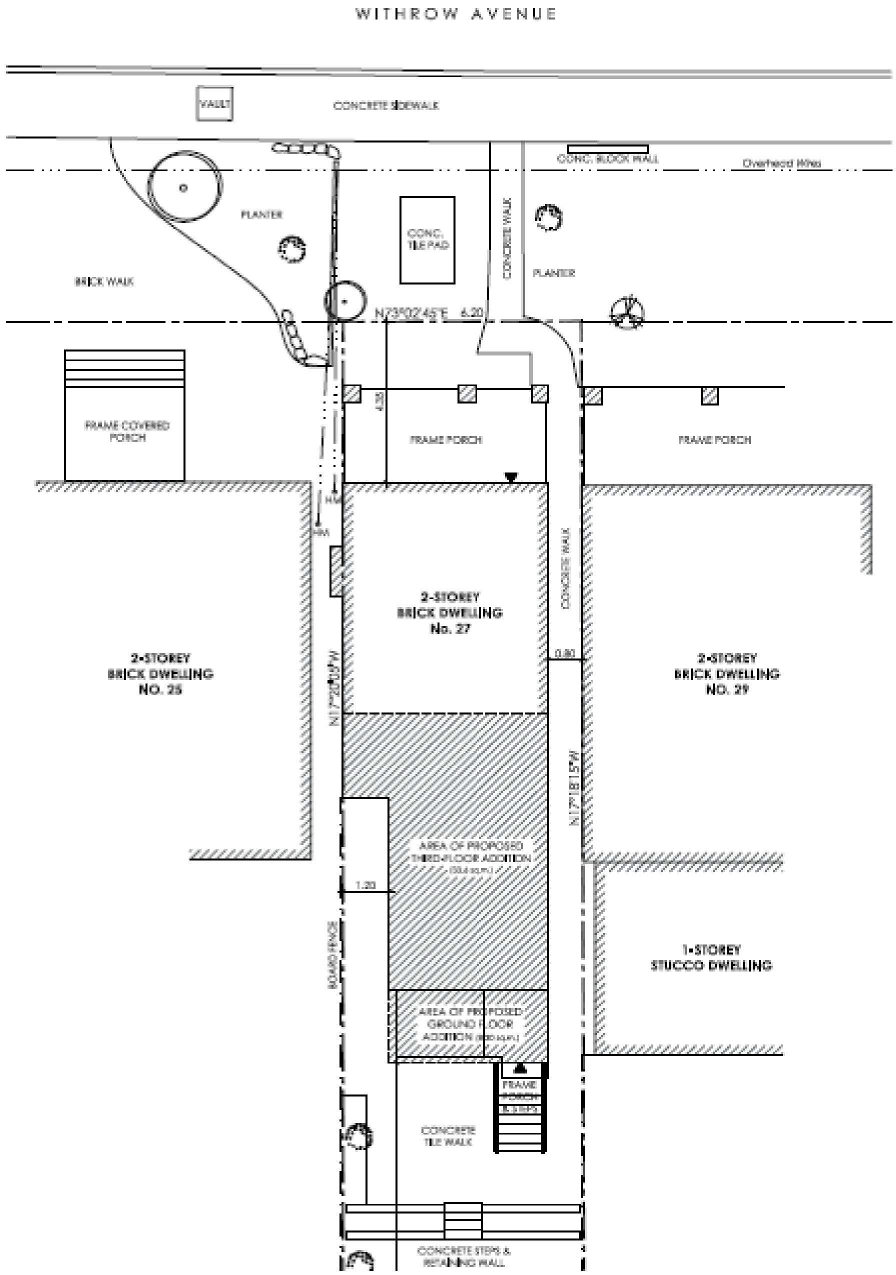
Appendix A- 2012 OBC Compliance Packages:

To view the Supplementary Standard 12 follow the link:
http://www.mah.gov.on.ca/Asset9372.aspx?method=1

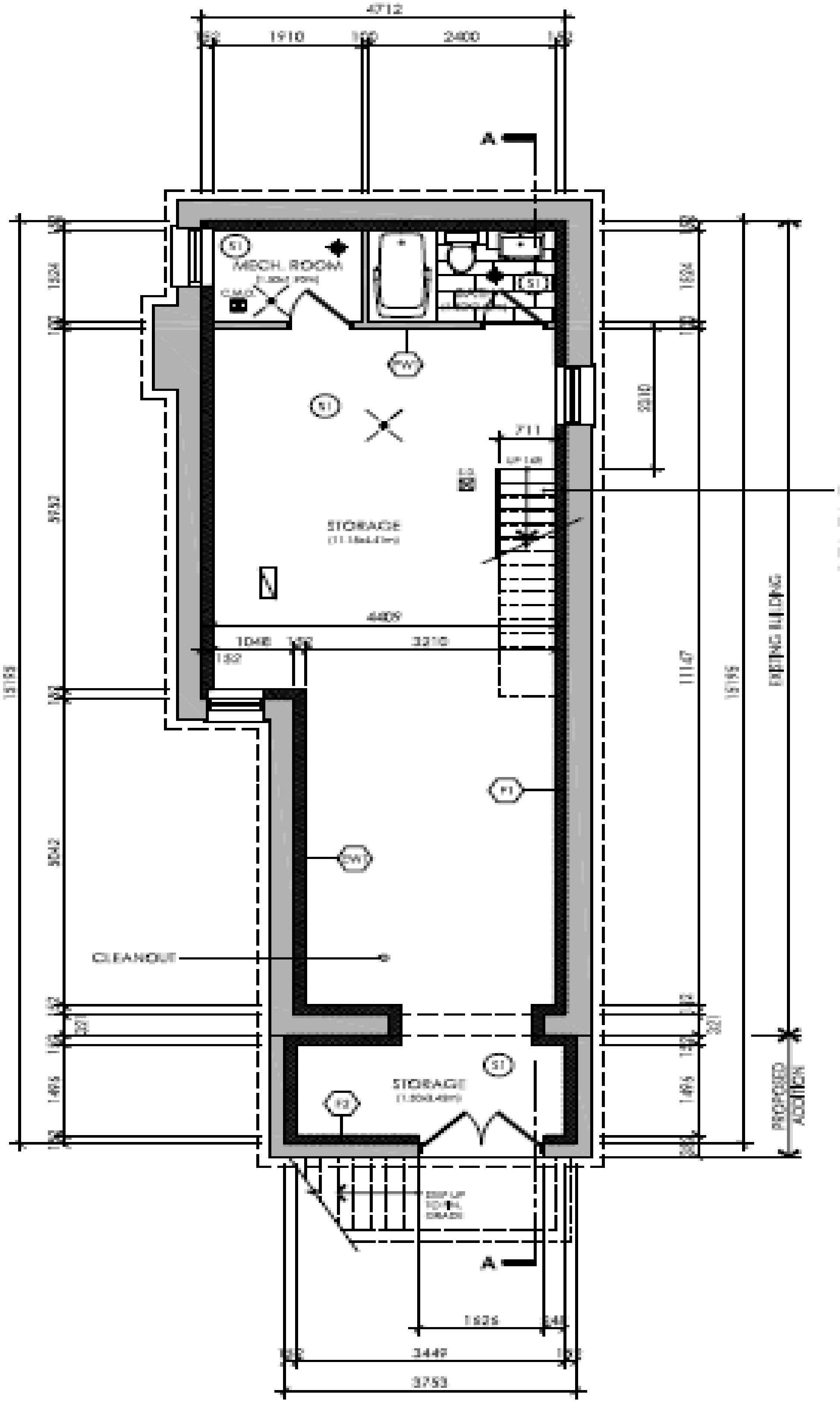
Appendix B- Building Plans & Specifications:

Urban Home (Russell Richman Consulting):

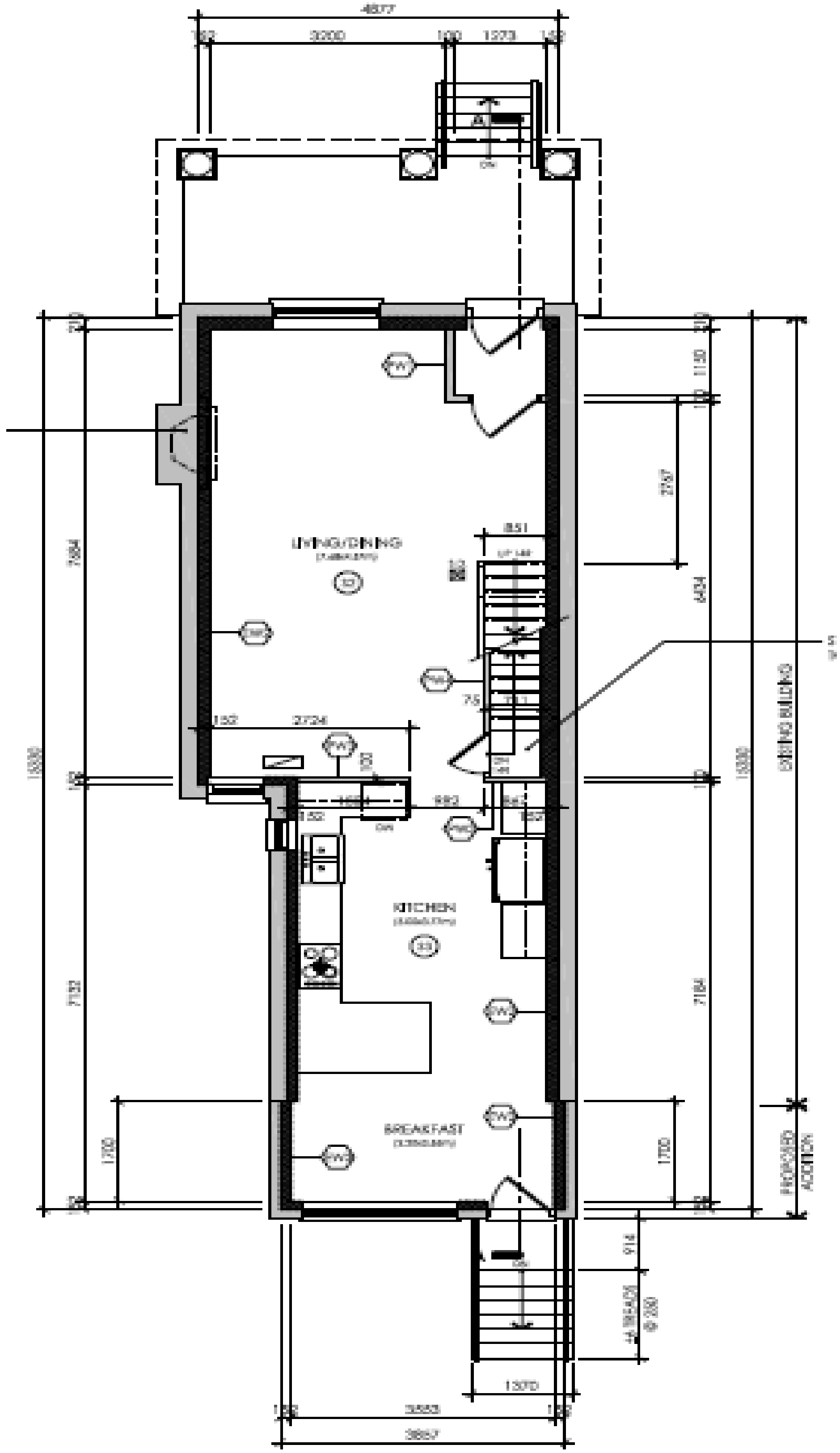
RUSSELL RICHMAN CONSULTING LIMITED					
Project: 27 WITHROW AVENUE, TORONTO				Project No.	No. C1
Subject: PROPOSED ADDITIONS	Drawn:	Checked:	Date: 4 MAR 2010	W.P. No.	Scale
APPLICANTS: RUSSELL RICHMAN AND CAROLYN MACDONALD				Reference	



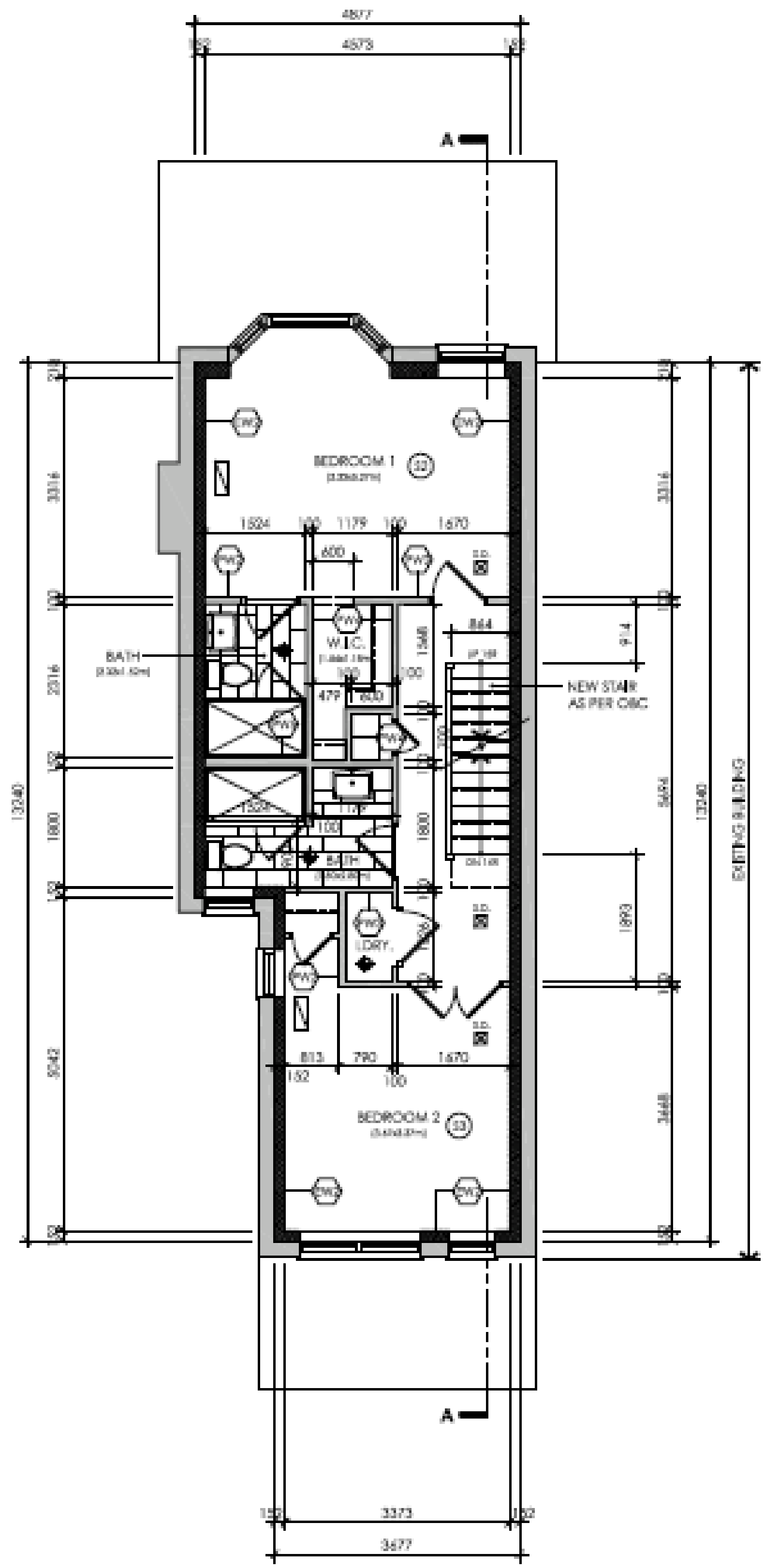
Site Plan


4712
1910
2400
MECH. ROOM
STORAGE
CLEANOUT
STORAGE
EXISTING BUILDING
PROPOSED ADDITION
1626
3449
3753

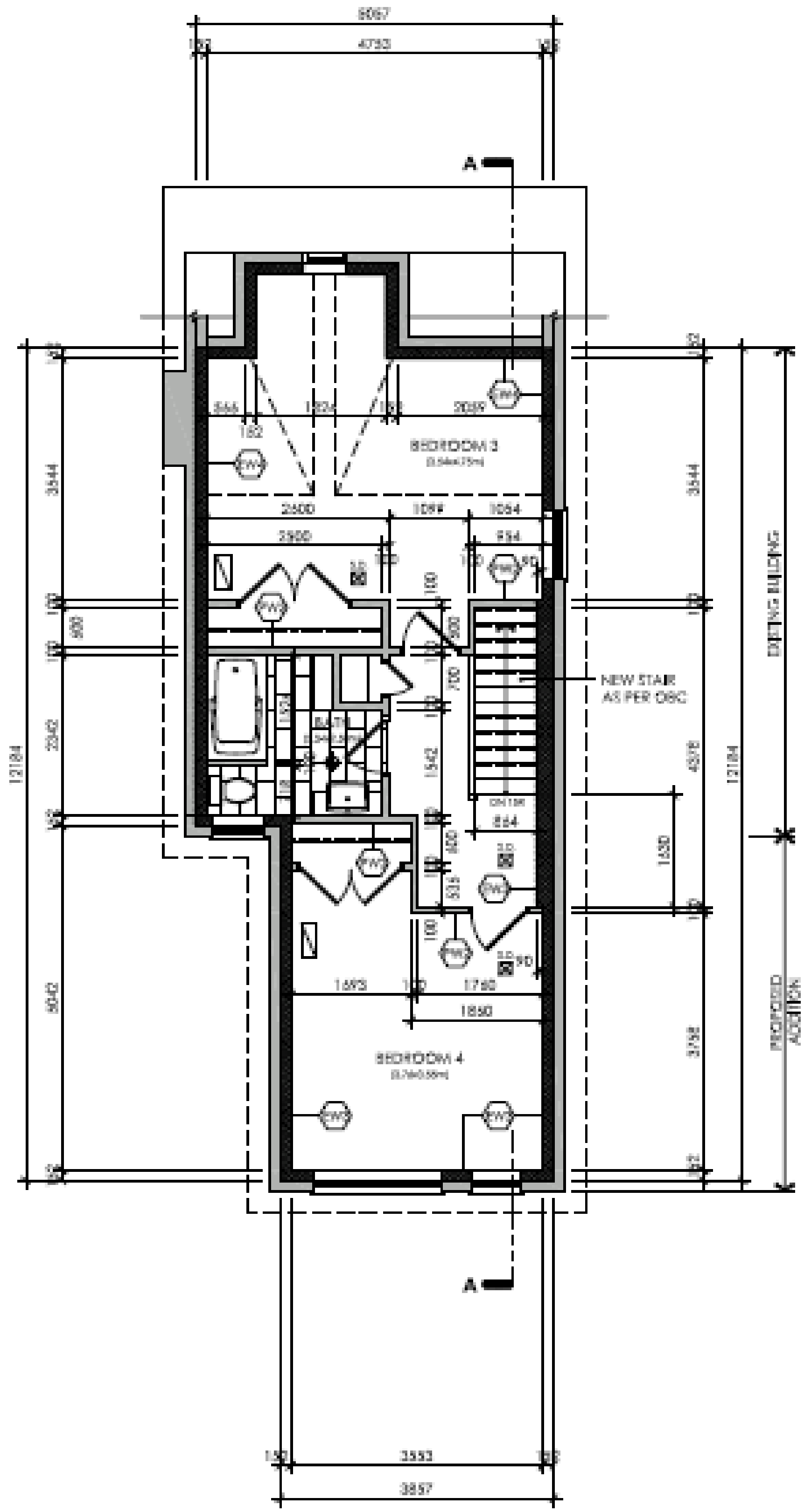
Basement



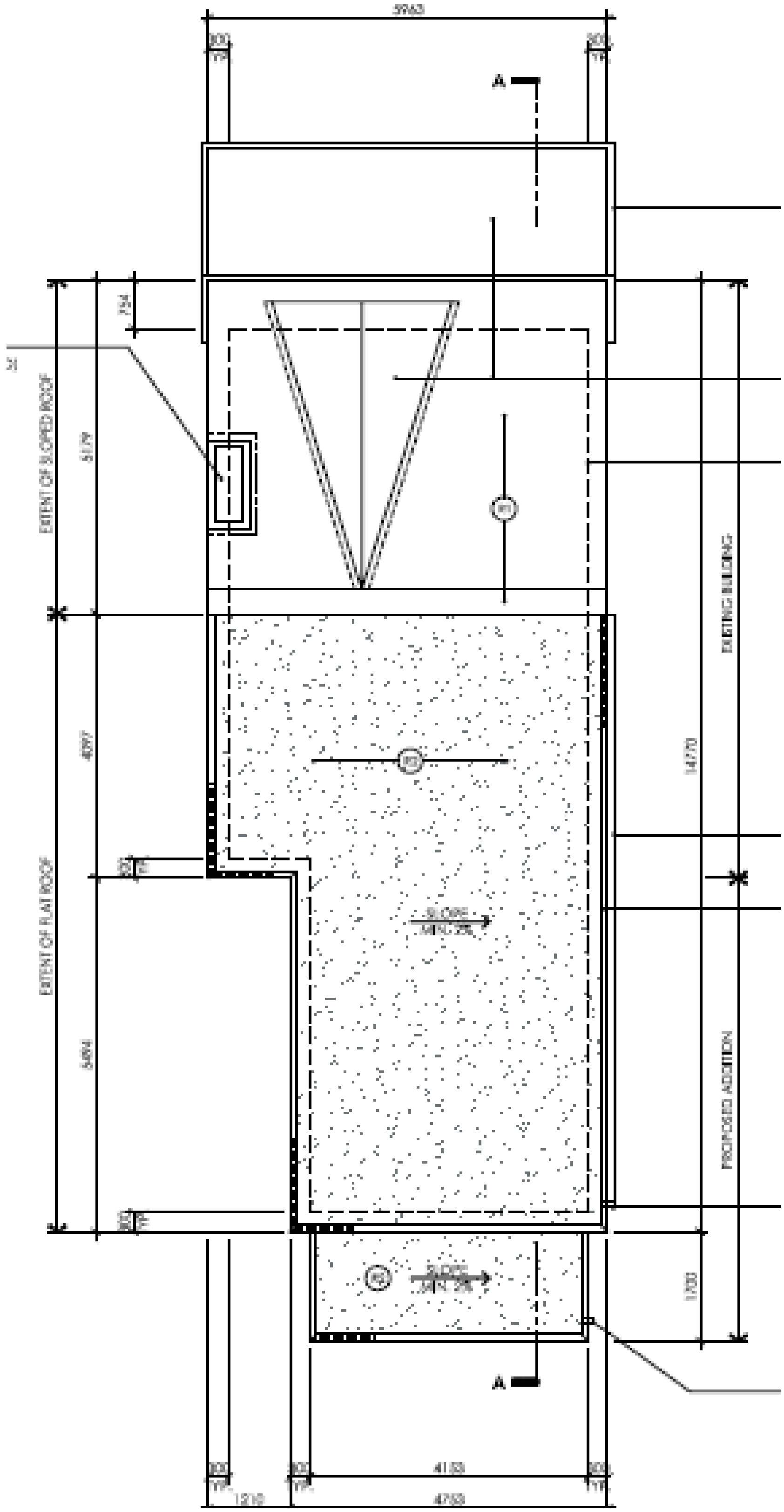
Ground Floor


BEDROOM 1
BEDROOM 2
BATH
W.I.C.
LDRY.
NEW STAIR
AS PER OBC
EXISTING BUILDING

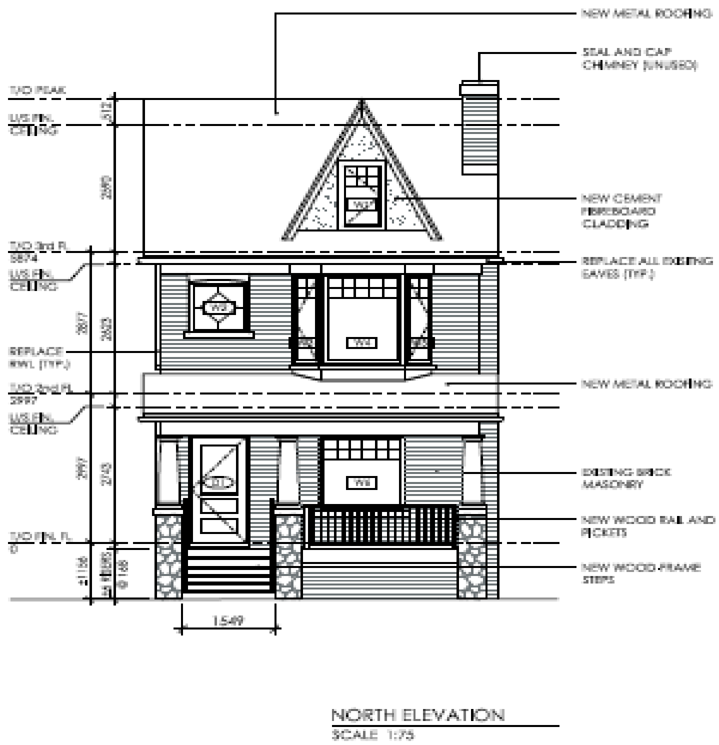
2nd Floor


BEDROOM 3
BATH
NEW STAIR
AS PER OBC
BEDROOM 4
EXISTING BUILDING
PROPOSED
ADDITION

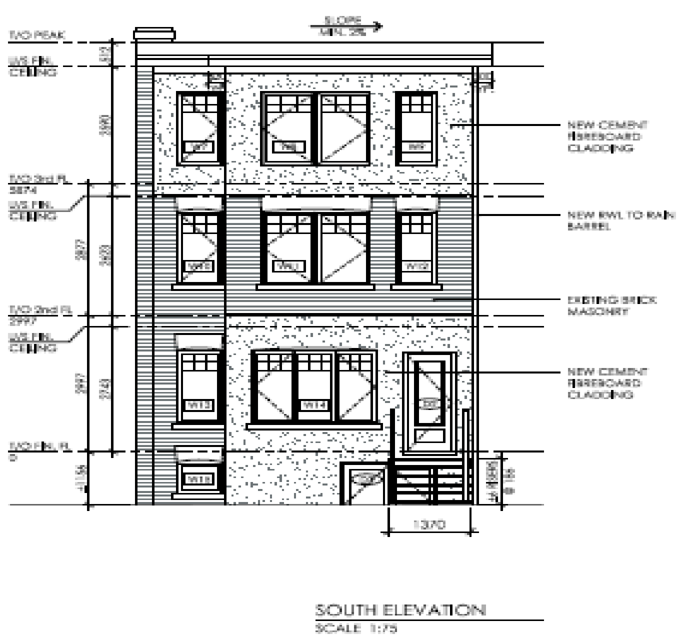
3rd Floor


5963
EXTENT OF SLOPED ROOF
EXTENT OF FLAT ROOF
EXISTING BUILDING
PROPOSED ADDITION
14770
SLOPE MIN. 2%
A
4153
4753

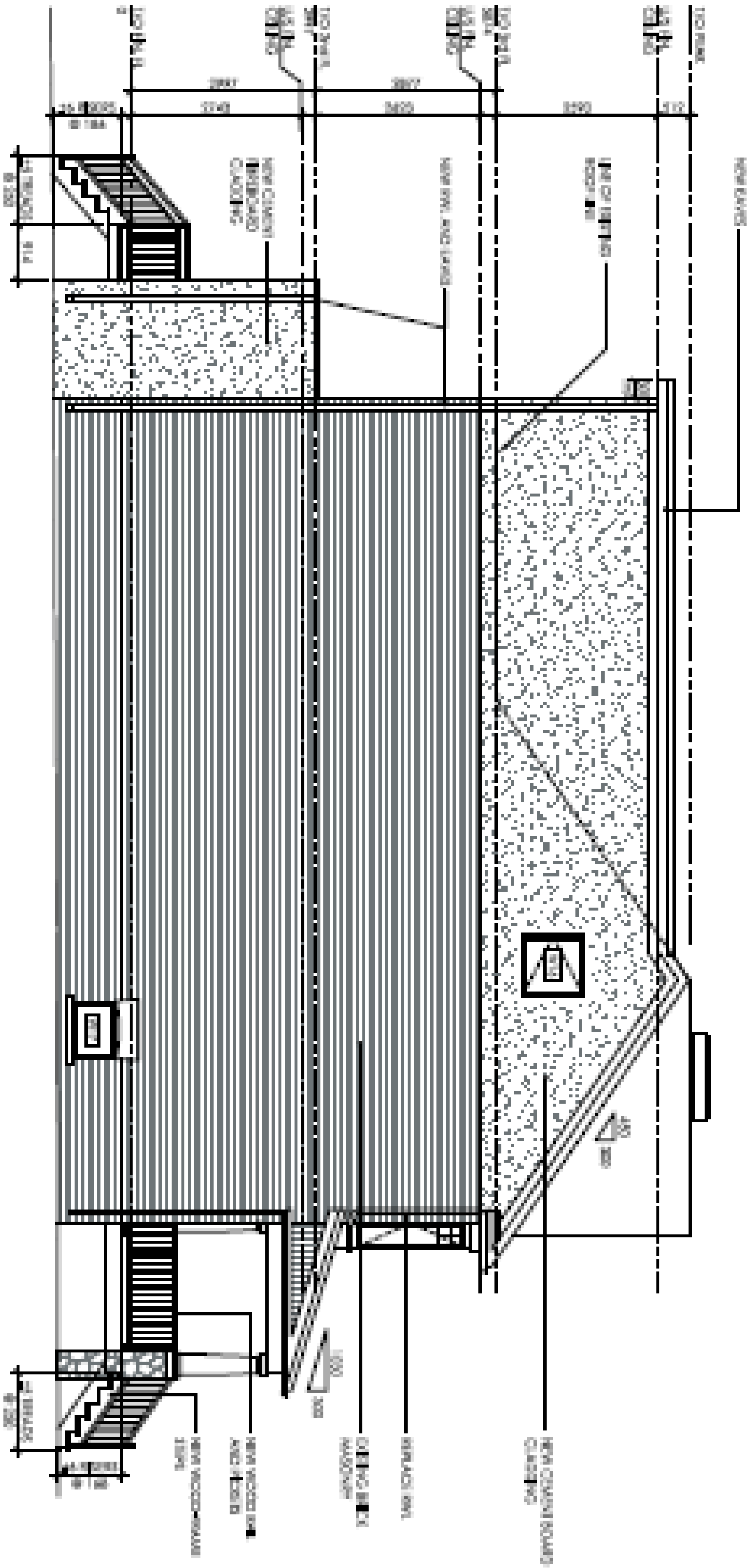
Roof Plan



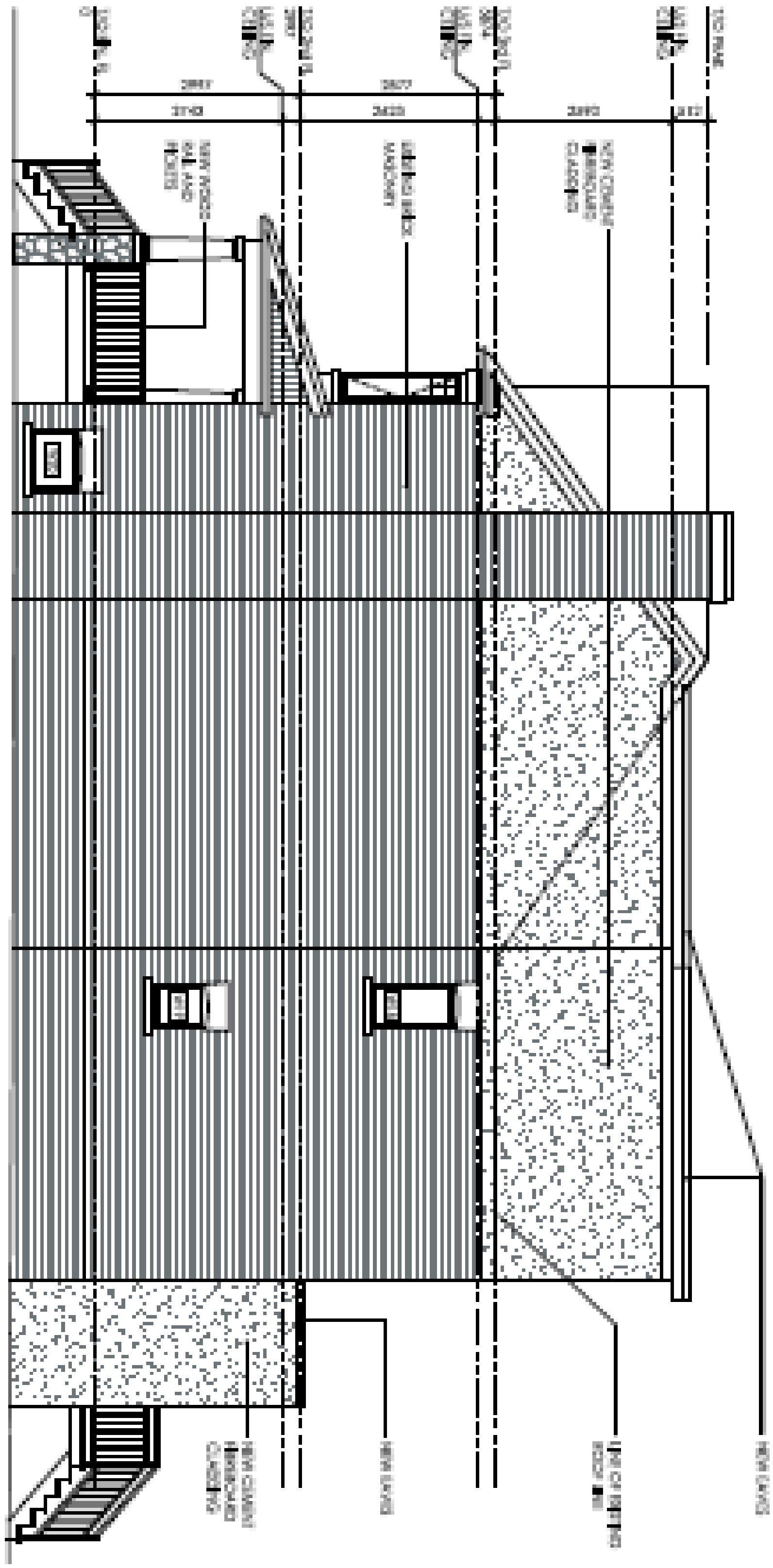
North Elevation



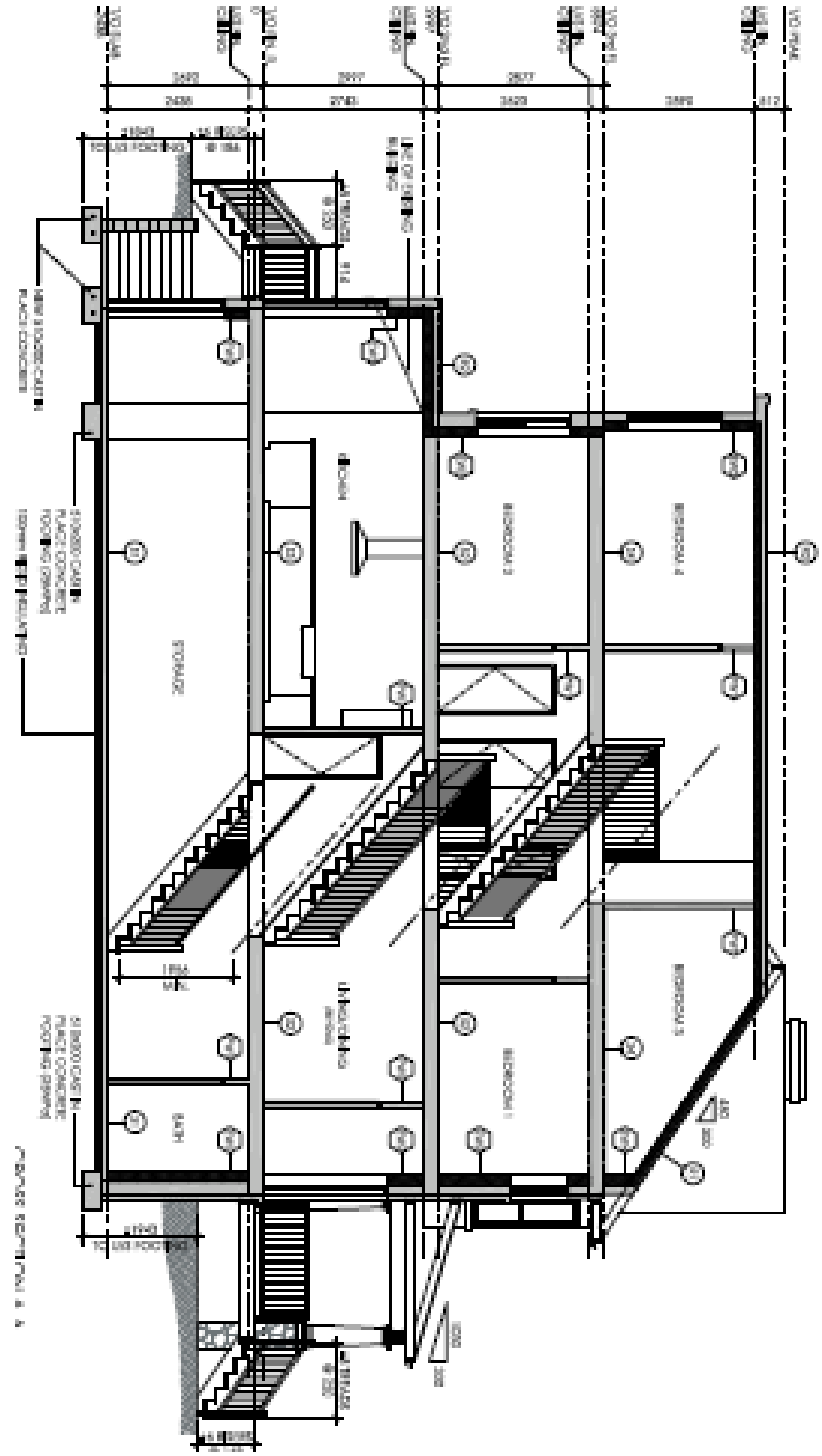
South Elevation



East Elevation

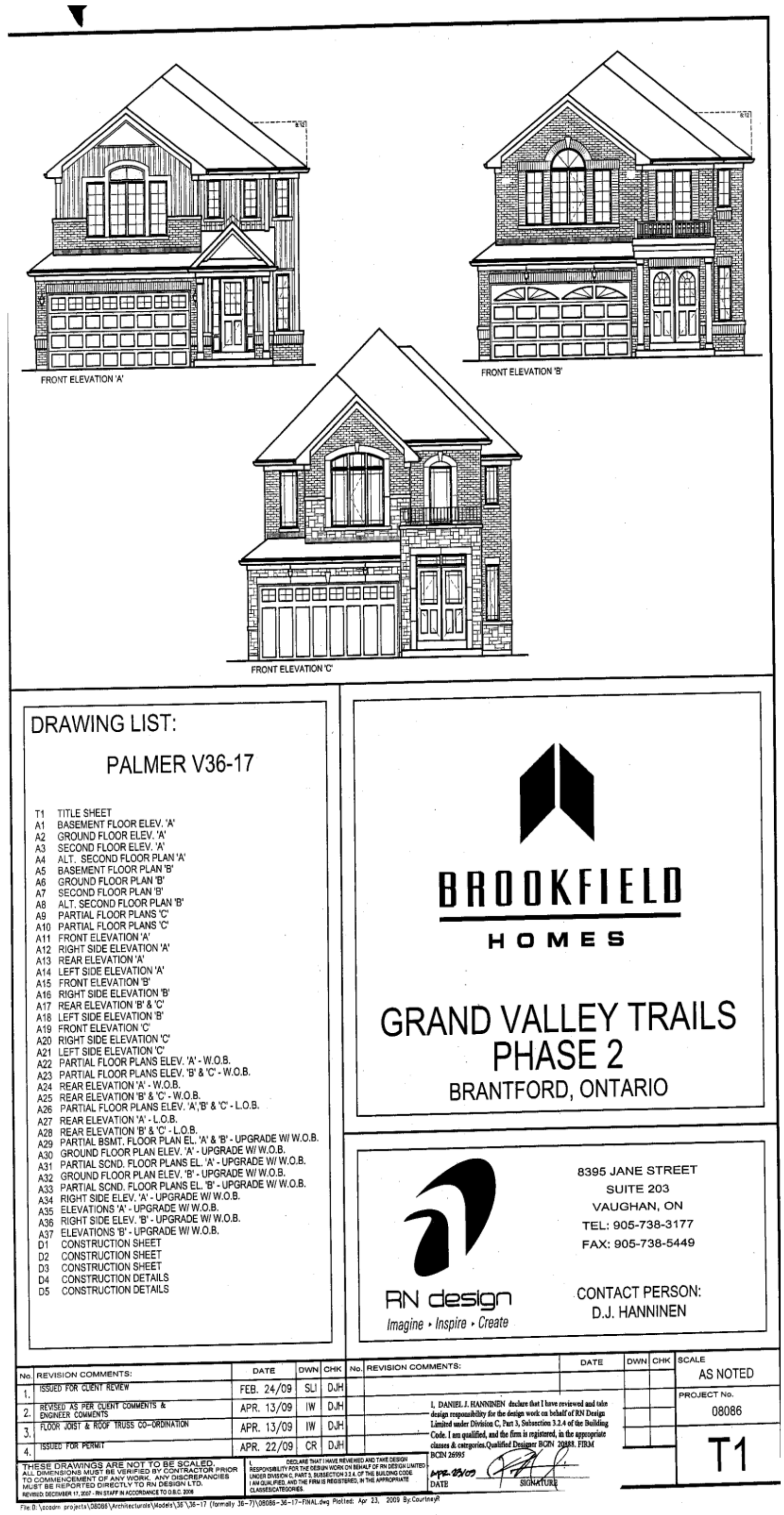


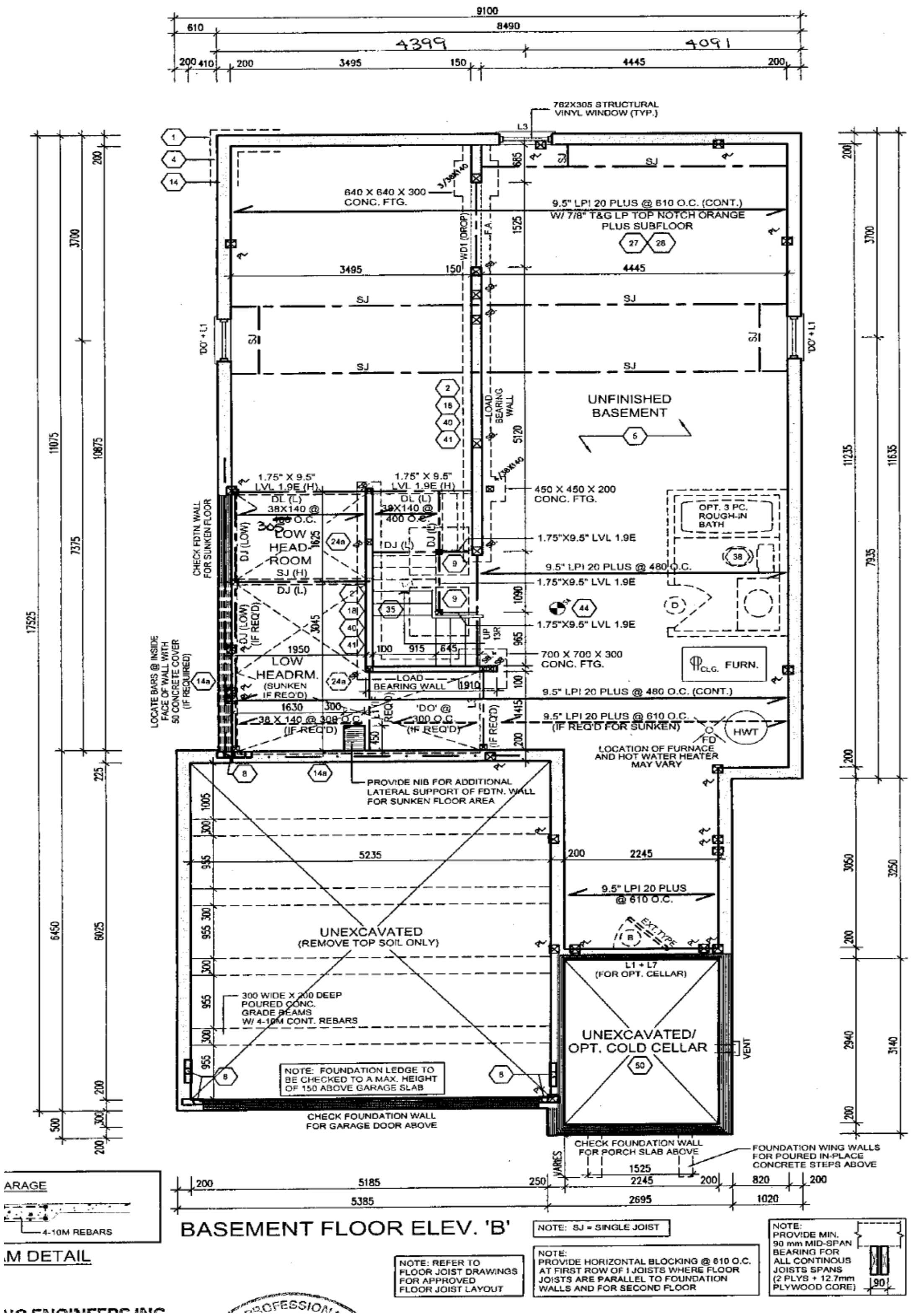
West Elevation

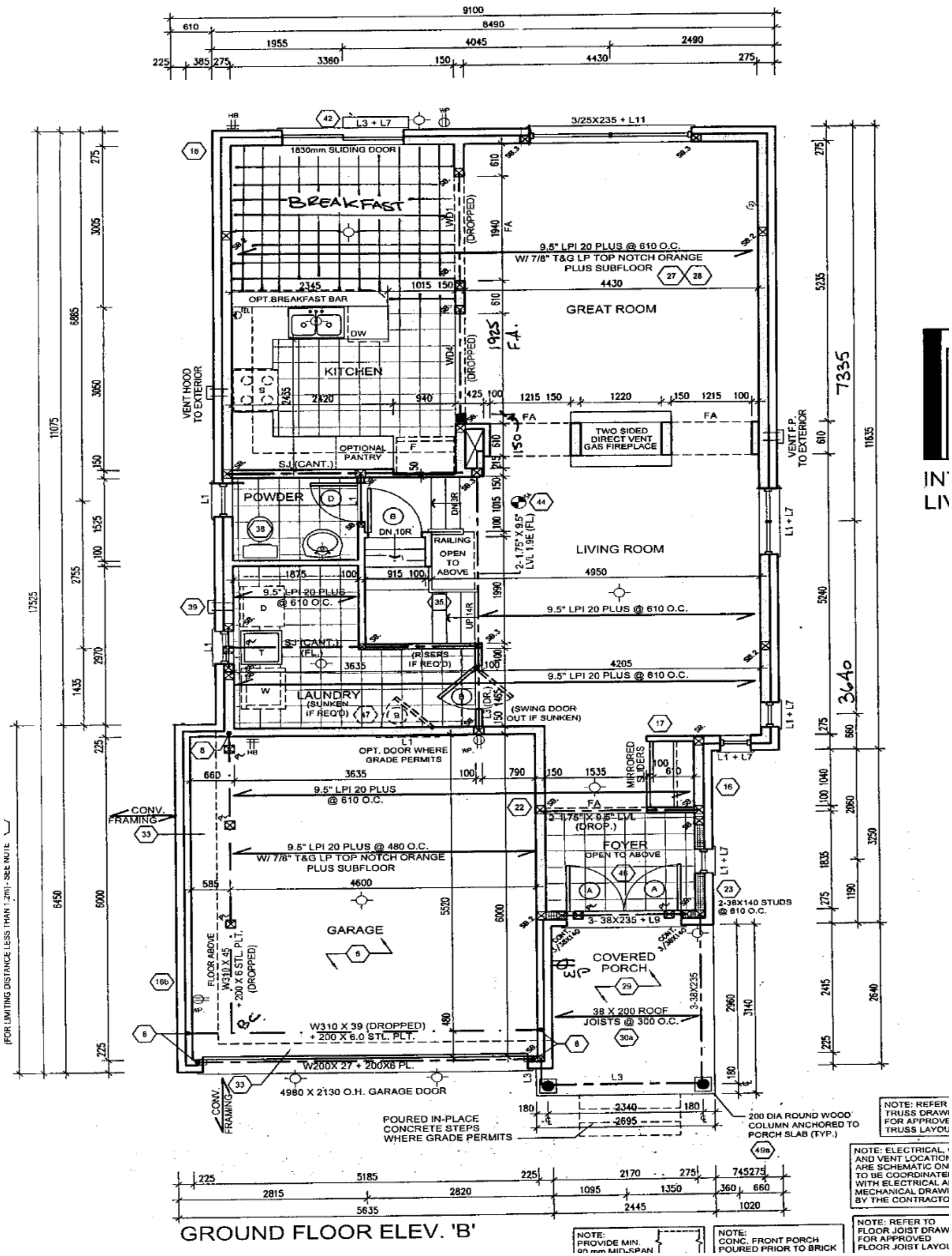


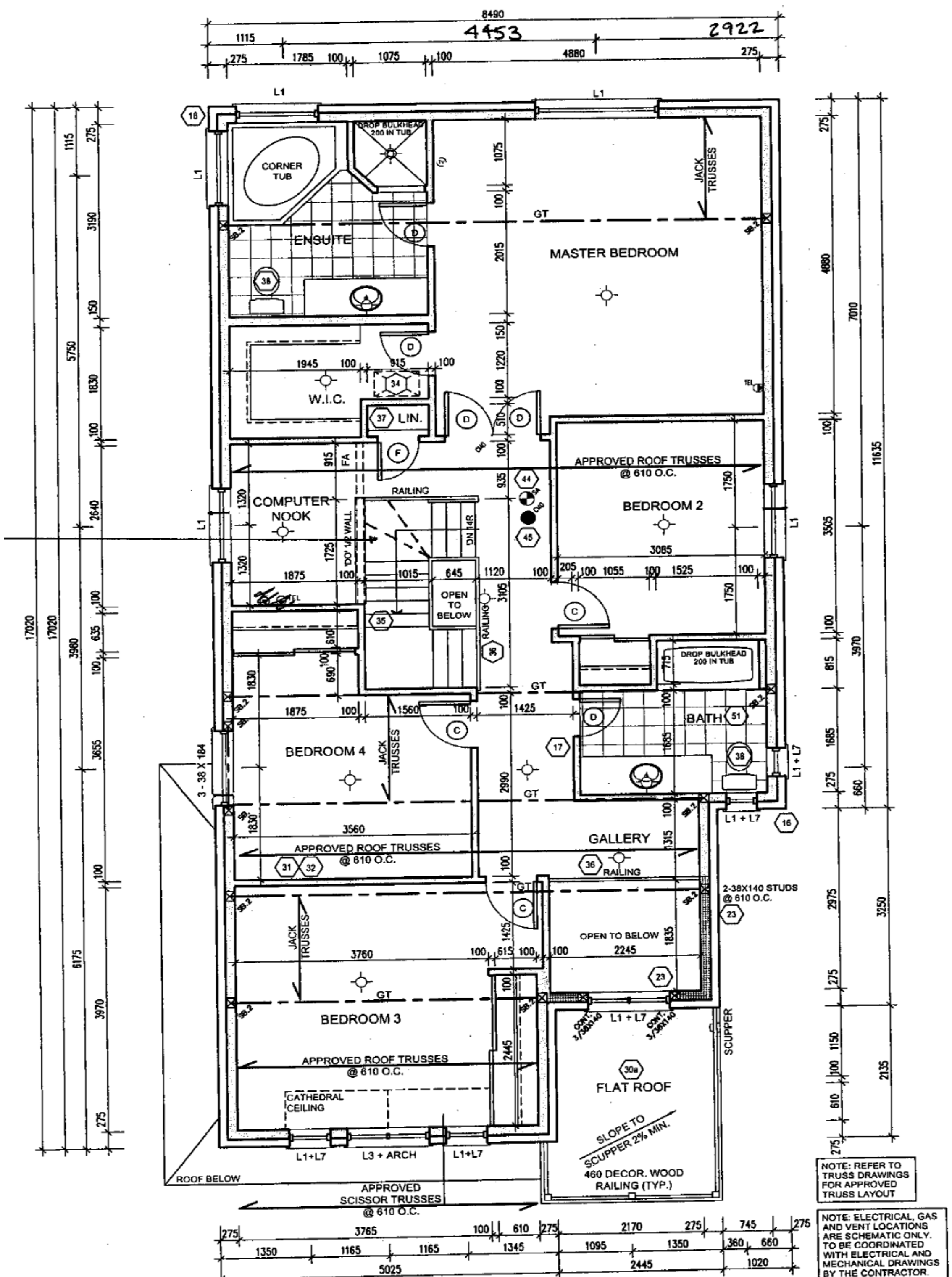
Cross Section

Suburban Home (Brookfield Homes):

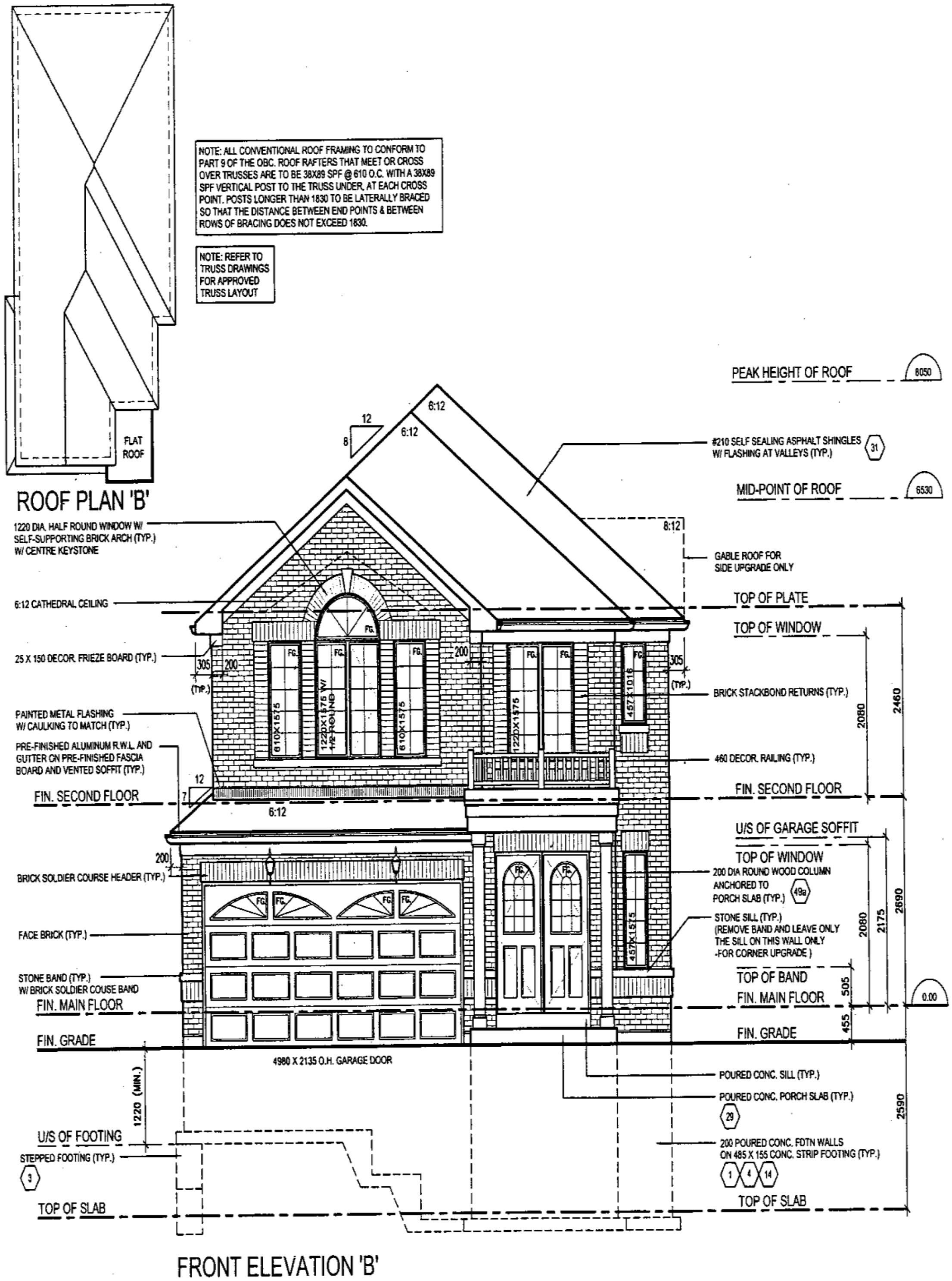


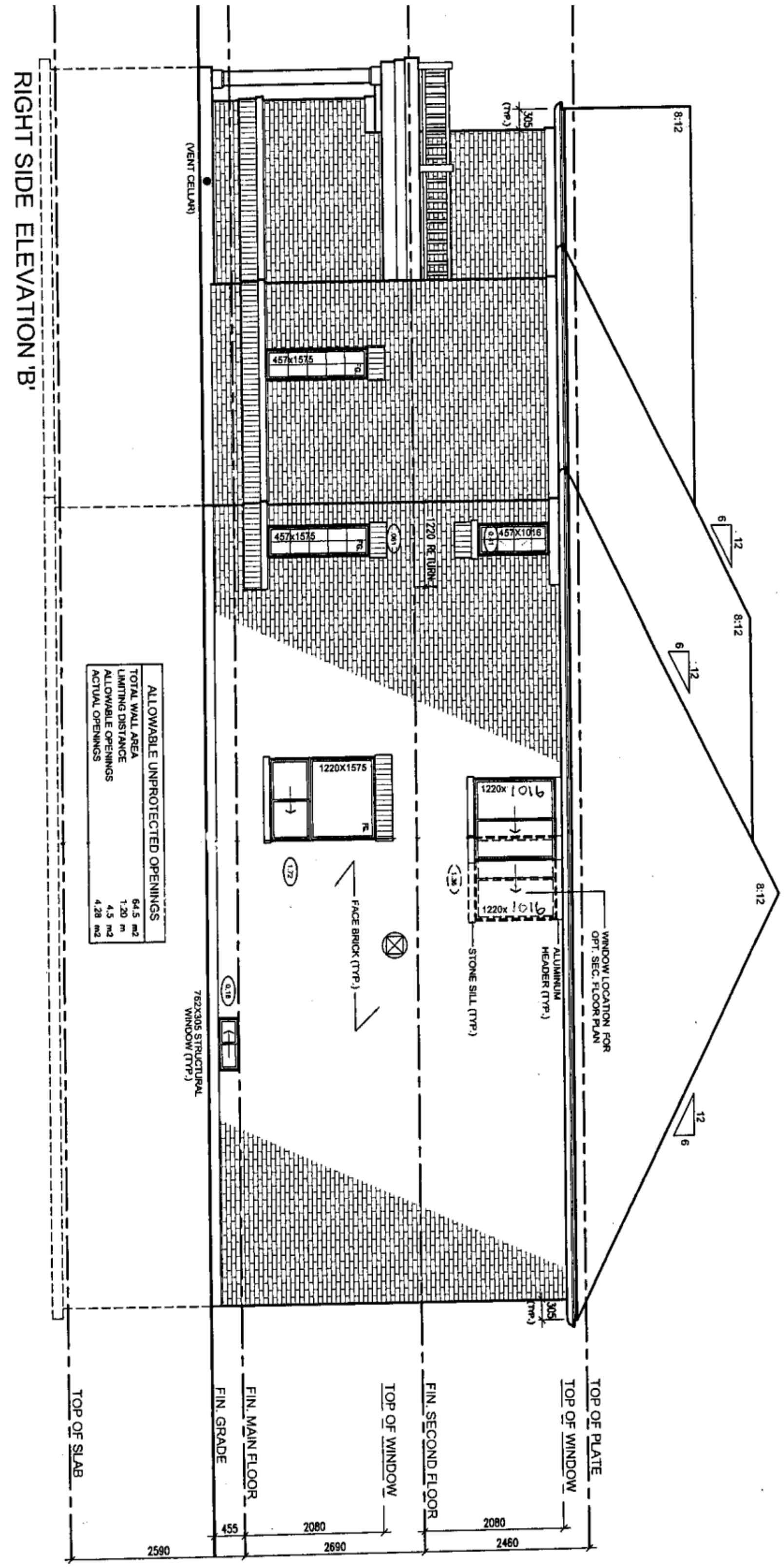

BASEMENT FLOOR ELEV. 'B'
NOTE: SJ = SINGLE JOIST
UNFINISHED BASEMENT
UNEXCAVATED (REMOVE TOP SOIL ONLY)
UNEXCAVATED/ OPT. COLD CELLAR
LOW HEAD-ROOM
LOW HEADRM. (SUNKEN IF REQ'D)
782X305 STRUCTURAL VINYL WINDOW (TYP.)
640 X 640 X 300 CONC. FTG.
9.5" LPI 20 PLUS @ 610 O.C. (CONT.) W/ 7/8" T&G LP TOP NOTCH ORANGE PLUS SUBFLOOR
450 X 450 X 200 CONC. FTG.
700 X 700 X 300 CONC. FTG.
1.75"X9.5" LVL 1.9E
9.5" LPI 20 PLUS @ 480 O.C.
9.5" LPI 20 PLUS @ 480 O.C. (CONT.)
9.5" LPI 20 PLUS @ 610 O.C. (IF REQ'D FOR SUNKEN)
OPT. 3 PC. ROUGH-IN BATH
FURN.
HWT
LOCATION OF FURNACE AND HOT WATER HEATER MAY VARY
PROVIDE NIB FOR ADDITIONAL LATERAL SUPPORT OF FDTN. WALL FOR SUNKEN FLOOR AREA
CHECK FDTN WALL FOR SUNKEN FLOOR
LOCATE BARS @ INSIDE FACE OF WALL WITH 50 CONCRETE COVER (IF REQUIRED)
LOAD BEARING WALL
9.5" LPI 20 PLUS @ 610 O.C.
L1 + L7 (FOR OPT. CELLAR)
300 WIDE X 200 DEEP POURED CONC. GRADE BEAMS W/ 4-10M CONT. REBARS
NOTE: FOUNDATION LEDGE TO BE CHECKED TO A MAX. HEIGHT OF 150 ABOVE GARAGE SLAB
CHECK FOUNDATION WALL FOR GARAGE DOOR ABOVE
CHECK FOUNDATION WALL FOR PORCH SLAB ABOVE
FOUNDATION WING WALLS FOR POURED IN-PLACE CONCRETE STEPS ABOVE
VENT
NOTE: REFER TO FLOOR JOIST DRAWINGS FOR APPROVED FLOOR JOIST LAYOUT
NOTE: PROVIDE HORIZONTAL BLOCKING @ 610 O.C. AT FIRST ROW OF I JOISTS WHERE FLOOR JOISTS ARE PARALLEL TO FOUNDATION WALLS AND FOR SECOND FLOOR
NOTE: PROVIDE MIN. 90 mm MID-SPAN BEARING FOR ALL CONTINOUS JOISTS SPANS (2 PLYS + 12.7mm PLYWOOD CORE)
ARAGE
4-10M REBARS
M DETAIL
9100
8490
4399
4091
5235
5185
5385
2695

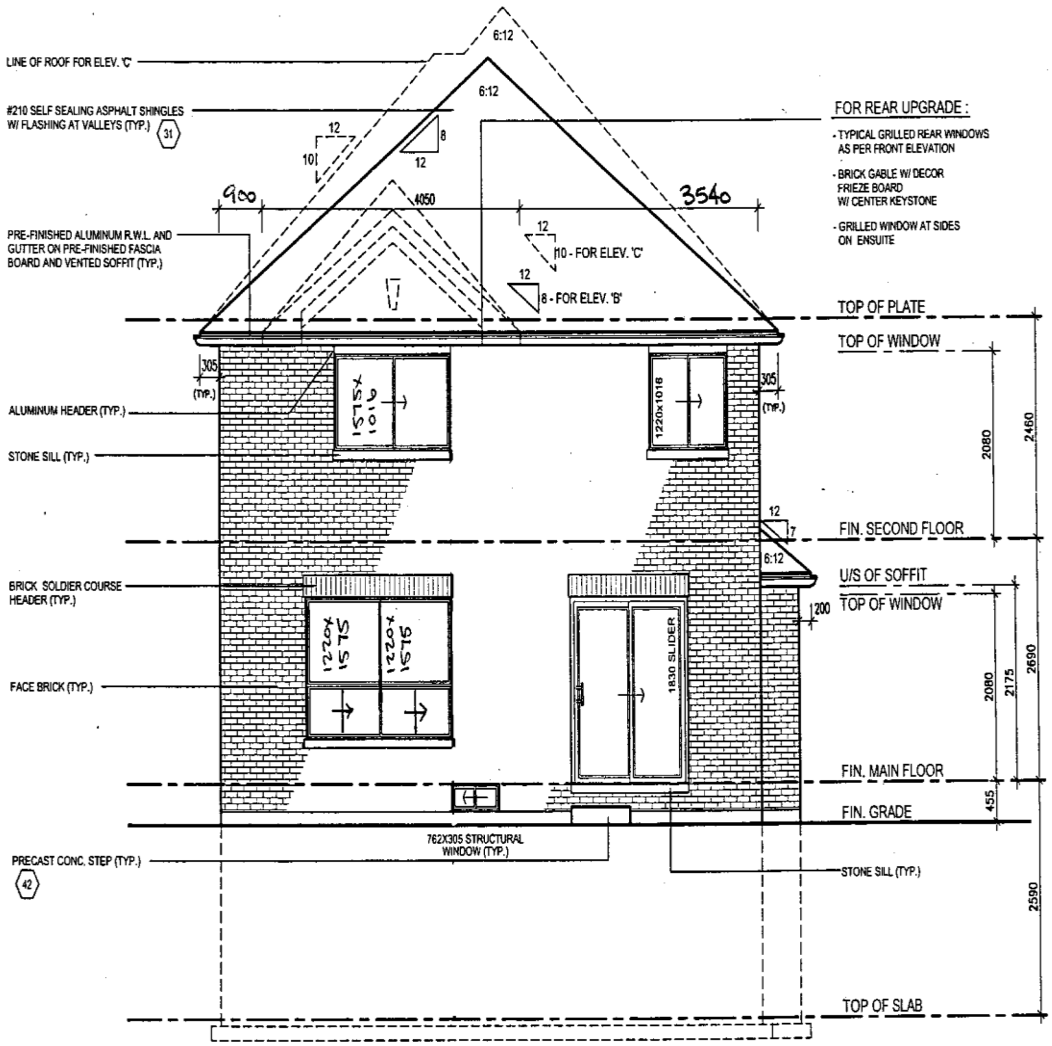

BREAKFAST
1830mm SLIDING DOOR
OPT.BREAKFAST BAR
KITCHEN
OPTIONAL PANTRY
GREAT ROOM
TWO SIDED DIRECT VENT GAS FIREPLACE
9.5" LPI 20 PLUS @ 610 O.C. W/ 7/8" T&G LP TOP NOTCH ORANGE PLUS SUBFLOOR
POWDER
LIVING ROOM
OPEN TO ABOVE
LAUNDRY (SUNKEN IF REQ'D)
FOYER OPEN TO ABOVE
GARAGE
COVERED PORCH
4980 X 2130 O.H. GARAGE DOOR
POURED IN-PLACE CONCRETE STEPS WHERE GRADE PERMITS
200 DIA ROUND WOOD COLUMN ANCHORED TO PORCH SLAB (TYP.)
VENT HOOD TO EXTERIOR
VENT F.P. TO EXTERIOR
GROUND FLOOR ELEV. 'B'



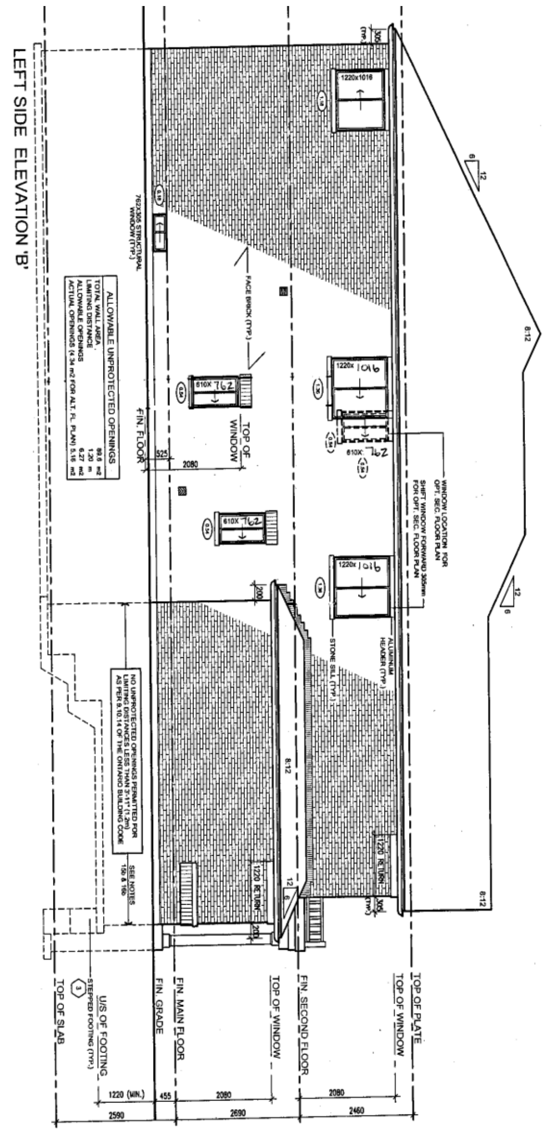
SECOND FLOOR ELEV. 'B'


NOTE: ALL CONVENTIONAL ROOF FRAMING TO CONFORM TO PART 9 OF THE OBC. ROOF RAFTERS THAT MEET OR CROSS OVER TRUSSES ARE TO BE 38X89 SPF @ 610 O.C. WITH A 38X89 SPF VERTICAL POST TO THE TRUSS UNDER, AT EACH CROSS POINT. POSTS LONGER THAN 1830 TO BE LATERALLY BRACED SO THAT THE DISTANCE BETWEEN END POINTS & BETWEEN ROWS OF BRACING DOES NOT EXCEED 1830.
NOTE: REFER TO TRUSS DRAWINGS FOR APPROVED TRUSS LAYOUT
FLAT ROOF
ROOF PLAN 'B'
PEAK HEIGHT OF ROOF 8050
#210 SELF SEALING ASPHALT SHINGLES W/ FLASHING AT VALLEYS (TYP.)
MID-POINT OF ROOF 6530
1220 DIA. HALF ROUND WINDOW W/ SELF-SUPPORTING BRICK ARCH (TYP.) W/ CENTRE KEYSTONE
GABLE ROOF FOR SIDE UPGRADE ONLY
6:12 CATHEDRAL CEILING
TOP OF PLATE
TOP OF WINDOW
25 X 150 DECOR. FRIEZE BOARD (TYP.)
BRICK STACKBOND RETURNS (TYP.)
PAINTED METAL FLASHING W/ CAULKING TO MATCH (TYP.)
PRE-FINISHED ALUMINUM R.W.L. AND GUTTER ON PRE-FINISHED FASCIA BOARD AND VENTED SOFFIT (TYP.)
460 DECOR. RAILING (TYP.)
FIN. SECOND FLOOR
U/S OF GARAGE SOFFIT
BRICK SOLDIER COURSE HEADER (TYP.)
200 DIA ROUND WOOD COLUMN ANCHORED TO PORCH SLAB (TYP.)
FACE BRICK (TYP.)
STONE SILL (TYP.) (REMOVE BAND AND LEAVE ONLY THE SILL ON THIS WALL ONLY -FOR CORNER UPGRADE)
STONE BAND (TYP.) W/ BRICK SOLDIER COUSE BAND
TOP OF BAND
FIN. MAIN FLOOR
FIN. GRADE
4980 X 2135 O.H. GARAGE DOOR
POURED CONC. SILL (TYP.)
POURED CONC. PORCH SLAB (TYP.)
U/S OF FOOTING
STEPPED FOOTING (TYP.)
200 POURED CONC. FDTN WALLS ON 485 X 155 CONC. STRIP FOOTING (TYP.)
TOP OF SLAB
FRONT ELEVATION 'B'


RIGHT SIDE ELEVATION 'B'
ALLOWABLE UNPROTECTED OPENINGS
TOTAL WALL AREA 64.5 m2
LIMITING DISTANCE 1.20 m
ALLOWABLE OPENINGS 4.5 m2
ACTUAL OPENINGS 4.28 m2
TOP OF PLATE
TOP OF WINDOW
FIN. SECOND FLOOR
TOP OF WINDOW
FIN. MAIN FLOOR
FIN. GRADE
TOP OF SLAB
WINDOW LOCATION FOR OPT. SEC. FLOOR PLAN
ALUMINUM HEADER (TYP.)
STONE SILL (TYP.)
FACE BRICK (TYP.)
762X305 STRUCTURAL WINDOW (TYP.)
(VENT CELLAR)
1220 RETURN
457x1575
457X1016
1220X1575
8:12
2590
455
2080
2690
2460



REAR ELEVATION 'B' & 'C'


LEFT SIDE ELEVATION 'B'
ALLOWABLE UNPROTECTED OPENINGS
FIN. FLOOR
TOP OF WINDOW
TOP OF PLATE
TOP OF WINDOW
FIN. SECOND FLOOR
TOP OF WINDOW
FIN. MAIN FLOOR
FIN. GRADE
U/S OF FOOTING
TOP OF SLAB
2590
2690
2460
2080
2080
1220 (MIN.)
455

Appendix C- HVAC Equipment Specifications:

24ABB3 Air Conditioner-
http://www.gmair121.ca/pdfs/24ABB3.pdf

58MCB Gas Furnace-
http://www.airmakers.ca/carrier_gas_furnace_base_90_58mcb_product_data.pdf

59SC5A Gas Furnace-
http://www.docs.hvacpartners.com/idc/groups/public/documents/techlit/59sc5a-01pd.pdf

Hot Water Tank-
http://www.giantinc.com/tech-data/FT-UG40ATM-An.pdf
http://www.giantinc.com/tech-data/manual_residential_pv1_FVIR_gas.pdf

Heat Recovery Ventilator-
http://www.vanee.ca/literature/install/60H.pdf
http://www.vanee.ca/literature-v2/specs/60H_HRV-spec-2011-10-07.pdf

Ventilation Equipment (Bathroom Fans, Range Hood, Whole Home ventilation System)-
http://hvi.org/proddirectory/HVICPD_CvrPgs_1Aug2012.pdf

Appendix D- Energuide Calculation:

Energuide Rating= 100 – (Estimated Total Energy Consumption/ Benchmark Total Energy Consumption)*20

Estimated Total Energy Consumption

Estimated Total Energy Consumption= S +O

S= Space Heating Consumption
O= Occupancy Consumption

Space Heating Consumption= (SE x BSE + SF +BSF)

SE= Estimated space-heating electrical energy consumption including fans (in MJ)
BSE= Base efficiency for electrical space heating= 100 percent
SF= Estimated fossil- energy consumption for space (in MJ)
BSF=base efficient for fossil-fuel space heating = 80 percent AFUE

Occupancy Consumption (O) = D+L

D= Estimated domestic hot water consumption
L= Appliance energy consumption= 31 536 per year
D= 1.136 x (DE x BDE + DF x BDF)

DE= estimated domestic hot water electrical energy consumption (in MJ)
BDE= base efficiency for electrical domestic hot water, energy factor (EF)= 0.88
DF= estimated domestic hot water fossil-fuel energy consumption (in MJ)
BDF= base efficiency for fossil- fuel domestic hot water, EF= 0.57
1.136= Factor needed to adjust the domestic hot water load to represent its share of total consumption, including standby losses

Benchmark Total Energy Consumption

Benchmark Total energy Consumption= space heating benchmark + domestic hot water benchmark + base load benchmark

Space heating benchmark= S x (49 x DD/6000) X (40 + V/2.5)

S= 4.5 MJ for fuel fired space heating systems or 1.0 kWh (3.6 MJ) for electrical space heating system
DD= Number of long-term average degree-days relative to a base of 18 ^{0}C
V= the heated volume (in m^3) of home

Domestic hot water benchmark

Domestic hot water benchmark= 4745 x W x (55-TW/ 55-9.5)

W= 1.72 kWh or 6.19 MJ, for fuel-fired DHW systems or 1.075 kWh or 3.87, for electric DHW systems
TW= local water mains or deep-soil temperature in degrees Celsius

Base load Benchmark= 31 536 MJ per year (based on 24 kWh per day)

Appendix E- HOT2000 Calculation Example:

HOT2000
Natural Resources CANADA
Version 10.51

File: **2012 OBC with 2x4 walls using builders spacing (suburban)**
Application Type: General

Weather Library: C:\H2KV10~1\Dat\Wth100.dir

Weather Data for TORONTO, ONTARIO

Builder Code:

Data Entry by:	Blaine Attwood
Date of entry:	12/14/2011
Company:	

Client name:	,
Street address:	

City:	**Region:**	Ontario
Postal code:	**Telephone:**	

GENERAL HOUSE CHARACTERISTICS

House type:	Single Detached	
Number of storeys:	Two storeys	
Plan shape:	Other, 7-8 corners	
Front orientation:	South	
Year House Built:	2012	
Wall colour:	Default	**Absorptivity:**0.40
Roof colour:	Medium brown	**Absorptivity:**0.84
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
2 Children for 50.0% of the time
0 Infants for 0.0% of the time

Sensible Internal Heat Gain From Occupants: 2.40 kWh/day

HOUSE TEMPERATURES

Heating Temperatures

Main Floor:	21.0 °C
Basement:	19.0 °C
TEMP. Rise from 21.0 °C:	2.8 °C
Cooling Temperature: Main Floor + Basement:	21.00 °C

Basement is- Heated: YES **Cooled:** YES **Separate T/S:** NO
Fraction of internal gains released in basement : 0.150

Indoor design temperatures for equipment sizing

Heating: 22.0 °C

Cooling: 24.0 °C

WINDOW CHARACTERISTICS

Label	Location	#	Overhang Width (m)	Header Height (m)	Tilt deg	Curtain Factor	Shutter (RSI)
South							
1220x1575 2nd S	Second level	1	0.30	0.38	90.0	1.00	0.00
1220x1575 2nd S	Second level	1	0.30	0.38	90.0	1.00	0.00
457x1016 2nd S	Second level	1	0.30	0.38	90.0	1.00	0.00
457x1575 1st S	Main floor	1	0.00	0.00	90.0	1.00	0.00
610x1575 2nd S	Second level	1	0.30	0.38	90.0	1.00	0.00
610x1575 2nd S	Second level	1	0.30	0.38	90.0	1.00	0.00
East							

1220x1016 2nd E	Second level	1	0.30	0.38	90.0	1.00	0.00
1220x1575 1st E	Main floor	1	0.00	0.00	90.0	1.00	0.00
457x1016 2nd E	Second level	1	0.30	0.38	90.0	1.00	0.00
457x1575 1st E	Main floor	2	0.00	0.00	90.0	1.00	0.00
East 762x305	Foundation - 1	1	0.00	0.00	90.0	1.00	0.00
North							
1220x1016 2nd N	Second level	1	0.30	0.38	90.0	1.00	0.00
1220x1575 1st N	Main floor	2	0.00	0.00	90.0	1.00	0.00
1575x1016 2nd N	Second level	1	0.30	0.38	90.0	1.00	0.00
North762x305	Foundation - 1	1	0.00	0.00	90.0	1.00	0.00
Sliding Door	Main floor	1	0.00	0.00	90.0	1.00	0.00
West							
1220x1016 2nd W	Second level	3	0.30	0.38	90.0	1.00	0.00
610x762 1st W	Main floor	1	0.00	0.00	90.0	1.00	0.00
610x762 1st W	Main floor	1	0.00	0.00	90.0	1.00	0.00
West 726x305	Foundation - 1	1	0.00	0.00	90.0	1.00	0.00

Label	**Type**	**#**	**Window Width (m)**	**Window Height (m)**	**Total Area (m^2)**	**Window RSI**	**SHGC**
South							
1220x1575 2nd S	1220x1575 1/2 round	1	1.22	2.00	2.44	0.544	0.4174
1220x1575 2nd S	picture window V3	1	1.22	1.58	1.92	0.571	0.4465
457x1016 2nd S	Hinged	1	0.46	1.02	0.46	0.566	0.3560
457x1575 1st S	Picture window	1	0.46	1.58	0.72	0.585	0.3659
610x1575 2nd S	Picture window V2	1	0.61	1.58	0.96	0.568	0.4161
610x1575 2nd S	Picture window V2	1	0.61	1.58	0.96	0.568	0.4161
East							
1220x1016 2nd E	slider with sash	1	1.22	1.02	1.24	0.565	0.3372
1220x1575 1st E	slider with sash V2	1	1.22	1.58	1.92	0.564	0.3903
457x1016 2nd E	Picture window	1	0.46	1.02	0.46	0.566	0.3560
457x1575 1st E	Picture window	2	0.46	1.58	1.44	0.585	0.3659
East 762x305	basement window V2	1	0.76	0.31	0.23	0.555	0.1681
North							
1220x1016 2nd N	slider with sash	1	1.22	1.02	1.24	0.565	0.3372

1220x1575 1st N	slider with sash V2	2	1.22	1.58	3.84	0.564	0.3903
1575x1016 2nd N	slider with sash V2	1	1.58	1.02	1.60	0.555	0.3809
North762x305	basement window V2	1	0.76	0.31	0.23	0.555	0.1681
Sliding Door	Sliding door	1	1.50	2.08	3.12	0.604	0.3553
West							
1220x1016 2nd W	slider with sash	3	1.22	1.02	3.72	0.565	0.3372
610x762 1st W	slider sash V2	1	0.61	0.76	0.46	0.598	0.2676
610x762 1st W	slider sash V2	1	0.61	0.76	0.46	0.598	0.2676
West 726x305	basement window V2	1	0.73	0.31	0.22	0.555	0.1648

WINDOW CODE SCHEDULE

Name	Internal Code	Description (Glazings, Coatings, Fill, Spacer, Type, Frame)
1220x1575 1/2 round	213014	Double/double with 1 coat, Low-E .04 (soft), 13 mm Argon, Metal, Hinged, Vinyl, RE* = -23.858, Eff. RSI= 0.47
picture window V3	213004	Double/double with 1 coat, Low-E .04 (soft), 13 mm Argon, Metal, Picture, Vinyl, RE* = -8.417, Eff. RSI= 0.56
Hinged	313004	Triple/triple with 1 coat, Low-E .04 (soft), 13 mm Argon, Metal, Picture, Vinyl, RE* = -2.850, Eff. RSI= 0.70
Picture window V2	214204	Double/double with 1 coat, Low-E .04 (soft), 9 mm Argon, Insulating, Picture, Vinyl, RE* = -6.465, Eff. RSI= 0.59
slider with sash	313024	Triple/triple with 1 coat, Low-E .04 (soft), 13 mm Argon, Metal, Slider with sash, Vinyl, RE* = -13.655, Eff. RSI= 0.58
slider with sash V2	213224	Double/double with 1 coat, Low-E .04 (soft), 13 mm Argon, Insulating, Slider with sash, Vinyl, RE* = -13.905, Eff. RSI= 0.55
basement window V2	313026	Triple/triple with 1 coat, Low-E .04 (soft), 13 mm Argon, Metal, Slider with sash, Fibreglass, RE* = -9.180, Eff. RSI= 0.69
Sliding door	313045	Triple/triple with 1 coat, Low-E .04 (soft), 13 mm Argon, Metal, Patio door, Reinforced vinyl, RE* = -9.335, Eff. RSI= 0.62
slider sash V2	313224	Triple/triple with 1 coat, Low-E .04 (soft), 13 mm Argon, Insulating, Slider with sash, Vinyl, RE* = -7.350, Eff. RSI= 0.70

* Window Standard Energy Rating estimated for assumed dimensions, and Air tightness type: CSA - A1; Leakage rate = 2.790 m^3/hr/m

BUILDING PARAMETER DETAILS

CEILING COMPONENTS

	Construction Type	Code Type	Roof Slope	Heel Ht.(m)	Section Area (m^2)	R. Value (RSI)
Ceiling	Attic/hip	2012 2x6 600 mm space ceil	6.000/12	0.15	127.75	7.77

MAIN WALL COMPONENTS

Label	Lintel Type	Fac. Dir	Number of Corn.	Number of Inter.	Height (m)	Perim. (m)	Area (m^2)	R. Value (RSI)
Main floor Type: 2012 2x4 400 mm spacing	106	N/A	8	0	2.44	46.00	112.24	3.76
Second level Type: 2012 2x4 400 mm spacing	106	N/A	8	0	2.46	51.00	125.46	3.77
BWhdr01 Type: 2012 2x4 floor header-2		N/A	4	4	0.25	46.00	11.50	4.95
MWhdr-02 Type: 2012 2x4 floor header-2		N/A	4	4	0.25	51.00	12.75	4.95

DOORS

Label	Type	Height (m)	Width (m)	Gross Area (m^2)	R. Value (RSI)
Front Entry Door Loc: Main floor	User specified	2.08	1.62	3.37	0.70

USER-DEFINED STRUCTURE CODES SCHEDULE

Name	Description
112012 2x4 400 mm spacing	
112012 2x4 floor header-2	Copy of 2006 2x4 floor header
212012 2x6 600 mm space ceil	

FOUNDATIONS

Foundation Name:	Foundation - 1		
Foundation Type:	Basement	**Volume:**	222.3 m^3
Data Type:	Library	**Opening to Main Floor:**	1.56 m^2
Total Wall Height:	2.34 m	**Non-Rectangular Floor Perimeter:**	46.00 m
Depth Below Grade:	2.13 m	**Floor Area:**	95.00 m^2
Interior wall type:	2x 4 basement walls	**R-value:**	1.79 RSI
Exterior wall type:	User specified	**R-Value:**	0.00 RSI
Number of corners :	8		

Lintel type:	N/A		
Added to slab type :	User specified	**R-Value:**	0.00 RSI
Floors Above Found.:	1st floor joists	**R-Value:**	0.77 RSI

Exposed areas for: Foundation - 1
Exposed Perimeter: 46.00 m

Configuration: BCIN_2
- concrete walls and floor
- interior surface of wall insulated from top of wall to 0.2 m from floor
- any first storey construction type

FOUNDATION CODE SCHEDULE

Interior Wall

Name	Code	Description (Fram., Spac., Studs, Ins/fram., Xtra ins, Int)
2x 4 basement walls	232201	38x89 mm (2x4 in) wood, 600 mm (24 in), 4 studs, RSI 2.1 (R 12) Batt, None, 12 mm (0.5 in) gypsum board

Floors Above Foundation

Name	Internal Code	Description (Structure, typ/size, Spacing, Insul1, 2, Int., Sheathing, Exterior, Drop Framing)
1st floor joists	4220000360	Wood frame, 38x184 mm (2x8 in), 305 mm (12 in), None, None, None, Waferboard/OSB 15.9 mm (5/8 in), Wood, No

Lintel Code Schedule

Name	Code	Description (Type, Material, Insulation)
106	106	Double, Wood, XTPS IV (38 mm, 1.5 in)

ROOF CAVITY INPUTS

Gable Ends		**Total Area:**	0.00 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:**	103.41 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:	88.6 m^3	**Ventilation Rate:**	0.50 ACH/hr

BUILDING ASSEMBLY DETAILS

Label	Construction Code	Nominal (RSI)	System (RSI)	Effective (RSI)
CEILING COMPONENTS				
Ceiling	2012 2x6 600 mm space ceil	8.88	8.83	7.77
MAIN WALL COMPONENTS				
Main floor	2012 2x4 400 mm spacing	3.86	3.77	3.76
Second level	2012 2x4 400 mm spacing	3.86	3.78	3.77
BWhdr01	2012 2x4 floor header-2	3.86	4.95	4.95
MWhdr-02	2012 2x4 floor header-2	3.86	4.95	4.95
FLOORS ABOVE BASEMENTS				
Foundation - 1	1st floor joists	0.00	0.77	0.77

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	127.75	127.75	7.77	4769.95	4.67
Main Walls	261.95	231.60	3.86	23905.87	23.42
Doors	3.37	3.37	0.70	2072.29	2.03
South Windows	7.47	7.47	0.56	5717.77	5.60
East Windows	5.06	5.06	0.57	3824.49	3.75
North Windows	9.80	9.80	0.57	7342.99	7.19
West Windows	4.65	4.65	0.57	3502.99	3.43
		ZONE 1 Totals:		**51136.37**	**50.11**

INTER-ZONE Heat Transfer : Floors Above Basement

Area m^2 Gross	Area m^2 Net	Effective (RSI)	Heat Loss MJ
95.00	95.00	0.767	11483.31

ZONE 2 : Basement

Component	Area m^2 Gross	Area m^2 Net	Effective (RSI)	Heat Loss MJ	% Annual Heat Loss
Walls above grade	9.66	8.97	-	3448.04	3.38
East windows	0.23	0.23	0.56	153.00	0.15
North windows	0.23	0.23	0.56	153.00	0.15
West windows	0.22	0.22	0.56	145.73	0.14
Below grade foundation	192.98	192.98	-	18548.31	18.17
		ZONE 2 Totals:		**22448.09**	**22.00**

Ventilation

House Volume	Air Change	Heat Loss MJ	% Annual Heat Loss
776.00 m^3	0.489 ACH	28472.844	27.90

AIR LEAKAGE AND VENTILATION

Building Envelope Surface Area: 592.34 m^2

Air Leakage Test Results at 50 Pa.(0.2 in H_2O) = 2.50 ACH

Equivalent Leakage Area @ 10 Pa = 724.40 cm2

Terrain Description	**Height**	**m**
@ Weather Station : Open flat terrain, grass	Anemometer	10.0
@ Building site : Suburban, forest	Bldg. Eaves	5.5

Local Shielding:	**Walls:**	Heavy
	Flue :	None

Leakage Fractions-	**Ceiling:** 0.200	**Walls:** 0.650	**Floors:** 0.150

Normalized Leakage Area @ 10 Pa:	1.2229 cm^2/m^2
Estimated Airflow to cause a 5 Pa Pressure Difference:	116 L/s
Estimated Airflow to cause a 10 Pa Pressure Difference:	181 L/s

F326 VENTILATION REQUIREMENTS

Kitchen, Living Room, Dining Room	3 rooms @ 5.0 L/s: 15.0 L/s
Utility Room	2 rooms @ 5.0 L/s: 10.0 L/s
Bedroom	1 rooms @ 10.0 L/s: 10.0 L/s
Bedroom	3 rooms @ 5.0 L/s: 15.0 L/s
Bathroom	3 rooms @ 5.0 L/s: 15.0 L/s
Other	1 rooms @ 5.0 L/s: 5.0 L/s
Basement Rooms	: 10.0 L/s

CENTRAL VENTILATION SYSTEM

System Type:	HRV
Manufacturer:	Vanee
Model Number:	60H

Fan and Preheater Power at 0.0 °C:	43 Watts
Fan and Preheater Power at -25.0 °C:	58 Watts
Preheater Capacity:	0 Watts
Sensible Heat Recovery Efficiency at 0.0 °C	67%

Sensible Heat Recovery Efficiency at -25.0 °C	57%
Total Heat Recovery Efficiency in Cooling Mode	50%

Low Temperature Ventilation Reduction:	22%
Low Temperature Ventilation Reduction: Airflow Adjustment	1 L/s (1.6%)

Vented combustion appliance depressurization limit: 5.00 Pa.

Ventilation Supply Duct

Location:	Basement	**Type:**	Flexible
Length:	1.5 m	**Diameter:**	125.0 mm
Insulation:	0.7 RSI	**Sealing Characteristics:**	Sealed

Ventilation Exhaust Duct

Location:	Basement	**Type:**	Flexible
Length:	1.5 m	**Diameter:**	125.0 mm
Insulation:	0.7 RSI	**Sealing Characteristics:**	Sealed

SECONDARY FANS & OTHER EXHAUST APPLIANCES

	Control	Supply (L/s)	Exhaust (L/s)
Other Fans	Continuous	0.00	4.80
Dryer	Continuous	-	1.20

Dryer is vented outdoors

Rated Fan Power 226.30 Watts

AIR LEAKAGE AND VENTILATION SUMMARY

F326 Required continuous 80.000 L/s (0.37 ACH)

ventilation:

Central Ventilation Supply Rate ():	80.000 L/s (0.37 ACH)
Other Continuous Supply Flow Rates:	0.000 L/s (0.00 ACH)
Other Continuous Exhaust Flow Rates:	4.800 L/s (0.02 ACH)
Total house ventilation is Balanced	
Gross Air Leakage and Ventilation Energy Load:	55040.863 MJ
Seasonal Heat Recovery Ventilator Efficiency:	66.559 %
Estimated Ventilation Electrical Load: Heating Hours:	1194.711 MJ
Estimated Ventilation Electrical Load: Non-Heating Hours:	166.431 MJ
Net Air Leakage and Ventilation Load:	29070.199 MJ

SPACE HEATING SYSTEM

Primary Heating Fuel:	Natural Gas
Equipment:	Condensing furnace/boiler
Manufacturer:	Carrier
Model:	58MCB
Specified Output Capacity:	17.00 kW
Pilot Light energy consumption:	25.30 MJ/day
AFUE:	95.50
Steady State Efficiency:	96.77
Fan Mode:	Auto
ECM Motor:	No
Low Speed Fan Power:	0 watts
High Speed Fan Power:	372 watts

AIR CONDITIONING SYSTEM

System Type:	Conventional A/C		
Manufacturer:	carrier		
Model:	24ABB330		
Capacity:	4526 Watts		
SEER	13.00	**Rated COP**	2.923
Sensible Heat Ratio:	0.76		
Indoor Fan Flow Rate:	252.31 L/s	**Fan Power (watts)**	195.54
Ventilator Flow Rate:	0.00 L/s	**Crankcase Heater Power (watts):**	180.00
Fraction of windows Openable	0.710		
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 Equipment:	Direct vent (sealed, pilot)		
Energy Factor:	0.670		
Manufacturer:	Giant Brand		
Model:	UG40-38TFPDV-N2U		
Tank Capacity =	151.40 Litres	**Tank Blanket Insulation**	2.4 RSI
Tank Location:	Basement		
Pilot Energy =	17.70 MJ/day	**Flue Diameter**	50.00 mm

ANNUAL DOMESTIC WATER HEATING SUMMARY

Daily Hot Water Consumption:	225.00 Litres
Hot Water Temperature:	55.00 °C
Estimated Domestic Water Heating Load:	15341 MJ
Primary Domestic Water Heating Energy	22347.22

Consumption:	MJ
Primary System Seasonal Efficiency:	68.65%

ANNUAL SPACE HEATING SUMMARY

Design Heat Loss at -20.00 °C (12.98 Watts / m3):	10073.16 Watts
Gross Space Heat Loss:	102057.30 MJ
Gross Space Heating Load:	100334.06 MJ
Usable Internal Gains:	24535.63 MJ
Usable Internal Gains Fraction:	24.04 %
Usable Solar Gains:	14001.79 MJ
Usable Solar Gains Fraction:	13.72 %
Auxiliary Energy Required:	61796.63 MJ
Space Heating System Load:	61796.63 MJ
Furnace/Boiler Seasonal efficiency:	84.59 %
Furnace/Boiler Annual Energy Consumption:	71728.53 MJ

ANNUAL SPACE COOLING SUMMARY

Design Cooling Load for July at 31.00 °C:	5538.48 Watts
Design Sensible Heat Ratio:	0.769
Estimated Annual Space Cooling Energy:	1883.58
Seasonal COP (June to September):	2.209

BASE LOADS SUMMARY

	kwh/day	**Annual kWh**
Interior Lighting	3.00	1095.00
Appliances	14.00	5110.00
Other	3.00	1095.00
Exterior Use	4.00	1460.00
HVAC Fans		
HRV/Exhaust	6.47	2360.48
Space Heating	1.01	367.60

Space Cooling	0.45	165.88
Total Average Electrical Load	31.93	11653.96

FAN OPERATION SUMMARY (kWh)

Hours	HRV/Exhaust Fans	Space Heating	Space Cooling
Heating	1715.5	367.6	0.0
Neither	360.8	0.0	0.0
Cooling	284.3	0.0	165.9
Total	2360.5	367.6	165.9

ENERGY CONSUMPTION SUMMARY REPORT

Estimated Annual Space Heating Energy Consumption	= 73051.88 MJ	= 20292.19 kWh
Ventilator Electrical Consumption: Heating Hours	= 1194.71 MJ	= 331.86 kWh
Estimated Annual DHW Heating Energy Consumption	= 22347.22 MJ	= 6207.56 kWh
ESTIMATED ANNUAL SPACE + DHW ENERGY CONSUMPTION	= 96593.81 MJ	= 26831.61 kWh

Estimated Greenhouse Gas Emissions 11.830 tonnes/year

ESTIMATED ANNUAL FUEL CONSUMPTION SUMMARY

Fuel	Space Heating	Space Cooling	DHW Heating	Appliance	Total
Natural Gas (m3)	1925.13	0.00	599.78	0.00	2524.91
Electricity (kWh)	2083.06	1883.58	0.00	9120.76	13087.40

ESTIMATED ANNUAL FUEL CONSUMPTION COSTS

Fuel Costs Library = Embedded

RATE	Electricity (Ottawa08)	Natural Gas (Ottawa08)	Oil (Ottawa08)	Propane (Ottawa08)	Wood (Sth Ont)	Total
$	1379.36	1491.59	0.00	0.00	0.00	2870.95

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 = Ottawa08	Gas Rate Block		
Rate Block		Dollars	Charge
	m3	Per m3	($)
Minimum	0.0		14.000
1	30.0	0.5338	

2	85.0	0.5277	
3	170.0	0.5229	
4	99999.0	0.5194	
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		Dollars	Charge

Block	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	17583.0	2482.9	1449.8	13650.3	65.9
Feb	15236.3	2236.2	1788.9	11211.3	66.0
Mar	13662.6	2483.4	2286.3	8892.9	66.4
Apr	9087.7	2422.8	1856.9	4807.9	66.6
May	5193.6	2531.0	1617.1	1045.5	66.7
Jun	1743.0	1457.5	285.5	0.0	67.0
Jul	312.5	312.5	0.0	0.0	67.2
Aug	715.9	702.8	13.1	0.0	67.8
Sep	3440.7	2395.6	945.7	99.4	66.7
Oct	7370.6	2558.5	1565.0	3247.1	66.5
Nov	10809.1	2449.2	1037.0	7322.9	66.5
Dec	15179.1	2503.2	1156.5	11519.3	66.3
Ann	100334.1	24535.6	14001.8	61796.6	66.6

FOUNDATION ENERGY PROFILE

			Heat Loss (MJ)		
Month	**Crawl Space**	**Slab**	**Basement**	**Walkout**	**Total**
Jan	0.0	0.0	1121.1	0.0	1121.1
Feb	0.0	0.0	920.6	0.0	920.6
Mar	0.0	0.0	730.2	0.0	730.2
Apr	0.0	0.0	394.8	0.0	394.8

May	0.0	0.0	85.8	0.0	85.8
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	8.2	0.0	8.2
Oct	0.0	0.0	266.5	0.0	266.5
Nov	0.0	0.0	601.2	0.0	601.2
Dec	0.0	0.0	945.8	0.0	945.8
Ann	0.0	0.0	5074.1	0.0	5074.1

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	0.148	0.547	5561.6
Feb	0.0	18.4	0.0	0.141	0.540	4733.4
Mar	0.0	18.4	0.0	0.126	0.525	4032.4
Apr	0.0	18.7	0.0	0.103	0.502	2450.8
May	0.0	19.2	0.0	0.069	0.468	1182.2
Jun	0.0	19.8	0.0	0.048	0.447	335.9
Jul	0.0	20.4	0.0	0.038	0.437	-88.4
Aug	0.0	20.4	0.0	0.036	0.435	60.5
Sep	0.0	20.0	0.0	0.054	0.453	717.0
Oct	0.0	19.6	0.0	0.082	0.481	1894.6
Nov	0.0	19.2	0.0	0.109	0.508	3015.8
Dec	0.0	18.9	0.0	0.131	0.530	4577.1
Ann	0.0	19.3	0.0	0.090	0.489	28472.8

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	13650.3	13804.3	784.3	292.3	0.0	14880.9	0.9
Feb	11211.3	11337.8	708.4	240.1	0.0	12286.3	0.9
Mar	8892.9	8993.2	784.3	190.4	0.0	9968.0	0.9
Apr	4807.9	4862.2	759.0	103.0	0.0	5724.1	0.8
May	1045.5	1057.3	784.3	22.4	0.0	1864.0	0.6
Jun	0.0	0.0	759.0	0.0	0.0	759.0	0.0
Jul	0.0	0.0	784.3	0.0	0.0	784.3	0.0
Aug	0.0	0.0	784.3	0.0	0.0	784.3	0.0
Sep	99.4	100.6	759.0	2.1	0.0	861.7	0.1
Oct	3247.1	3283.7	784.3	69.5	0.0	4137.6	0.8
Nov	7322.9	7405.5	759.0	156.8	0.0	8321.3	0.9
Dec	11519.3	11649.3	784.3	246.7	0.0	12680.3	0.9
Ann	61796.6	62494.0	9234.5	1323.4	0.0	73051.9	0.8

AIR CONDITIONING SYSTEM PERFORMANCE

Month	**Sensible Load MJ**	**Latent Load MJ**	**AirCond Energy kWh**	**Fan Energy kWh**	**Ventilator Energy kWh**	**Total Energy kWh**	**COP**	**Av.RH %**
Jun	2051.9	513.1	220.9	33.7	0.0	345.6	2.1	49.5
Jul	3782.9	1209.3	429.5	64.8	0.0	555.4	2.5	53.1
Aug	2989.7	1039.6	347.7	52.6	0.0	473.1	2.4	54.0
Sep	870.7	261.6	97.7	14.8	0.0	225.2	1.4	51.9
Ann	9695.1	3023.6	1095.7	165.9	0.0	1599.3	2.2	52.5

MONTHLY ESTIMATED ENERGY CONSUMPTION BY DEVICE (MJ)

	Space Heating		**DHW Heating**		**Lights &**	**HRV &**	**Air**
Month	**Primary**	**Secondary**	**Primary**	**Secondary**	**Appliances**	**FANS**	**Conditioner**
Jan	14588.6	0.0	2090.9	0.0	2678.4	1016.0	0.0
Feb	12046.2	0.0	1915.7	0.0	2419.2	893.2	0.0
Mar	9777.5	0.0	2091.5	0.0	2678.4	912.0	0.0
Apr	5621.2	0.0	1945.3	0.0	2592.0	801.0	0.0
May	1841.6	0.0	1898.8	0.0	2678.4	743.7	0.0
Jun	759.0	0.0	1731.6	0.0	2592.0	819.3	1122.9
Jul	784.3	0.0	1708.9	0.0	2678.4	954.4	1766.5

Aug	784.3	0.0	1679.4	0.0	2678.4	910.8	1513.6
Sep	859.6	0.0	1650.6	0.0	2592.0	753.5	757.5
Oct	4068.0	0.0	1787.5	0.0	2678.4	790.8	0.0
Nov	8164.5	0.0	1837.3	0.0	2592.0	854.8	0.0
Dec	12433.6	0.0	2009.7	0.0	2678.4	968.8	0.0
Ann	71728.5	0.0	22347.2	0.0	31536.0	10418.3	5160.4

ESTIMATED FUEL COSTS (Dollars)

Month	Electricity	Natural Gas	Oil	Propane	Wood	Total
Jan	108.41	247.70	0.00	0.00	0.00	356.11
Feb	97.62	209.82	0.00	0.00	0.00	307.44
Mar	105.47	180.64	0.00	0.00	0.00	286.11
Apr	99.90	120.66	0.00	0.00	0.00	220.56
May	100.72	67.09	0.00	0.00	0.00	167.80
Jun	132.10	49.46	0.00	0.00	0.00	181.56
Jul	156.52	49.49	0.00	0.00	0.00	206.01
Aug	148.15	49.08	0.00	0.00	0.00	197.23
Sep	119.93	49.74	0.00	0.00	0.00	169.67
Oct	102.05	96.77	0.00	0.00	0.00	198.82
Nov	101.42	154.61	0.00	0.00	0.00	256.03
Dec	107.07	216.53	0.00	0.00	0.00	323.60
Ann	1379.36	1491.59	0.00	0.00	0.00	2870.95

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.

Appendix F- THERM Assumption and Inputs:

- 90 mm Brick- 0.72 w/mk (Hutcheon & Handegord 1995), emissivity 0.94 (American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc, 2009).
- 25 mm air space- 0.071 w/mk (Natural Resources Canada, 2011), assume 0.9 emissivity.
- 6 mm plywood – 0.12 w/mk (Hutcheon & Handegord 1995), 0.9 emissivity from THERM.
- Studs- 0.09 w/mk, (American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc 2009)0.9 emmistivity from THERM.
- 1.41 RSI Rigid insulation- 1/1.41=0.71 w/m^{2}k*0.038mm= 0.0269 w/mk.
- 0.70 RSI rigid insulation- 1/0.70= 1.42 w/m^{2}k*0.019mm= 0.027 w/mk.
- 3.87 RSI insulation-1/3.87=0.258 w/m^{2}k*0.14mm=0.036 w/mk.
- 2.64 RSI insulation- 1/2.64= 0.378 w/m^{2}k*0.089mm=0.0336 w/mk.
- 2.46 RSI Insulation-1/2.46=0.378 w/m^{2}k*0.089mm=0.0337 w/mk.
- 3.34 RSI Insulation- 1/3.34= 0.299 w/m^{2}k*0.089= 0.026 w/mk.
- 7 RSI Insulation-1/7=0.143 w/m^{2}k*0.2955mm= 0.042 w/mk.
- 8.8 RSI Insulation- 1/8.8=0.113 w/m^{2}k*0.3745mm=0.042 w/mk.
- Denmark rigid insulation= 0.038 w/mk (Rose 2012).
- Denmark basement slab insulation average 0.05 w/mk (Rose 2012).
- Germany expanded polystyrene with Neopor additive 0.32 w/mk (Hanse House 2010).
- Germany mineral fiber quilt 0.038 w/mk (Hanse House 2010).
- Germany XPS insulation under basement slab 0.039 w/mk (Hanse House 2010).
- Germany XPS on exterior of basement wall 0.041 w/mk (Glatthaar Fertigeller 2008).
- Germany spray foam insulation between concrete basement wall 0.031 w/mk (Glatthaar Fertigeller 2008).
  - All insulation has an emmistivity of 0.90 as per THERM.
- Ventilated attic space assumed to be same as exterior boundary condition (Richman 2012).
- 15 mm HDPE drainage sheet and 4 mm 2 coat bitumen on the German Basement walls, is not being considered because they have negligible thermal properties.
- 12.7 mm drywall- 0.16 w/mk (American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc 2009), assume 0.90 emissivity.
- Concrete- 2 w/mk (Straube & Burnett 2005), 0.91 emissivity (American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc 2009).
- LECA Blocks- 0.25 w/mk (Laterlite 2007), 0.91 emmistivity as it is similar to concrete (American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc 2009).

- Soil (Ground)-1.6 w/mk (Straube & Burnett 2005), 0.94 emissivity (American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc 2009).
- Asphalt shingles- 0.0625 w/mk (Hutcheon & Handegord 1995), 0.88 emissivity (assumed similar to asphalt (American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc 2009).
- Acoustical insulation/Denmark Insulation- 0.034 w/mk (Rose, 2012), 0.90 emissivity from THERM.
- Air space- assumed still air 0.025 w/mk (Hutcheon & Handegord 1995), assume 0.90 emissivity This was used where there were gaps between the drywall and vapour retarder/ insulation when stripping is used (Denmark and Germany) in the roof examples. It was assumed that the air would be still because it is inside two air barriers that being a vapour barrier and drywall.
- Plywood between floors (22.5 mm)- 0.12 w/mk (Hutcheon & Handegord 1995) 0.9 emmistivity from THERM.
- Plaster- 0.38 w/mk (American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc 2009), 0.89 emmistivity (American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc 2009)
- Assume 9 mm wind barrier is drywall K value of 0.16 w/mk and 0.9 emmissitivity as per THERM.
- OSB 0.10 w/mk (American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc, 2009), 0.90 emmistivity from Therm.
- Zip System Wall sheathing (assume to be like OSB) 0.10 w/mk (American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc 2009), 0.90 emissivity from THERM.
- ICF forms EPS rigid insulation 0.038 w/mk (Nudura 2010), emissivity 0.90 as per THERM.
- Dense blow insulation in Passive House (wall) and blow in premium insulation (ceiling) 0.04125 (Nu Wool 2008), emissivity of 0.90 from THERM.
- 254 mm EPS Insulation below the slab 0.0288 w/mk (Owens Corning 2004), 0.90 emissivity from THERM.
- Passive House insulation between slab and basement wall is assumed to be similar to the ICF forms EPS rigid insulation value.
- The air space between the basement wall and 38 x 140 mm basement wall in the Passive House is assumed to be 0.0239 w/mk. (3.85 w/m^{2}k, average of 92 mm air space for emissivity of 0.03 and 0.82 for all positions and directions of air flow for a mean temperature of 10 ^{0}C and a temperature difference of 20 ^{0}C (Hutcheon & Handegord 1995). Emissivity 0.43 average used (Hutcheon & Handegord 1995).
- Note for all simulations conducted the exterior elements consisted of 90 mm brick, 25 mm air space and 6 mm plywood. This was done so a fair comparison could be made. In some cases some of the details had to be modified in order for these exterior elements to represent how the building

envelope section would look if incorporated on either the urban or suburban home.

- A majority of the materials were also assumed to have an emissivity value of 0.90 as this is what THERM assumed for the majority of the materials.

Boundary Conditions

- Exterior condition# 1 - -4.5 ^{0}C as this is the daily average (City of Toronto 2012), 34 w/m^{2}k (American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc 2009).
- Interior conditions- Interior, 21.1 ^{0}C (as per supplementary 12 requirements for HOT2000 simulations), Film coefficient 8.3 w/m^{2}k (under 0.90 emissivity, assumed to be an average, as surface conductance's can vary) (American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc 2009).
- Exterior condition # 2- Ground, 10.1 ^{0}C (average in Toronto) (Canadian Geothermal Coalition, 2012), Film coefficient infinity 10,000 w/m^{2}k (Richman 2012).
- Ground/ Interior Average Condition- 15.6 ^{0}C ((21.1+10.1)/2), No film coefficient.
- Ground/Exterior Average Condition- 2.8 ^{0}C Average of -4.5 and 10.1.No film coefficient.

Appendix G- Ontario Building Codes History:

Canada has an extremely cold climate, meaning the design and construction of the building envelope is an integral aspect. The province of Ontario is home to 12, 851,821 people, is approximately 980, 607 square kilometers and has a varying climate because of its sheer size (Statistics Canada 2012). Ontario has four distinct seasons. Temperatures can vary from an average of -13.3^{0} C in Sudbury to -4.5^{0} C in Toronto during the coldest times of the winter, to an average of 19 ^{0}C in Sudbury to 22.1 ^{0}C in Toronto during the warmest days in the summer (Goverment of Ontario 2012). In addition to this, Toronto has 3956 heating degree days (American Society of Heating, Refrigerating and Air Conditioning Engineers Inc 2009). Due to this varying climate, the location with the largest population, the Greater Toronto Area shall be used as a reference for Ontario's climate.

Figure G- 1: Ontario Map

(Ontario Travel Information 2012)

In Ontario, the first building code came into effect in 1941 as part of the national building code (Natural Research Council Canada 2011). This building code regulated Ontario through to 1975, and between the time periods of 1941 to 1975, approximately five building codes were established (Natural Research Council Canada 2011). Once Ontario formed its own regulations in 1975, they carried forward many of the same requirements as the National Building Code, yet made specific changes for Ontarian homes (Ontario Ministry of Municipal Affairs and Housing 2010). Since its inception in 1975, there have been seven additions of the OBC with the latest edition being released January 1st, 2012 (Ontario Ministry of Municipal Affairs and Housing 2010).

As a province, Ontario believes strongly in allowing its developers and builders flexible standards by giving a variety of options that are also very clear and uniform to improve Ontario (Ministry of Municipal Affairs and Housing 2011). Throughout the building code's history, most changes or adaptations occur because of amendments in other jurisdictions, government priorities, other public proposals, new technologies and industry standards (Ministry of Municipal Affairs and Housing 2011). Execution of these types of changes are dependent on a variety of entities such as the potential impact it may have on stakeholders/public, if it is enforceable, the effect it may have on the workload for the municipalities, plus any liability that may be associated with the change, the capability of the industry to understand the change and adopting the changes to meet a foreseen goal (Ministry of Municipal Affairs and Housing 2011). In Ontario, the ministry of Municipal Affairs and Housing administers the building code and reviews the code every five years.

In the 1941, insulation was not used as much for a dwelling to utilize less energy, as it was more directed towards negating condensation problems within the building envelope (National Housing Administration Department of Finance and the Codes and Specfications Section National Research Council of Canada 1941). As for the other portions of the building envelope such as the windows, their main use consisted of allowing light into the habitable areas of the house for its occupants, as opposed to providing solar heat gain or insulation from the heat loss through windows (National Housing Administration Department of Finance and the Codes and Specfications Section National Research Council of Canada 1941).

The first installment of the National Building Code, was in 1941 where:

- An RSI value of 0.7 (m^2K/W) was the minimum requirement for walls and 0.5 (m^2K/W) for the ceiling (National Housing Administration Department of Finance and the Codes and Specfications Section National Research Council of Canada 1941).
- It was not necessary to provide a home with a window or door that had a specific minimum U-value or RSI, as the major concern in this time period

was providing ventilation and lighting to the home through these openings within the building envelope.

- Windows had at least 88 % light transmission rate (National Housing Administration Department of Finance and the Codes and Specfications Section National Research Council of Canada 1941).
- The vapour retarder was to be placed between the stud and the material (drywall) on the interior side of the wall, which was instilled throughout every building code going forward.
- Basements had no minimum RSI value, while the only requirement was to have insulation to prevent the chance of condensation on the interior side of the wall during the summer months (National Housing Administration Department of Finance and the Codes and Specfications Section National Research Council of Canada 1941).

When the 1953 revision was adopted, no changes were made in terms of the building envelope from that of the 1941 version (National Research Council 1953).

A new OBC was revealed in 1960 and was the first to incorporate part 9 'Housing and Small Buildings' into the building code (National Research Council 1960). However, it was not until 1963 when Supplement Number 5 was introduced that the minimum RSI values increased (National Research Council 1960). In this supplement, the insulation values for walls, ceilings and floors started to take into consideration the annual degree days where the requirements were in place:

- At least 1.2 (m^2K/W) for areas with annual degree days not exceeding 8000,
- 1.5 (m^2K/W) for areas with annual degree days exceeding 8000 but not exceeding 11000 and,
- 1.76 (m^2K/W) for areas with annual degree- days exceeding 11000 (National Research Council 1960).
- In habitable basements insulation had to extend at least 300 mm down from the outside grade and was still required to prevent condensation

problems, but there was no minimum RSI value stated (National Research Council 1960).

- Around slabs on grade, insulation was also to be placed around the perimeter at least 150 mm below grade (National Research Council 1960).
- There were also two types of vapour retarders introduced, type 1 and type 2. Type 1 vapour retarder intended for a high resistance to vapour movement, while the type 2 could be used in all other locations.
- Windows and doors had to meet the Canadian Standards Association Benchmark; however, there was no minimum RSI value (National Research Council 1960). This standard expected windows and doors to be made out of certain materials, in addition to going through a series of tests to ensure their durability and performance. In particular, windows now had to be double- glazed and meet an air infiltration rate of 1.2 L/s per meter of crack length (National Research Canada 1960).

The 1965 National Building Code considered a different approach and based its minimum RSI values on the type of energy being used to heat a dwelling and its cost. In Table G-1, this breakdown can be seen.

Table G- 1: 1965 National Building Code Requirements

1965 National Building Code Requirements	**Gas costing 0.23 cents per m^3 or less**		**Gas costing more than 0.23 cents per m^3**		**Electrical**	
Location	Walls	Ceilings	Walls	Ceilings	Walls	Ceilings
	Floors	Roof	Floors	Roof	Floors	Roof
8000 total annual degree days or less	1.2	1.2	1.5	1.6	1.96	2.5
8000 to 11,00 total annual degree days	1.2	1.2	1.6	1.96	2.2	2.93
11,000 total annual degree days or more	1.26	1.35	1.76	2.2	2.2	3.52
* All values in RSI						

(National Research Canada, 1965)

Unlike the 1960 code, the 1965 code established a minimum RSI value for the edges of slabs that were on or near grade level. This RSI value was a modest 0.88 (m^2K/W) RSI and had to extend at least 300 mm below the finished grade (National Research Canada 1965). Windows and doors had very little changes meaning there was still no minimum ‘U’-value; however, there were now more accepted types of windows from the CSA (National Research Canada 1965). In the end, the last National Building code prior to the first Ontario Building code was in 1970 and in comparison to the 1965 NBC there were no significant changes to the building envelope (National Research Council Of Canada 1970).

As the first of its kind, the 1975 Ontario Building Code, represented standards that were above and beyond the National Building Codes, providing Ontarians with a ‘higher’ quality home (Ministry of Municipal Affairs and Housing 1975). Compared to previous building codes, the minimum insulation RSI value was now for all degree days, thus it increased immensely, with (Ministry of Municipal Affairs and Housing 1975):

- Ceilings 4.93 (m^2K/W),
- Flat roofs or ceiling without attic space 3.52 (m^2K/W),
- Walls 2.11 (m^2K/W),
- Exposed floors 3.52 (m^2K/W),
- Foundation walls 1.41 (m^2K/W) if solid or 2.11 (m^2K/W) if framed 50 % exposed,
- Slab on grade, (unheated)1.41(m^2K/W), heated 1.76 (m^2K/W).
- Basement insulation requirement went from 300 mm to 600 mm below finished grade level.
- No set U-value for windows or doors.

The second version of the OBC was established in 1983 and the changes that occurred were (Ministry of Municipal Affairs and Housing 1983):

- Exposed ceilings were 5.64 (m^2K/W),
- Exposed floors 4.58 (m^2K/W),
- All other locations where insulation was to be placed, stayed the same RSI as the 1975 OBC (Ministry of Municipal Affairs and Housing 1983).
- Windows now had to be at least 3.3 (w/m^2K), with a lowered infiltration rate of 0.775 L/s per meter crack length at 75 PA (Ministry of Municipal Affairs and Housing 1983).
- Doors had to be at least 0.7 (m^2K/W) with an infiltration rate of 6.5 l/s per m^2 of door at 75 PA.

A few years later, Ontario presented a 1986 edition to the Ontario market where, the building envelope had very little changes other than (Ministry of Municipal Affairs and Housing 1983):

- The ceiling dropped to 5.4 (m^2K/W),
- The exposed floors to 4.4 (m^2K/W).

The 1990 OBC, had minimum thermal resistances reintroduced under the degree day format once again. Figure G-2 shows, there were two categories 'Zone 1' and 'Zone 2' (Jeld-Wen Windows & Doors 2012). Zone 1 consisted of the areas in Ontario that had less than 5000 degree days, whereas Zone 2 was 5000 or more degree days. For the purpose of this research, Zone 1 was used to represent Ontario because the majority of Ontarians live in Zone 1. When comparing Zone 1 to the 1986 code, the only visible differences pertained to (Ministry of Municipal Affairs and Housing, 1990):

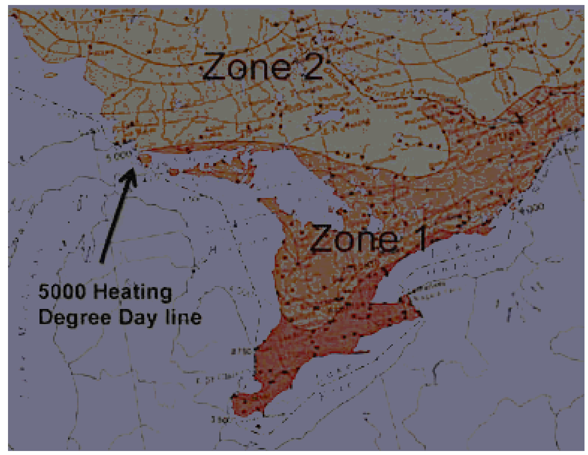


Figure G- 2: Ontario HDD Zones

(Jeld-Wen Windows & Doors 2012)

- The walls, where 3.25 (m^2K/W) was now the minimum insulation value.
- The foundation walls, where 2.11 (m^2K/W) was the minimum insulation value no matter what type of wall the foundation was constructed out of (Ministry of Municipal Affairs and Housing 1990).

Beyond these changes there were no other differentiations between 1986 and 1990 editions (Ministry of Municipal Affairs and Housing 1990).

Seven years later, the 1997 OBC was mandated as the newest standards. Even though there were a few changes, a third category was created that dealt with electric space heating. Beyond this no other changes occurred.

Table G- 2: 1997 Ontario Building Code Requirements

1997 Ontario Building Code			
Building envelope element	**Zone 1**	**Zone 2**	**Electric**
	less than 5000	**5000 or more**	**both zones**
Ceiling with attic	5.4	6.7	7
Flat roof Ceiling without attic	3.52	3.52	3.87
Walls	3.25	3.87	4.7
Foundation walls	2.11	2.11	3.25
Exposed floor	4.4	4.4	4.4
Slab on grade with pipes	1.76	1.76	1.76
Slab on grade without pipes	1.41	1.41	1.41
* All values in RSI (m^2K/W)			

(Ministry of Municipal Affairs and Housing 1997)

The 2006 OBC marked the beginning of major changes for Ontario in contrast to recent years. For the most part, the main components of the building envelope increased drastically, as observed in the 2006 Ontario Building Code Table G- 3. Although these changes were made, builders had the option to also design and construct their homes to the Energuide 80 level or for new homes, the Energy star level, which essentially were energy efficient labels (Ministry Municipal Affairs and Housing 2006). The Energy star for new homes minimum level was also the equivalent to an Energuide 80 level (Natural Resources Canada 2010).

Table G- 3: 2006 Ontario Building Code Requirements

2006 Ontario Building Code			
Building envelope element	**Zone 1**	**Zone 2**	**Electric**
	less than 5000	**5000 or more**	**both zones**
Ceiling with attic	7	7	8.8
Flat roof or ceiling without attic	4.93	4.93	4.93
Walls	3.34	4.22	5.1
Foundation walls	2.11	2.11	3.34
Exposed floor	4.4	4.4	4.4
Slab on grade with pipes	1.76	1.76	1.76
Slab on grade without pipes	1.41	1.41	1.76
* All values in RSI (m2K/W)			

(Ministry Municipal Affairs and Housing 2006)

The 2006 edition marked a great change in the history of the OBC, with the following adjustments:

- Thermal bridging requirements were instilled in the building envelope for all above grade walls. In these wall assemblies, where there were studs with an RSI less than a 0.9 thermal resistance, at least 25 % of the required assembly RSI value must be ensured or in cases where this 25 % does not meet 0.90, a minimum of 0.90 thermal resistances must be met (Ministry Municipal Affairs and Housing 2006). To provide an example, a wall in Zone 1 must have an RSI of 0.835 (3.34 *0.25), in this case the 0.90 RSI had to be met.
- Windows had to have a U-value of 2.0 (W/m^{2}K) or an energy rating of 17 for operable windows and 27 for fixed windows. This was acceptable for Zones 1 and 2 (Ministry Municipal Affairs and Housing 2006). While for electrically heated homes, the windows that are installed must be 0.625 (m^{2}K/W) or higher and in terms of air infiltration for windows and doors they stay the same (Ministry Municipal Affairs and Housing 2006).

- Furnaces were to have a minimum AFUE rate of 90 % for propane and natural gas and hot water tanks had to have at least 0.67 energy factors (Ministry Municipal Affairs and Housing 2006).

The current OBC that is now enforced as of December 31, 2011, has the most radical changes thus far. Overall, there are 21 unique packages that builders can choose from for Zone 1 and 16 unique packages for Zone 2. Nevertheless, each one of these packages, are calculated to be an equivalent to the minimum requirement of an Energuide 80 rating (Lio & Associates 2010). For those that choose not to follow one of the 37 packages, there is the option to either meet the Energuide 80 level or comply with Energy Star for new homes, which is equivalent to an Energuide 83 level (Natural Resources Canada 2010). These 37 packages, allow builders to design and construct their homes in a variety of ways. For example, dependent on the annual fuel utilization efficiency (AFUE) chosen, the building envelope can vary considerably. In total, there were 13 packages for Zone 1, where space heating is at least 90% AFUE, followed by another six for space heating that is between 78 % and 90 % AFUE and an additional two more packages for electric space heating (Ministry of Municipal Affairs and Housing 2012). Each of the packages that are available allow a builder to determine which way he or she may want to design and construct their homes by either having a higher AFUE furnace with a lower performing building envelope or vice versa (Ministry of Municipal Affairs and Housing 2012).

According to Daniel Lacroix of Brookfield homes, the cheapest and easiest compliance package tends to win in an economy like Ontario's that is fast tracked. This is why, his company builds to compliance package J (Lacroix 2012). The reasoning behind using this package is because most of the homes building envelope designs would not have to be severely altered, and only an increase in HVAC efficiency is needed which meant little to no extra costs in labour and materials. To further verify the use of compliance package J, Ron Plum of Jeld-Wen Windows and Doors, who is a major supplier to Ontario home builders, also states that the majority of homes that he supplies to are constructed to meet compliance package J (Plum 2012). With such an overwhelming response directed towards package J, this compliance package will act as the representation for Ontario and from a building envelope perspective was the weakest out of all compliance packages that could have been chosen by Ontario builders.

Table G- 4: 2012 Ontario Building Code Supplementary 12

2012 Ontario Building Code		
Component	**Zone 1**	**Zone 2**
Ceiling with attic space	8.81	8.81
Ceiling without attic space	5.46	5.46
Exposed floor	5.46	5.46
Walls	3.87	4.23
Basement walls	2.11	2.11
Below slab on grade entire surface >600 mm	-	-
Edge of slab on grade <600 mm	1.76	1.76
Heated slab or slab < 600 mm	1.76	1.76
Windows and sliding doors	0.56	0.63
Skylights	*0.36*	0.36
Space heating equipment	94%	94%
HRV	60%	60%
Domestic hot water heater	0.67	0.67
* All values in italics are in RSI (m2K/W)		

(Ministry of Municipal Affairs and Housing 2012)

To view additional information on the compliance packages, see Appendix A (Ministry of Municipal Affairs and Housing 2012).

In comparing the 2006 OBC, to compliance package J, every component except the basement walls, thermal bridging and the heated slab on grade increased in terms of RSI value. Other options specifically for package J are:

- That blown-in insulation or spray applied insulation of at least 3.52 (m^2K/W) for above grade walls can be installed, with either an upgrade in glazing to 1.6 or an increase in basement wall insulation that increases to 3.52 (m^2K/W) optional (Ministry of Municipal Affairs and Housing 2012).

- There is also a few other alternatives for having a minimum of 3.52 RSI insulation in the above grade walls where (Ministry of Municipal Affairs and Housing 2012):
    - Either the HRV efficiency is increased by no lower than 8 percentage points.
    - The attic space must increase to 10.55 RSI,
    - An AFUE space heating increase of not less than 2 points,
    - The energy factor of the hot water tank must increase by 4 percentage points (Ministry of Municipal Affairs and Housing 2012).

Last but not least, depending on the window to wall ratio, the U-value of the windows can potentially change. Where homes have up to 17 % window to wall ratio, the windows abide by the compliance packages; however, for a 17% to 22 % window to wall ratio, windows must upgrade. For example: 2 (w/m^2K) to 1.8, 1.8 to 1.6 and 1.6 to 1.4 (Ministry of Municipal Affairs and Housing 2012). In cases where the window to wall ratio is more than 22 %, a simulation has to be completed proving that the proposed building does not use more energy than the compliance package base building with windows of less than a 22 % window to wall ratio.

Overall, one of the most distinct alterations from previous codes is the mandatory simulated annual energy use of the proposed residential building not being able to exceed the simulated compliance package it is being compared against (Ministry of Municipal Affairs and Housing 2012). The compliance packages are simulated using the same components as the proposed building, in addition to also being simulated with the same location, dimensions and orientation. The simulated compliance package, however, is mandated to have details such as 400 mm O.C spacing for wall studs, floor joists, roof joists and rafters, and 600 mm O.C spacing for roof trusses for all of its simulations (Ministry of Municipal Affairs and Housing 2012). Where the proposed building can have the spacing designers feel is necessary as long as it is structurally sound. Other inputs include a maximum air changes per hour (ACH) that is 2.5 ACH for detached homes and 3.1 for attached homes (Ministry of Municipal Affairs and Housing 2012). Although, at this point in time there is no requirement yet to ensure that these values are met when the home is completed. But for an Energuide or Energy Star rating, a blower door test is needed. Possible simulations programs accepted for the 2012 OBC simulating standard are (Ministry of Municipal Affairs and Housing 2012):

- HOT2000 (version 9.34C or newer),
- Resnet,
- Optimiser,
- Energygauge,
- EnergyInsights,
- REM/Rate.

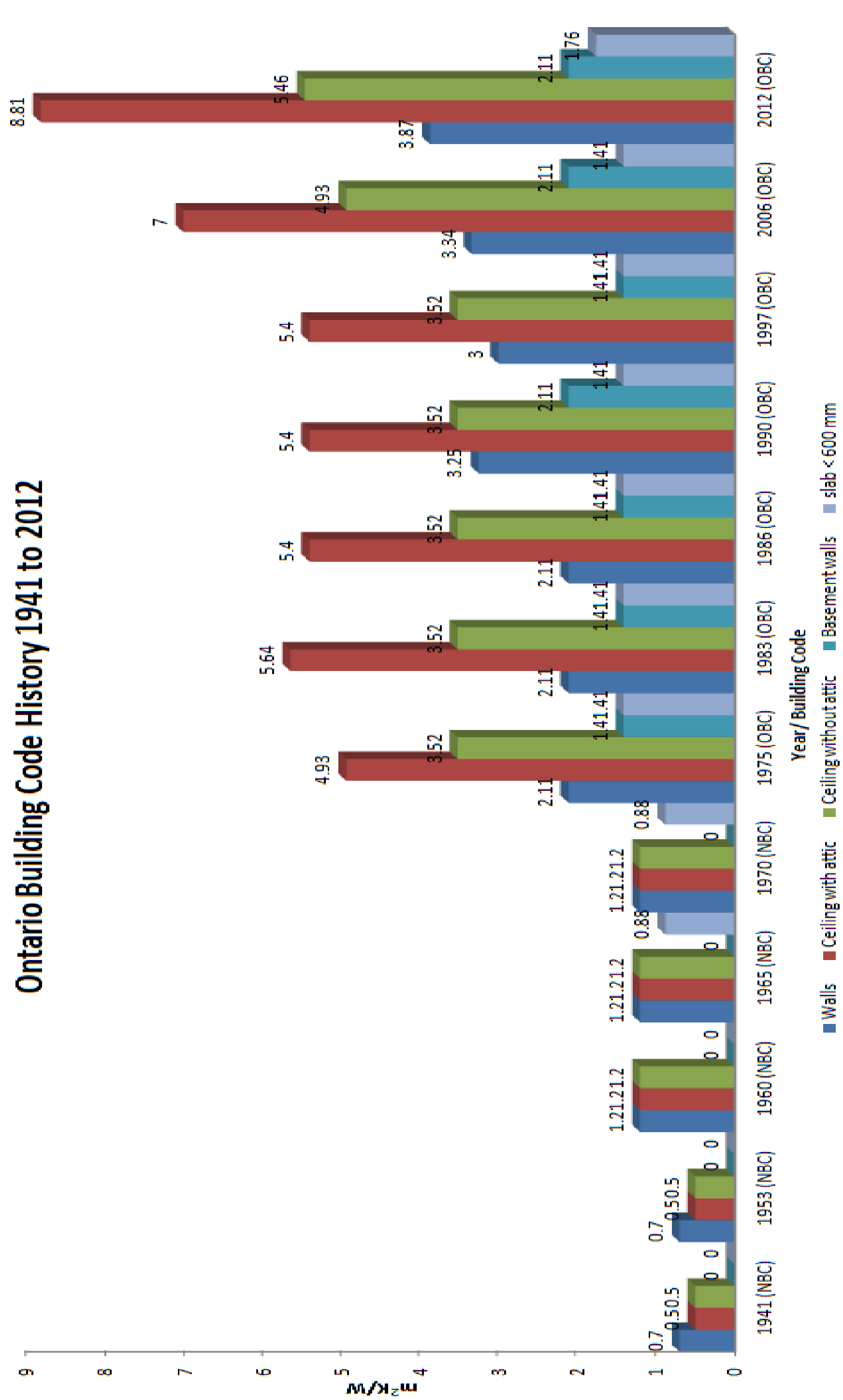


Figure G- 3: Ontario Building Codes History 1941 to 2012

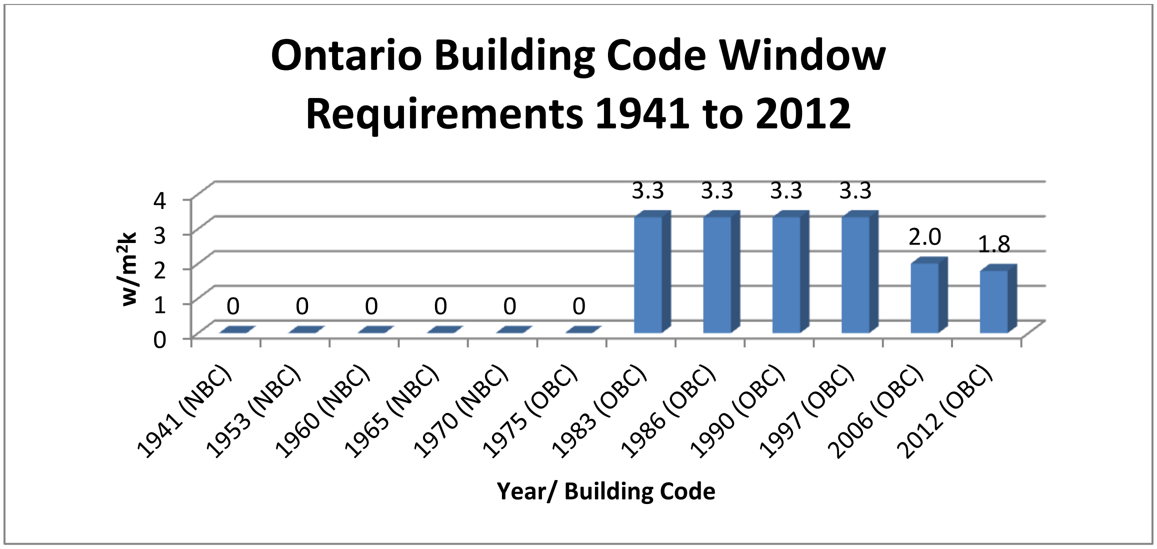


Figure G- 4: Ontario Building Code Window Requirements 1941 to 2012

In Figures G- 3 and 4, the history of the Ontario Building Code is illustrated. What is evident in these graphs, however, is the consistent growth that has occurred from 1941 to 2012. Over the span of 70+ years, there was one instance where the basement walls and above grade walls decreased in RSI value when compared to the earlier code. This one case was between 1990 and 1997 where the above grade walls went from 3.25 (m^2K/W) to 3 (m^2K/W) and the basement walls went from 2.11 (m^2K/W) to 1.41 (m^2K/W). Overall, the most drastic changes occurred once the Ontario Building Code was established in 1975, comparing these graphs of the building envelope to Figure G- 5 (Natural Resources Canada 2006). The homes that were evaluated prior to their retrofit had higher amounts of air leakage and there was a downward slope from pre-1945 to 2004 because construction methods and designs improved.

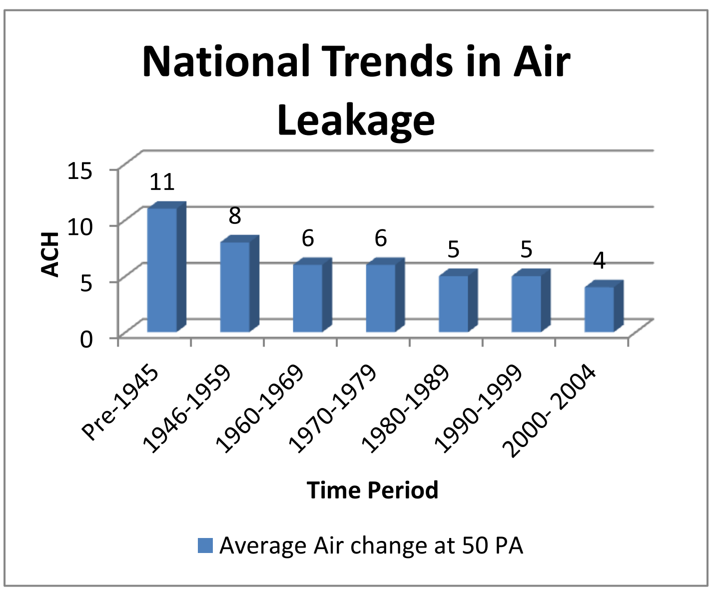


Figure G- 5: National Trends in Air Leakage for Houses in Canada

(Natural Resources Canada 2006)

Also available within this research were the building's average energy use for space heating and hot water tanks, as per Figure G- 6 (Natural Resources Canada 2006). Similar to the air leakage graph from pre -1945 until 2004, there was a consistent drop in the amount of energy used per year for these houses, which was highlighted in the dark blue columns. When comparing the building envelope graph with the air leakage graph, an obvious trend was clear. This trend showed as the building envelope increased there was less air leakage, which ultimately decreased the amount of energy annually used by Ontario homes. For the most recent building codes, the 2006 and 2012, this trend can be assumed to continue because the building envelope has intensified and air leakage should be lower with better practices. Although this was dependent on the builder as some builders do perform the blower door test to ensure the new homes meet the 2012 ACH standard even though the 2012 OBC does not state it requires it for prescriptive requirements.

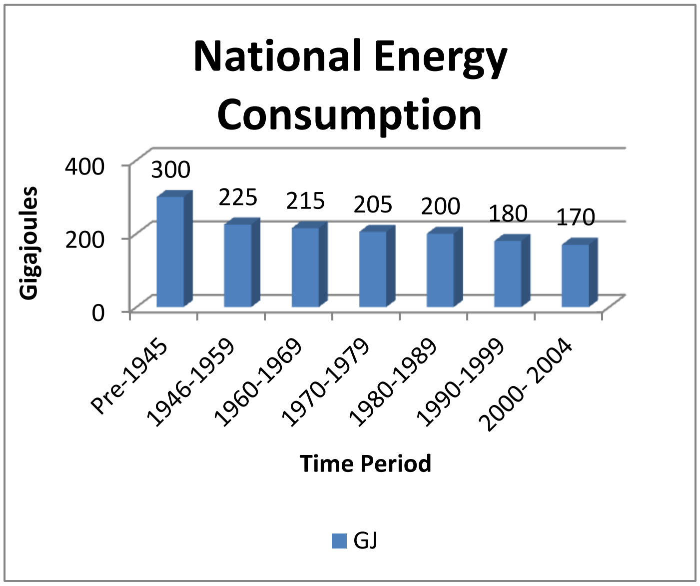


Figure G- 6: National Residential Energy Use in Canada

(Natural Resources Canada 2006)

Appendix H- Danish Building Regulations History:

The country of Denmark had approximately 2,735,000 dwellings, in 2009, and a growth rate of approximately 0.7 percent per year (Togeby, Kjaerbye, & Larsen 2011). Heating Denmark's residences accounts for about 25 % of Denmark's energy usage (Togeby,

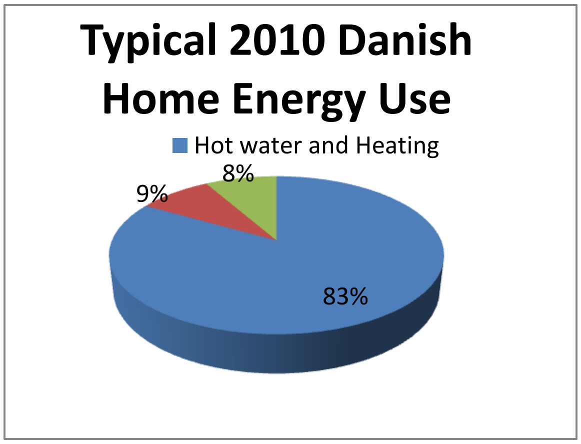


Figure H- 1: Denmark Map

(Danish Energy Agency 2011)

Figure H- 2: Typical 2010 Danish Home Energy Use

(U.S Department of State 2011)

Kjaerbye, & Larsen 2011). Overall, Denmark has 43,094 square kilometres and has a population of approximately 5,557,709 (U.S.Department of State 2011). Copenhagen, Denmark has 3653 heating degree days (American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc 2009). Denmark's coldest month is February, with an average around 0 ^{0}C, and their warmest month is July, with an average temperature of 17 ^{0}C (Danish Climate Centre 2012). Figure H- 1 shows, the average Danish home's energy use breakdown in 2010 and it was highly evident that the majority of consumption was from space heating and hot water heating accounting for 83 % (Danish Energy Agency 2011).

The first introduction of the Danish building regulations was in 1961 and from the period of 1961 until 2012, there had been nine editions of the Building Regulations ('BR') (Rose 2012). These editions became more advanced, due to developments in building technology that continually progressed towards higher performing components and equipment (Togeby, Kjaerbye, & Larsen 2011). As this new technology was introduced, it was later enforced as the new regulations. Eventually this encouraged companies and people to cultivate more efficient building materials. Also pressuring the growth of these regulations from a home-owner's perspective was the high taxes on energy consumption, where the Danish government gouges inefficient homes (Togeby, Kjaerbye, & Larsen 2011).

Prior to the 1961 regulation, there were prescriptive requirements for insulation in the building envelope (Rasmussen 2010). The 1961 edition, did not concern itself with the energy consumption aspect of building (Rasmussen 2010). At that time, the following components of the building envelope were enforced (The Danish Ministry of Economic and Business Affairs 1961):

- Walls greater than 100 kg/m^2 had to have a RSI value of at least 1 (m^2K/W).
- Walls that were less than 100 kg/m^2 had to have an RSI of at least 1.7 (m^2K/W).

For the purpose of this research, walls greater than 100 kg/m^2 were to be known as heavy-weight walls and walls less than 100 kg/m^2 were to be considered light-weight walls.

- Heavy walls tend to be the most commonly constructed type of wall and were usually made out of brick on the exterior, with either brick or light-weight concrete on the interior side (Rose 2012).
- Light-weight walls were constructed with brick and, the most commonly used light-weight wall material, lumber or in a few cases light-gauge steel (Rose 2012).

As for other portions of the building envelope (The Danish Ministry of Economic and Business Affairs 1961):

- Walls against unheated rooms was 0.5 (m^2K/W),
- Slab floors 2.2 (m^2K/W),
- Slab floor with floor heating 2 (m^2K/W),
- Floors facing outside 2.2 (m^2K/W),
- Floors facing unheated rooms 1.7 (m^2K/W),

- Floors facing heated rooms 1.3 (m^2K/W),
- Roof/ceiling 2.2 (m^2K/W).

In addition, these RSI values represented the entire assembly from the exterior to interior along with general thermal bridging in structural elements, except for the basement walls (The Danish Ministry of Economic and Business Affairs 1961). As far as slab floors were concerned, the insulation values prescribed through the entire regulation from past to present included the entire floor and was not dependent on the depth of the slab (Rose 2012).

Table H- 1: Danish Building Regulation History (New Extensions)

Building Envelope (RSI)	BR61	BR66	BR72	BR77	BR82	BR85	BR98	BR08	BR10
Wall >100kg/m^2	1.0	1.0	1.0	2.5	2.5	2.9	3.3	5.0	6.7
Wall < 100kg/m^2	1.7	1.7	1.7	3.3	3.3	3.3	5.0	5.0	6.7
Wall against unheated room	0.5	0.5	0.5	2.0	2.0	2.0	2.5	2.5	2.5
Basement wall	0.0	0.0	0.0	0.0	0.0	0.0	3.3	5.0	6.7
Slab floor	2.2	2.2	2.2	3.3	3.3	3.3	5.0	6.7	10.0
Slab floor with floor heating	2.2	2.2	2.2	3.3	3.3	3.3	6.7	8.3	10.0
Floor facing outside	2.2	2.2	2.2	5.0	5.0	5.0	5.0	6.7	10.0
Floor facing unheated room	1.7	1.7	1.7	2.5	2.5	2.0	2.5	2.5	2.5
Floor facing partly heated room	1.3	1.3	1.3	1.7	1.7	1.7	2.5	2.5	2.5
Roof/ceiling	2.2	2.2	2.2	5.0	5.0	5.0	5.0	6.7	10.0
Windows (U-value)	0	3	3.6	2.9	2.9	2.9	1.8	1.5	1.4
Doors (U -value)	0	3	3.6	2	2	2	1.8	1.5	1.4
Roof lights/ skylights (U -value)	0	0	0	0	0	0	1.8	1.8	1.7
Joints (in W/mK)	**BR61**	**BR66**	**BR72**	**BR77**	**BR82**	**BR85**	**BR98**	**BR08**	**BR10**
Foundation	0	0	0	0	0	0	0.2	0.12	0.12
Window/wall joint	0	0	0	0	0	0	0.06	0.03	0.03
Roof light/ skylight/roof joint	0	0	0	0	0	0	0.2	0.1	0.1

In 1966, the second edition was available which can be viewed in Table H- 1 above. Within this regulation, the only changes consisted of:

- Doors and windows with a minimum U-value of 3 W/m^{2}K as the bare minimum (The Danish Ministry of Economic and Business Affairs 1966).

The 1972 BR had a decreased U-value for the windows and doors to 3 from 3.6 W/m^{2}K (The Danish Ministry of Economic and Business Affairs 1972). Once the 1977 BR was imposed, the thermal resistances of the building envelope, rose higher then both the 1972 BR and the 1966 BR (The Danish Ministry of Economic and Business Affairs 1977). More importantly, changes to the main elements occurred such as (The Danish Ministry of Economic and Business Affairs 1977):

- Walls > 100 kg/m^2 changed to 2.5 (m^{2}K/W),
- Walls <100 kg/m^2 to 3.33 (m^{2}K/W),
- Slab floor to 3.33 (m^{2}K/W),
- Roof/ceiling to 5 (m^{2}K/W),
- Windows 2.9 (W/m^{2}K),
- Doors to 2 (W/m^{2}K).
- For other amendments see Table H- 1.

In (1977) of the BR, a limit was established based on the percentage of windows used in the building envelope. This limit stated that there cannot be more than 15 % windows on the exterior walls in comparison to the total heated floor area (The Danish Ministry of Economic and Business Affairs 1977). In cases where some homes did exceed this percentage, a calculation had to be provided supporting that the added windows were not creating more heat loss than the 15 % maximum window/door area percentage. Thus a reference building was created with the maximum 15 % window/door percentage and then compared against the proposed housing plans (Rose 2012). If the proposed housing plans had less heat loss than the reference building, it would pass.

In the 1985 edition's, there were two minor alterations to the prescriptive requirements, where heavy walls adjusted to 2.9 (m^{2}K/W) from 2.5 (m^{2}K/W) and floors facing unheated rooms went from 2.5 (m^{2}K/W) to 2 (m^{2}K/W) (The Danish Ministry of

Economic and Business Affairs 1985). Also different that year, was an energy frame calculation of 7.2 GJ + 0.252 x A (GJ), which only had to be used if the 15 % window/door requirement was breached. In this calculation, 'A' represented the total heated area and the energy frame only dealt with heating and ventilation (The Danish Ministry of Economic and Business Affairs 1985). The idea behind the energy frame was to allow building designers a wide boundary in which to design in, so that the building regulations did not handcuff their creativity (Rose 2012). In 1985 they introduced the first low energy building definition, which was made an option to the Danish building community. In order to be considered a 'low energy building' the dwelling had to utilize 50 % less energy than a building that fulfills the minimum requirements instilled by regulations (The Danish Ministry of Economic and Business Affairs 1985). Denmark did this to help prepare for the future, by developing low energy home options. They were then able to provide the construction industry with a glimpse into future requirements so new solutions and designs could be created, to help ease industry professionals into the next set of regulations (Rose 2012).

In 1998, a great transformation occurred in terms of the building envelope. For the first time specific thermal bridging joints were taken into consideration. However, the thermal bridges were only calculated and checked to ensure that it was 'OK' (Rose 2012). The specific thermal bridges included, but were not limited to, (The Danish Ministry of Economic and Business Affairs 1998):

- Around the foundation,
- Around the window/wall joint,
- The roof joint/sky light.

Before this launched, older versions of the regulations only stated that that building construction was only concerned with thermal bridges that did not result in potential condensation issues (Rose 2012). According to Jorgen Rose, who was a senior researcher for the Danish Building Research Institute and an expert in Denmark's thermal bridging field, The principle behind the thermal bridging demands were not to reduce heat loss but to ensuring that thermal bridging did not lead to mould or condensation problems within the assembly (Rose 2012). Table H- 1, showed that in 1998 the building envelope included some new increases/facets such as (The Danish Ministry of Economic and Business Affairs 1998):

- The basement wall and sky lights were introduced and respectively had an RSI of 3.33 (m^2K/W) and a U-value of 1.8 (W/m^2K),
- Heavy walls were valued at 3.3 (m^2K/W),
- Light walls were valued at 5 (m^2K/W),
- Slab floor were valued at 5 (m^2K/W),
- Windows and doors were valued at 1.8 (W/m^2K)

Note there were some other adjustments that can be examined in Table H- 1. The purpose behind basements not having minimum RSI values prior to this point was because basements were not to be used as habitable areas. When the top of the basement floor was lower than 1.25 m below grade, they were instead used for storage and laundry (Rose 2012). Due to this reason, basements tend to be expensive to add and the Danish population, in general, prefered to expand the ground floor area as opposed to excavating for a basement.

As for the energy frame, a new calculation was included in 1995 between the 1985 BR and 1998 BR. This calculation was 160 + 110/A MJ/m^2 per year (heating and ventilation) and stayed the same for the 1998 BR (The Danish Ministry of Economic and Business Affairs 1998). Furthermore in 1998, home builders had the option to either meet the energy frame, the heat loss frame, or the RSI (U-value) requirements for extensions in Table H- 1. In cases where there were more than 22 % windows/doors than heated floor area, the heat loss frame/energy frame calculation was to be used (The Danish Ministry of Economic and Business Affairs 1998). The process by which this was calculated was of a dwelling with exactly 22 % windows/doors to heated floor area and then another calculation of the actual dwellings window/ doors percentage to heated floor area. The goal was to provide assurances that the dwelling with more windows/doors was not using more energy than the dwelling with exactly 22 % windows/doors (The Danish Ministry of Economic and Business Affairs 1998).

In cases where the home did not have more than 22 % windows/doors to heated floor area the minimum requirements for extensions could be used as is. Since the energy frame in 1998, there had also been a minimum RSI (U-value Table), incorporated into the building regulations that was the minimum to safeguard against moisture problems within the building envelope (see Table H- 2) (Rose 2012). It was important to point out that if these minimum values were used, a home could not meet the energy frame and thus not meet building regulations. Therefore, it was generally accepted that the extensions RSI (U-value) seen in Table H- 2 has to be used to meet the energy frame, thus making it Denmark's real minimum requirements (Rose 2012). Due to the energy frame enabling creativity, builders could potentially increase other RSI values of the building envelope (above the extension requirements) and decrease another aspect of the building envelope to meet the minimum requirements to protect against condensation (Rose 2012).

Table H- 2: Denmark Minimum Requirements from 1998 to 2010

Building Envelope (RSI)	BR98	BR08	BR10
Wall >100kg/m2	3.3	2.5	3.3
Wall < 100kg/m2	2.5	2.5	3.3
Wall against unheated room	1.7	2.5	3.3
Basement wall	2.5	2.5	3.3
Slab floor	3.3	3.3	5.0
Slab floor with floor heating	3.3	3.3	5.0
Floor facing outside	3.3	3.3	5.0
Floor facing unheated room	3.3	3.3	5.0
Floor facing partly heated room	3.3	3.3	5.0
Roof/ceiling	4	4	5
Windows (U value)	2.9	2	1.8
Doors (U value)	2.9	2	1.8
Rooflight/skylight (U value)	2.9	2	1.8
Joints (in W/mK)			
Foundation	-	0.4	0.4
Foundation floor heating	-	0.2	0.2
Window/wall joint	-	0.06	0.06
Rooflight/skylight /roof joint	-	0.2	0.2

Overall, the cost of construction, drives what occurs in the Danish low-rise, residential market and the RSI of the building envelope (Rose 2012). In terms of low-energy buildings, there were now two options, a low-energy class 2 which was calculated using 50 + 1600/A kWh/m^2 per year (heating and ventilation) and low energy class 1, that was calculated by the formula 35 + 1100/A kWh/m^2 per year (heating and ventilation) (The Danish Ministry of Economic and Business Affairs 1998). It was essential to note, that these low-energy buildings were not introduced until 2006 even though they were considered part of the 1998 building regulation amendment.

Ten years later, the 2008 BR revolutionized the residential building industry. At this time, an energy frame was introduced that was not dependent on the window to heated floor area ratio (Rose 2012). The energy frame allowed designers to have a wider set of boundaries, so that a greater variety of diverse designs could be produced (Rose 2012). In 2008, the energy frame calculation changed to 70 + 2200/A= (kWh/m^2 per year) where A was the gross heated floor area and the result represented heating, cooling, domestic hot water and electricity to run fans, pumps and other equipment for heating, cooling and ventilation (The Danish Ministry of Economic and Business Affairs 2008). Even though the window to heated floor area ratio did not impact the energy frame, it did impact the prescriptive requirements found in Table H-1 because those values were based on windows/doors not exceeding 22 % of the heated floor area (The Danish Ministry of Economic and Business Affairs 2008).

In addition to the new energy frame, there was also an assortment of areas within the building envelope that developed where (The Danish Ministry of Economic and Business Affairs 2008):

- Heavyweight walls had to have the same RSI as lightweight walls of 5 (m^2K/W) (The Danish Ministry of Economic and Business Affairs 2008). This was due to the fact that it was thought that heavyweight walls had more thermal mass than the lightweight walls in previous editions, which would offset the difference in thermal resistance, creating the walls to be similar overall (Rasmussen 2010).
- Windows and doors also were better performing, where the U-value differed from 1.8 (W/m^2 K) to 1.5 (W/m^2 K),

- Basement walls strengthened to 5 (m^2K/W),
- Slab floor strengthened to 6.7 (m^2K/W),
- Roof/ceiling strengthened to 6.7 (m^2K/W).
- Thermal bridging went to:
    - 0.12 (W/mk) for foundations,
    - 0.03 (W/mk) for window/wall joints and,
    - 0.01 (W/mk) for roof joints.

The Danish construction industry also converted their stance on constructing homes that could 'breathe', hence a new maximum air change rate of 1.5 l/s per m^2, that worked out to be an equivalent of around 2.1 air changes per hour at a blower door test at 50 PA (The Danish Ministry of Economic and Business Affairs 2008). For other revisions that occurred to the envelope, see Table H- 1.

Prior to the 2008 building regulation, the European Performance of Building Directive c was put in place by the European commission and set minimum requirements for both new and renovated buildings. On top of this, there was also the need for an energy performance certificate to be created specifically for Denmark. Since 2006, any home that was newly constructed, was having major renovations, was sold or even rented had to have an energy label (IDEAL-EPBD 2012). This energy labeling system had a series of increments or levels from A to G (Figure H-3 below) that represented a series of separate energy requirements (IDEAL-EPBD 2012). To meet the 2008 BR, energy label 'B' had to be fulfilled. It was thought that this type of system allows for equilibrium throughout Europe and made it possible for the design to meet the final built

kWh/m^2 per year

Label	Residential	Non-residential
A1	< 35 + 1100/A	< 50 + 1100/A
A2	< 50 + 1600/A	< 70 + 1600/A
B	< 70 + 2200/A	< 95 + 2200/A
C	< 110 + 3200/A	< 135 + 3200/A
D	< 150 + 4200/A	< 175 + 4200/A
E	< 190 + 5200/A	< 215 + 5200/A
F	< 240 + 6500/A	< 265 + 6500/A
G	> 240 + 6500/A	> 265 + 6500/A

Figure H- 3: EPBD Energy Certificate Labeling System

(Aggerholm, Thomson, & Wittchen 2011)

building.

In 2010, the regulation that currently controls the Danish residential sector became available. As per the trend that has been occurring since 1961 it is the strictest, with the latest energy frame being 52.5 + 1650/A (kWh/m^2 per year) that represented the maximum amount of energy that can be consumed for heating, cooling, domestic hot water and electricity to run fans, pumps and other equipment for heating, cooling and ventilation (The Danish Ministry of Economic and Business Affairs 2010). Since the inception of the energy frame, the basement area is not included in the calculation because it is not considered a habitable area due to the basement floor being 1.25 m below grade (Rose 2012). The purpose behind such a rule is for safety precautions from a fire, as it is thought that the occupants would not be able to safely escape. In comparison to 2008, the 2010 regulations now require the following (The Danish Ministry of Economic and Business Affairs 2010):

- Walls at 6.67 (m^2K/W),
- Basement walls at 6.67 (m^2K/W),
- Slab floors at 10 (m^2K/W),
- Floors facing outside 10 (m^2K/W),
- Roofs/ceilings 10 (m^2K/W),
- Windows/doors 1.4 (W/m^2 K)
- Skylights to be 1.7 (W/m^2 K)
- Low-energy homes:
    - Class 1 Low-Energy building class 2020 - 20 + 1000/A kWh m^2 per year
    - Class 2 Low- Energy building class 2015- 30 + 1000/A kWh m^2 per year

As well, the air changes per hour did not change nor did the thermal bridging.

A new feature that launched in the 2010 regulation is the energy labelling for windows/doors and skylights. The label requires a minimum -33 kWh/m^2 for windows and -10 kWh/m^2 for skylights to be achieved, which is a heat balance specifically for

Denmark (The Danish Ministry of Economic and Business Affairs 2010). It is to be calculated using the following formula:

$$Eref = I \times Gw \times - G \times Uw \qquad \text{[Eq. 1]}$$

The letters stand for the following:

I-solar heat gain,

Gw- overall window solar energy transmittance,

G- the degree hours for the heating season (20 ^{o}C indoor temperature) and

U_w- Window's thermal transmission coefficient

(The Danish Ministry of Economic and Business Affairs 2010).

Since windows can be oriented a variety of distinct ways, the base reference distribution consists of the following: north 26 %, south 41 %, west 33 % and east 33 %, along with specific size of a window (1.23 x 1.48 m) and door (1.23 x 2.18) (The Danish Ministry of Economic and Business Affairs 2010). Equation 1 can be utilized in two different ways: one for windows, where 'I' is 196.4, 'G' 90.36, and one for skylights, where 'I' was 345 and G 90.36. The principle behind this energy label is to provide an efficient window that takes in consideration U-value and solar heat gain.

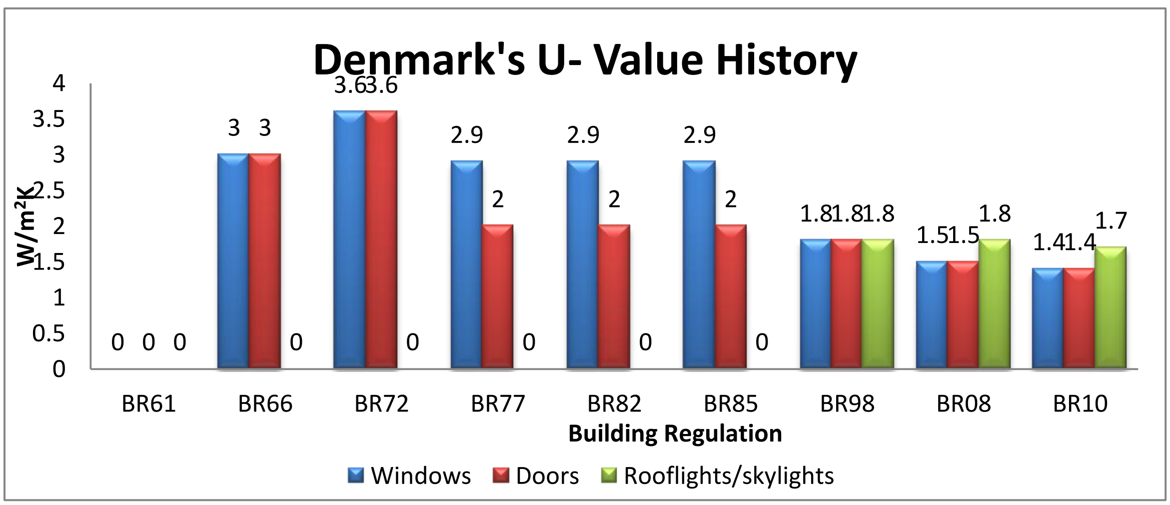


Figure H- 4: Denmark's U-value History

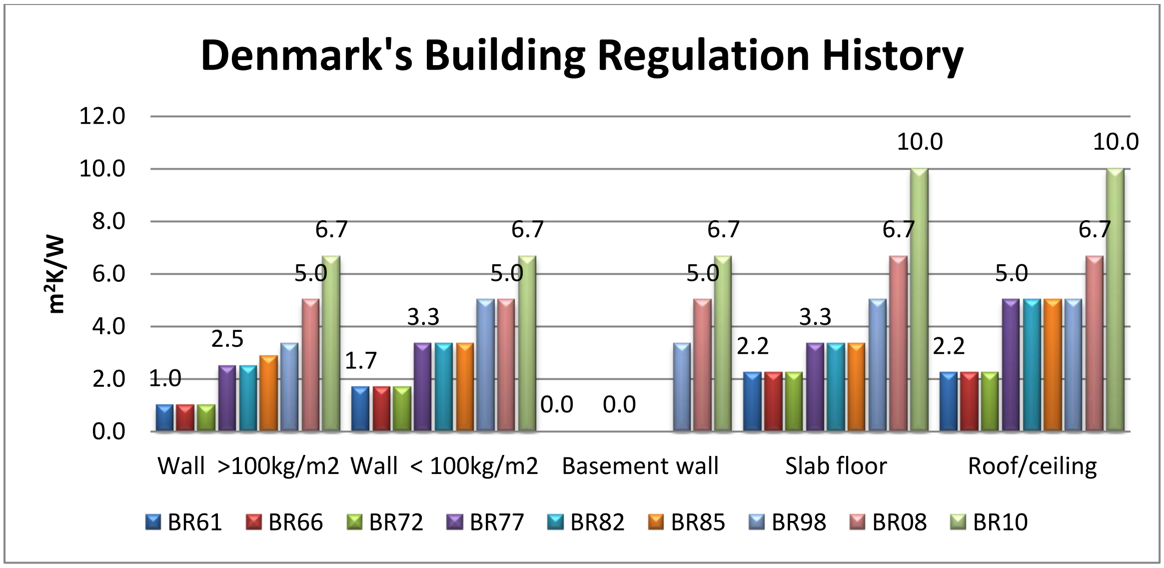


Figure H- 5: Denmark's Building Regulation History

According to (Figures H- 4 and 5) a graphical representation could be visualized that showed the main components of Denmark's building envelope from 1961 the first building regulation to 2010 which is the most current. It was evident that there has been continual development in the increased RSI and decreased U-values throughout Denmark's history of building regulations. When comparing these positive changes from between regulations to Figure H- 6, which was named 'Denmark's Natural Gas Consumption (heating)'.The influence of the building regulations was able to be clearly seen, due to the fact that the energy used by residential buildings had decreased from the 1961 BR to the 2010 BR. Between the years of Pre- 1930 to 1998, the yearly kWh/m^2 was gathered from

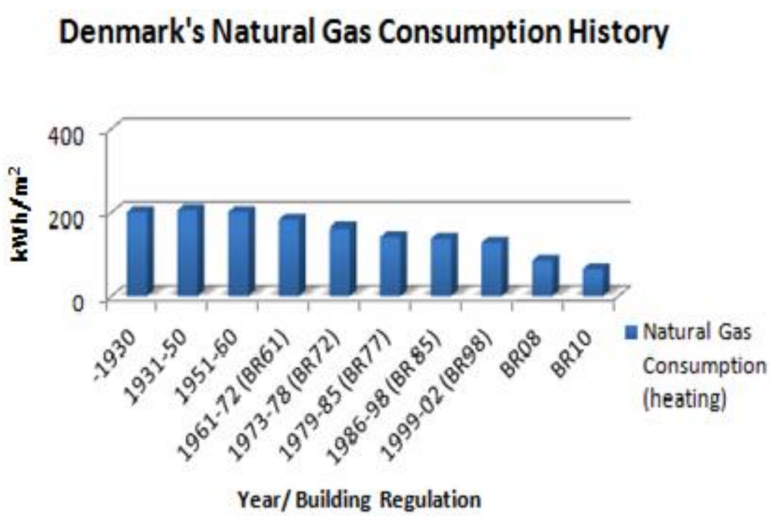


Figure H- 6: Denmark's Natural Gas Consumption History

(Kjaerbye, Larsen, & Togeby 2011)

a previous research by Togeby, Kjaerbye and Larsen that conducted a survey to help determine the yearly natural gas use per m^2 for heating and domestic hot water (Togeby, Kjaerbye, & Larsen 2011).

Overall, the research by these three authors represented a list of over 54,000 Danish homes with house sizes varying between 128 m^2 to 161 m^2 (Togeby, Kjaerbye, & Larsen 2011). In order to stay consistent with the 1998 building regulation, the average house size of 145 m^2 was instilled into the bar graph where the energy frame was then calculated. Thus, as far as the 2008 and 2010 building regulations are concerned, the kWh/m^2 was based on the maximum amount of energy allowed to be consumed per m^2 for heating, domestic hot water and electricity used for fans for heating, cooling and ventilation. Based on this information, the 2008 and 2010 building regulation energy usage results are a little biased in comparison to the years between 1930 and 1998. However, since domestic hot water and heating do in fact represent a large fraction of the 2008 and 2010 energy use, it can be assumed that (Figure H- 6) is generally accurate. Looking into the future, low energy homes, are going to become the minimum energy frame standard in 2015 and 2020, with the goal of have net zero energy homes implemented by 2020 (Danish Building Research Institute 2010).

Appendix I- Germany's Building Regulations History:

In Germany, household uses accounted for approximately 15% of the country's energy consumption and out of this, roughly 75% was used for space heating (Olonscheck, Holsten, & Kropp 2011). As a whole, there were 18 million residential buildings in Germany that made up 40 million homes (Olonscheck, Holsten, & Kropp 2011). These homes are spread out over 16 states covering 357,114 km^2, with an approximate population of 81,471,834 (U.S Department of State 2012). In the month of January, an average temperature of 3 ^{0}C occurred, while in July, the average temperature is 22 ^{0} C (Columbus Media Travel Ltd. 2012). Overall, this accounts for a total average of 3321 heating degree days (American Society of Heating, Refrigerating and Air-Conditioning Engineers).

Figure I- 1: Denmark Map

(U.S Department of State 2012)

In 1977, the first WSVO regulations were established in Germany. This regulation was the first thermal insulation regulation ordinance of its kind in Germany and was based off of the German Energy Savings Act (The Federal Institute of Building, Urban Affairs and Spatial Development 2012). It was established due to the oil crisis that occurred in the 1970's and was implemented to reduce Germany's reliance on imported energy (Federal Institute for Research on Building, Urban Affairs and Spatial Development 2012). Germany began to focus on putting in place stringent demands for the heating of its buildings to reduce the amount of energy consumed (Federal Ministry of Economics and Technology 2008). Prior to this, technical standards were the only regulations, which were called DIN 4108 (The Federal Institute of Building, Urban Affairs and Spatial Development 2012). In total, there have been three Thermal Insulation Regulation Ordinances and thus four Energy Saving Ordinances with a fifth set to become availabe in the later half of 2012 (The Federal Institute of Building, Urban Affairs and Spatial Development 2012). Before the first WSVO in 1977, technical standards such as the DIN 4108 were used as tools and standards meant to provide protection from humidity and mould growth throughout the building envelope, which also helped reduce heat loss (DIN 4108 1969).

For these regulations to be successful, Germany believed that a program had to be integrated into the country through the means of 'three pillars', which was thought of as the foundation of the Energy Saving Regulations (Power & Zulauf 2011):

(i) A legislated regulation,
(ii) Promoted alternatives,
(iii) Professional information/advice.

The legislated regulation, for the purpose of this research, was the EnEV (WSVO), which was considered because it dealt strictly with building regulations. Promoted alternatives, however, were concerned with government affiliated programs like the 'kFw' that were available to help promote energy conservation through providing grants, subsidies or other funds (Power & Zulauf, 2011). The last of the pillars pertained to information and advice available to the public to educate them on energy efficiency. This pillar was completed by training experts within the field, along with an adequate support of information and campaigns to help spread the word (Power & Zulauf 2011). By incorporating all of these pillars, Germany excelled at implementing a system that created a reduction in energy consumption within the country. In fact, in an international research of green measures, Germany's energy efficiency in buildings methods were ranked 1st out of 100 policy enforced countries (Hohne, Burck, Eisbrenner, Vieweg, & Griebhaber 2009).

Since the 'KfW' was such a vital part of Germanys' success, it should be explained in more detail. The 'KfW' stands for Kreditanstalt für Wiederaufbau and translates as the mean bank of reconstruction (Power & Zulauf 2011). This was an investment bank used to finance energy conservation and renewable energy infrastructure, in the residential industry (Blok, Boermans, Hermelink, & Schimschar 2011). Set up after World War II to replenish the building stock, it was a regional and federal government bank in Germany whose purpose was to help support the energy efficiency industry (Power & Zulauf 2011. In addition to providing financing for renovations or refurbishment, the KfW also provided support to new construction loans were able to be attained and were dependent on the percentage of energy saving the home would accumulate over the German Saving Ordinance (KfW 2012). For example, a 'KfW55' home used 55 % of the primary energy demand of a home that met the 2009 EnEV (Blok, Boermans, Hermelink, & Schimschar 2011). Based on this percentage, larger loans or lower interest rates were available for more energy efficient homes (KfW 2012). For more detailed information about the rules and loan amounts, please see the KfW website (KfW 2012).

The 1977 WSVO was broken down into two categories: buildings with normal indoor temperatures and buildings with low indoors temperatures. The residential sector fell under the buildings with normal indoor temperatures (19 ^{0}C + temperature). The requirements under this ordinance could vary for the exterior walls (including windows and doors) and were dependent on the ground plan as per Figure I- 2 where (WärmeschutzV 1977):

- A minimum RSI of 0.69 (m^{2}K/W) for the building on the left was required,
- A minimum 0.65 (m^{2}K/W) for the building in the middle, and
- A 0.57 (m^{2}K/W) for the building on the right (WärmeschutzV 1977).

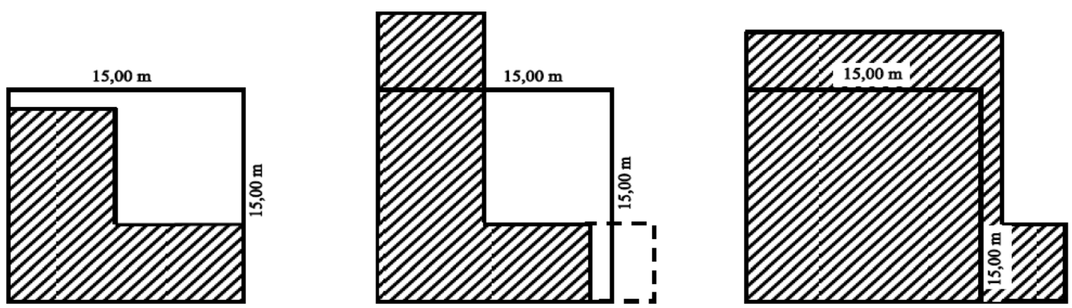


Figure I- 2: German WSVO 1977 Ground Plan Requirements

(WärmeschutzV 1977)

These three values included, the windows and doors within the exterior walls and also represent the entire RSI value for the wall from outside to inside. Laboratory tested windows were also highlighted within the ordinance where the maximum U-value found was 3.5 W / (m² · K) (WärmeschutzV 1977). In other locations of the building envelope individual requirements, included (WärmeschutzV 1977):

- A minimum Roof/ ceiling 2.22 (m^2K/W) was required,
- Basements ceilings and walls or ceilings against unheated rooms were 1.25 (m^2K/W),
- Ceilings and walls were in contact with soil were 1.11 (m^2K/W).

Throughout the 1977 WSVO, there were other ways to determine the minimum resistance to heat flow through the means of calculations for external walls only, which consisted of utilizing the heat transmittance surface area and divided it by the volume of the building (WärmeschutzV 1977). This ratio created the external walls' RSI to vary from 0.71 to 1.67 (m^2K/W) (WärmeschutzV 1977). Around windows and doors there were also strict joint permeability coefficients demanded, according to DIN 18055 (WärmeschutzV 1977).

On February 24 1982, an amended version of the thermal insulation ordinance (WSVO) was made available and governed German building with some new demands (The Federal Institute of Building, Urban Affairs and Spatial Development 2012). Although it came into effect in 1982, it was 100 % officially implemented in 1984 (The Federal Institute of Building, Urban Affairs and Spatial Development 2012). Thus, it was named the thermal insulation ordinance 1982/1984. Like the first ordinance in 1977, buildings were broken up into the categories of normal indoor temperature and low indoor temperature. However, the thermal resistance values increased on all accounts. For buildings that fell under the category of Figure I- 2 (WärmeschutzV 1982):

- 0.83 (m^2K/W) was now the minimum for the left and middle buildings external walls (with doors and windows),
- 0.67 (m^2K/W) was now the minimum for the buildings to the right external walls (with windows and doors),
- Roofs/ ceiling increased to a 3.33 (m^2K/W),

- Basement ceilings, walls and ceilings against unheated spaces were now grouped together with ceilings/walls that were against the soil and 1.8 (m^2K/W) was the new requirement.

Also similar to 1977, was the calculation of heat transmittances as the area divided by volume to determine external wall (only) assemblies RSI that increased to 0.83 (m^2K/W), at its lowest to 1.67 (m^2K/W), at its highest (WärmeschutzV 1982). Also in terms of windows, they were now 3.1 W / ($m^2 \cdot K$) (WärmeschutzV 1982).

The last edition of the WSVO was established in 1995. With the introduction of low-E glazing in the early 1990's, windows were now to have a positive energy balance as long as they were oriented and designed accordingly (The Federal Institute of Building, Urban Affairs and Spatial Development 2012). This enabled Germany to approach the 1995 WSVO differently and they therefore incorporated for the first time an annual heating demand for small residential buildings up to two stories. Similar to the previous WSVO's, normal indoor temperature buildings were used and the heat transmittance surface area plus volume of the building were divided to determine the ratio. This ratio was then input into the following equation:

$$Q'H=13.82+17.(A\div V) \quad \textbf{[Eq. 2]}$$

Where Q'H was the buildings heading demand kWh / ($m^3 \cdot$ a)
A, area of building enclosure (m^2)
V, volume of building (m^3)
(WärmeschutzV 1994).

The answer was then divided by 0.32 to find what the maximum annual heating demand was in kWh/($m^2 \cdot$a). More in depth calculations for the annual heating demand, were available to include ventilation heat demand, internal heat gain, solar heat gain and the transmission of heat loss (WärmeschutzV 1994). This equation was the following:

$$Q'H = 0.9 \times QT + QL) - (QI + QS) \quad \textbf{[Eq. 3]}$$

with QH representing a buildings heating demand (kWh/a)
QT, transmission of heat demand (kWh/a)
QL, ventilation heat demand (kWH/a)
QI, internal heat gains (kWh/a)
QS, solar heat gain (kWh/a)
(WärmeschutzV 1994).

In cases where these values were not being used, the other method might have been instilled to help determine the maximum annual heating demand. There were, however, overall building envelope values that must be at minimum (WärmeschutzV 1994):

- An RSI of 2 (m^2K/W) for exterior walls (with windows and doors not being included anymore),
- A maximum windows U-value of 1.8 W / ($m^2 \cdot K$),
- Ceilings RSI 3.33 (m^2K/W),
- Basement ceilings and walls/ceilings against unheated rooms/ ground 2 (m^2K/W) must be supplied (WärmeschutzV 1994).

Beyond this, there were no other differences in comparison to the 1982/1984 version.

Many significant modifications emerged in 2002, with the most noticeable being that the name thermal insulation ordinance changed. The thermal insulation ordinance was now known as the EnEV or Energy Savings Ordinance (Verordnung über energiesparenden Wärmeschutz und energiesparende Anlagentechnik bei Gebäuden 2001). The 2002 EnEV continued with the annual primary energy demand trend. However, now there were a variety of different scenarios to determine the annual primary heating energy demand. Either a table could be used to break down specific area/volume ratios, creating ratios in 0.10 increments. Or in cases where the specific area and volume were in between these increments the equations were as follows:

$$Qp'' = 50.94 + 75.29 \cdot A \div Ve + 2600 \div (100 + AN) \quad \textbf{[Eq. 4]}$$

Where Qp'' is the annual primary energy demand (kWh $m^2 \cdot a$)
A, heat transmitting surface area (m^2)

Ve, heated building volume (m^3)
AN, 0.32 Ve
(Verordnung über energiesparenden Wärmeschutz und energiesparende Anlagentechnik bei Gebäuden 2001).

This equation had to be used for residential buildings that were not heated by electricity (Verordnung über energiesparenden Wärmeschutz und energiesparende Anlagentechnik bei Gebäuden 2001). As for those that had water heated by electricity, the equation was:

$$Qp''=72.94+75.29\cdot A\div Ve \quad \text{[Eq. 5]}$$

Where Qp'' is the annual primary energy demand (kWh m^2 ·a)
A, heat transmitting surface area (m^2)
Ve, heated building volume (m^3)
(Verordnung über energiesparenden Wärmeschutz und energiesparende Anlagentechnik bei Gebäuden 2001).

Equation 5 was the annual primary energy demand accounting for heating, hot water and ventilation. The final result of this calculation represented a maximum energy demand for a reference building with the same geometry, floor area and layout as the proposed building (Verordnung über energiesparenden Wärmeschutz und energiesparende Anlagentechnik bei Gebäuden 2001). Other ways to determine the annual primary energy demand, were:

$$Qp''=(Qh+ep\cdot Qw) \quad \text{[Eq. 6]}$$

Where Qp'' is the annual primary energy demand (kWh m^2 ·a)
Qh, represents annual heating requirement, (kWh m^2 ·a)
ep, a consumption Figure in DIN V 4701-10: 2001-02
Qw, hot water surcharge (kWh m^2 ·a)
(Verordnung über energiesparenden Wärmeschutz und energiesparende Anlagentechnik bei Gebäuden 2001).

The third way to determine annual energy demand was by abiding by DIN EN 832: 2001-02.

Also, the maximum heat loss transmission rates were added to this new ordinance to be calculated using the following equations:

$$H = Qp + 16.2 \cdot AN, \div AN \qquad \textbf{[Eq. 12]}$$

Qp,c'', was annual primary energy demand for cooling kWh/(m²a)
16.2 kWh/(m²a)
AN,c , cooled area of the home (m^2)
AN, 0.32 *Ve
Ve, heated building volume (m^3)
(Verordnung über energiesparenden Wärmeschutz und energiesparende Anlagentechnik bei Gebäuden 2007).

Other than these alterations, nothing else was mandated to increase the RSI values of the building envelope, thermal bridging requirements or decrease the air changes per hour.

The current EnEV reigning over Germany is the 2009 version. New to this ordinance (Verordnung über energiesparenden Wärmeschutz und energiesparende Anlagentechnik bei Gebäuden 2009):

- 3.57 m^2K/W, exterior wall against ground,
- 2.86 m^2K/W, basement walls, foundation slab and ceilings against unheated areas/ground,
- 5 m^2K/W roofs/ ceiling,
- 1.30 W/(m²K) windows (SHGC minimum 0.60),
- 1.80 W/(m²K) doors.
- Specific transmission heat loss was now 0.40 w/m^2k.
- Thermal bridging heat tolerances were governed to use the 0.05 w/m^2k for the entire surface to help limit heat loss To simplify, basically the 0.05 was added to the coefficients of heat transfer which was also the case in the past EnEV's (Verordnung über energiesparenden Wärmeschutz und energiesparende Anlagentechnik bei Gebäuden 2009).

Beyond this, no additional adjustments were made to the EnEV 2009, other than the calculations which were not highlighted in the document as they were now completed by simulation software (Verordnung über energiesparenden Wärmeschutz und energiesparende Anlagentechnik bei Gebäuden 2009). It must be noted that this brief history of Germany's regulations were the general requirements or concepts and that there were more in depth calculations, regulations and variables that were also taken into consideration throughout the WSVO's and EnEV's. Therefore, for a more in depth review, it is recommended to thoroughly examine these documents as a whole. Sara Kunkel, who works for the Federal office for Building and Regional Planning, stated that simulation software such as 'EnEV plus' was extremely important because of all the standards details that were incorporated in the calculations (Kunkel 2012). This software makes it possible to calculate the whole buildings energy use thoroughly, comparing it against a reference building (proposed versus baseline) using the same climate, geometry, building use and orientation (Kunkel 2012).

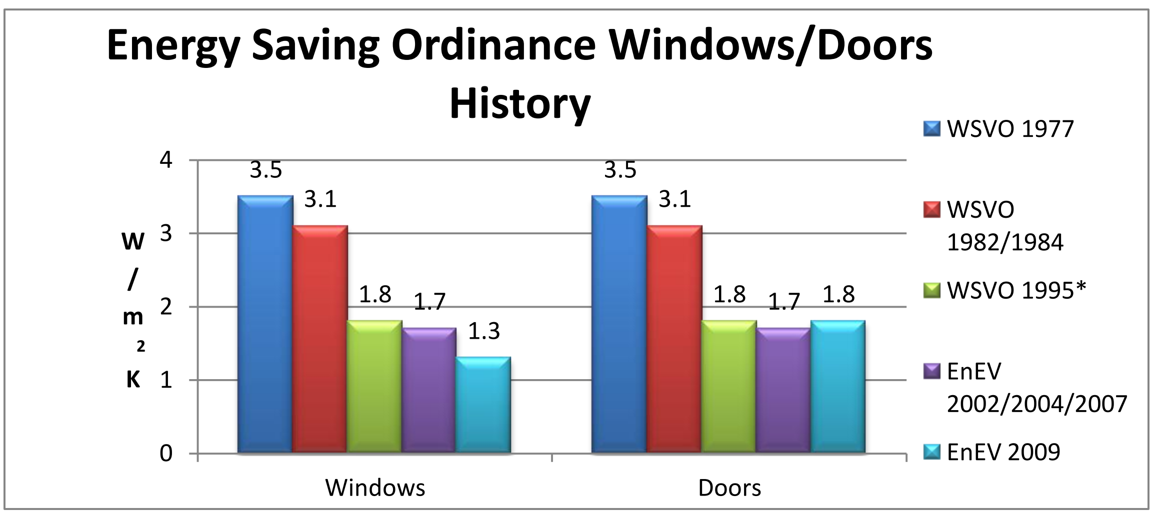


Figure I- 3: German Energy Saving Ordinance Windows/ Doors History

A historical representation could be viewed in Figures I- 3 (above) and I- 4 (below). Figures I- 3 and I- 4, represent the general consensus that progress has been positive in terms of the building envelope. When comparing Figures I- 3 and I- 4 to the annual heat demand line graph (Figure I- 5), the growth of the building envelope and reduction in air leakage throughout ordinances' history, impacted the minimum heating demand (heating, hot water and auxiliary equipment for heating) for low-rise, residential dwellings (Blok, Boermans, Hermelink, & Schimschar 2011). This impact has drastically reduced the amount of energy used per square meter of a house from the 1977 WSVO to the 2009 EnEV. An amended EnEV is set to release in 2012, 2015 and 2018. These editions are reportedly going to increase energy savings 30% for each release, thus ultimately allowing Germany to become closer to its goal of net-zero energy buildings or Passive House Standard by 2021 (Blok, Boermans, Hermelink, & Schimschar 2011).

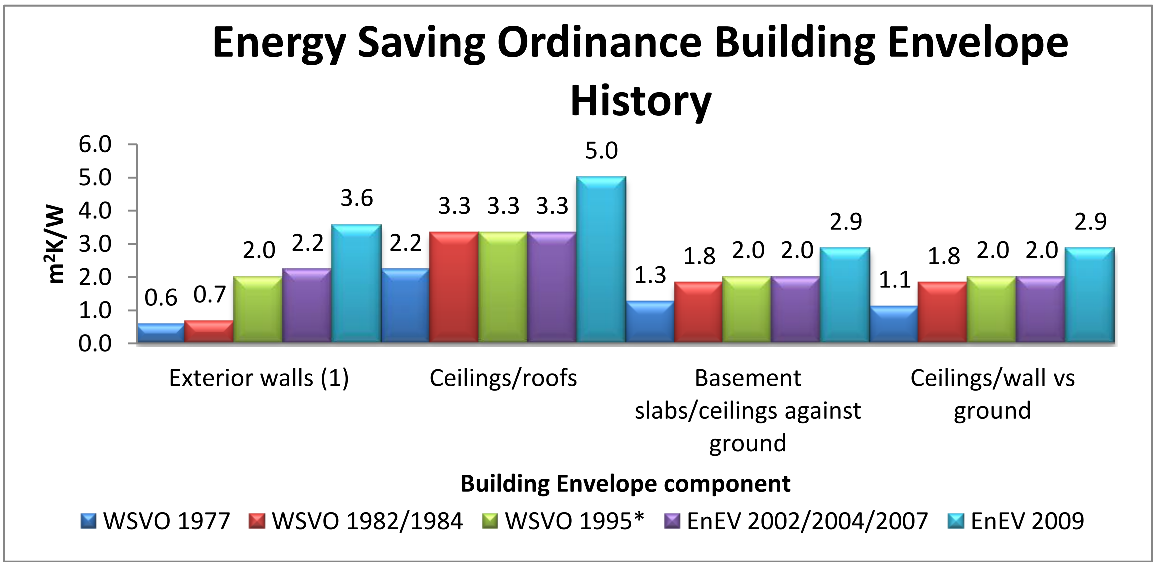


Figure I- 4: Energy Saving Ordinance Building Envelope History

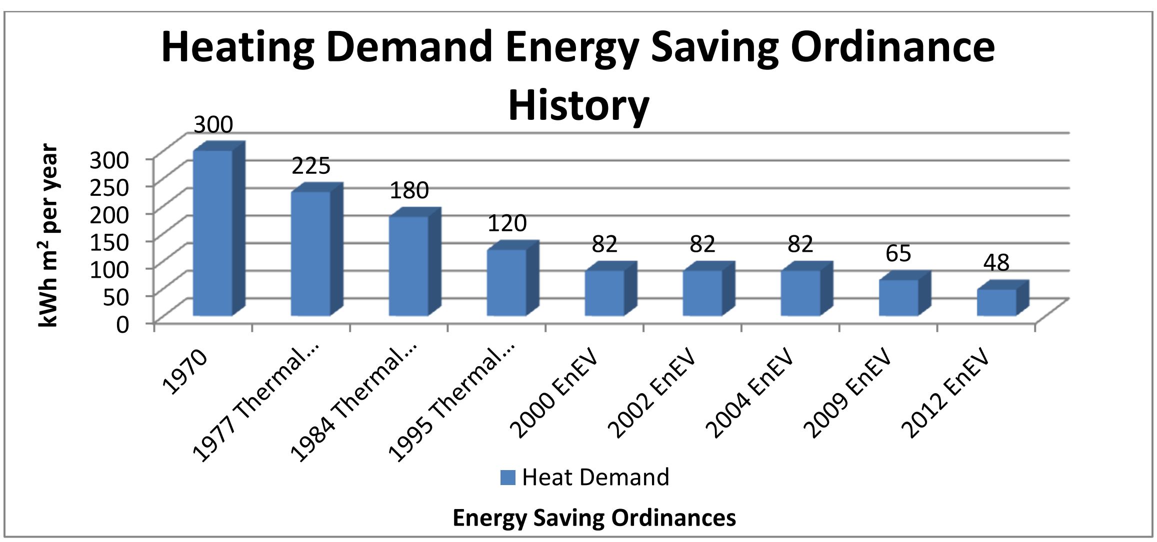


Figure I- 5: Heating Demand Energy Saving Ordinance History

(Schettler-Kohler & Kunkel 2010)

Appendix J- Passive House Standard:

The Passive House is a standard that incorporates a high level of comfort with extremely low energy consumption (International Passive House Association 2010). To accomplish this, the Passive House includes the following: thick amounts of thermal insulation, triple-glazed windows with insulated frames, an airtight building, thermal bridge-free construction, and a very efficient heat recovery and ventilation system. A Passive House can built anywhere in the world, with minor/major adjustments depending on the climate. This type of dwelling does not use more than 1.5 m^3 of natural gas or 15 kWh annually per square meter of living space (International Passive House Association 2010). As a result, a small amount of heating is required because little heat is lost through the building envelope. In fact, a majority of the heat sources that are used pertain to solar heat gain, the occupants, appliances and heat from the extracted inside air.

n order to be certified as a Passive house, the heating demand (not including ventilation, fans or pumps) cannot exceed 15 kWh per square meter of living space per year (Promotion of European Passive Houses' 2007). In addition, the heating load must not be more than 10 W/m^2 (International Passive House Association 2010). For a climate where cooling is required, the energy demand cannot go beyond the 15 kWh per square meter of living space per year for heating. The air tightness of the building envelope must also be less than 0.6 air changes per hour. Whereas for the overall home, the primary energy requirement which includes hot water, cooling, heating, auxiliary equipment, and other household electricity is not to exceed 120 $kWh/m^2/A$ per year (International Passive House Association 2010).

The windows that are used for these types of homes are at least triple-glazed with well-insulated frames for colder climates, and the orientation in which these windows are placed is very important (International Passive House Association 2010). The ultimate goal for the windows is to ensure that they do not lose more energy than what they gain. Simultaneously, overheating is also a concern at certain times of the year, thus the locations of windows must be planned accordingly and are to be below 0.80 W/m^2k with at least 50 % solar energy transmittance (International Passive House Association 2010). In terms of a thermal bridge free design, details of the building envelope must ensure that heat loss does not occur above a maximum of 0.01 w/mk throughout any point in the building; essentially this means there are to be virtually no thermal bridges. This is specifically important, at corners, edges, connections and areas where there are penetrations (International Passive House Insitute 2010).

Another important aspect of the Passive House is its airtight construction. This not only reduces the heat loss drastically, it also allows for a comfortable interior when other ventilation is provided. The benefit of having an airtight home is it limits the chances of having mould or decay within the building envelope assemblies because the warm moist air is not able to transfer through the wall towards the outside (International Passive House Association 2010). Due to these types of dwellings being air tight, ventilation is therefore very important and the most common rule is that at least 30 m^3 of fresh air is to be provided per person per hour (International Passive House Association 2010). Other features of a Passive Home include a heat recovery ventilator (HRV) that is a minimum of 75 % efficient, with a minimal energy consumption of less than 0.45 Wh/m^3 (Passive House Institute U.S 2012). Also extreme amounts of insulation are required: at least 6.67 (m^2K/W) for the walls, ceiling, slab and other exterior components (International Passive House Association 2010).

The Passive House standard was formed in1988 by Dr. Wolfgang Feist and Professor Bo Adamson. In1988, they began building a Passive House as a demonstration model. However, it was not until 1991 that the model was fully occupied and energy consumption was monitored to achieve the standard 15 kWh/m^2 per year, which was approximately 90 % less than an average typical home (Passive House Insitute 2007). Since that time, there have been more than 13,000 Passive Houses constructed in Germany and the standard has continued to grow on an international level (International House Insitute 2010). The Passive House planning package is now available for developers, builders, architects, engineers and energy auditors to calculate whether their design meets the Passive House Standard. This planning package is strictly made for the

Passive House and prepares energy balances, calculates heating loads, helps determine the dimensions of the ventilation system, as well as many other features (Passive House Insitute 2007). To be acknowledged as a Passive House, the home must be awarded a certificate from an accredited certifier (International Passive House Association 2010).

Appendix K- Ontario 2006 and 2012 THERM Results:

For the assumptions and inputs placed into THERM for these simulations, go to Appendix E. These building envelope sections represent what is typically done in Brookfield Homes (Brookfield Homes 2012).

Inside Corners:

38 x 140 mm (2x6) 2012-

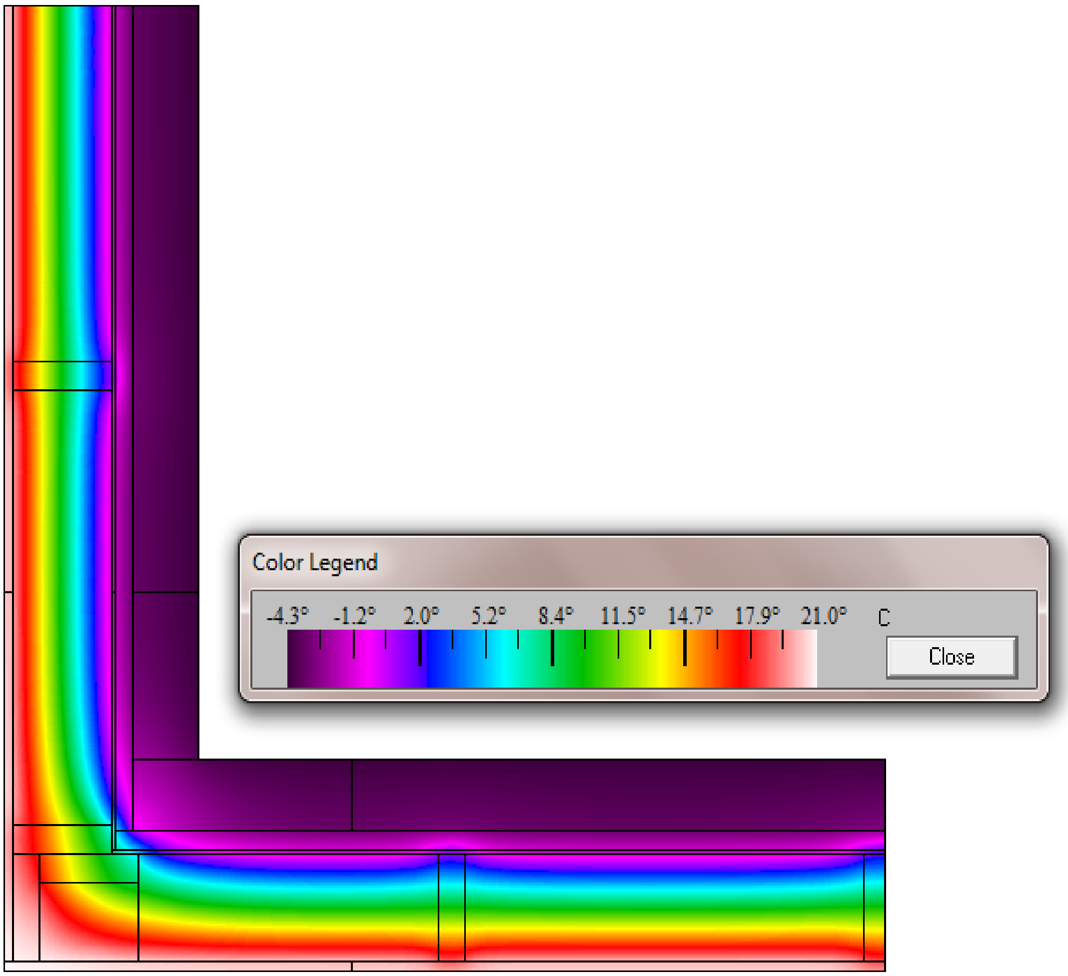


Figure K- 1: 38 x 140 mm OBC 2012 Inside Corner

38 x 89 mm (2x4) 2012-

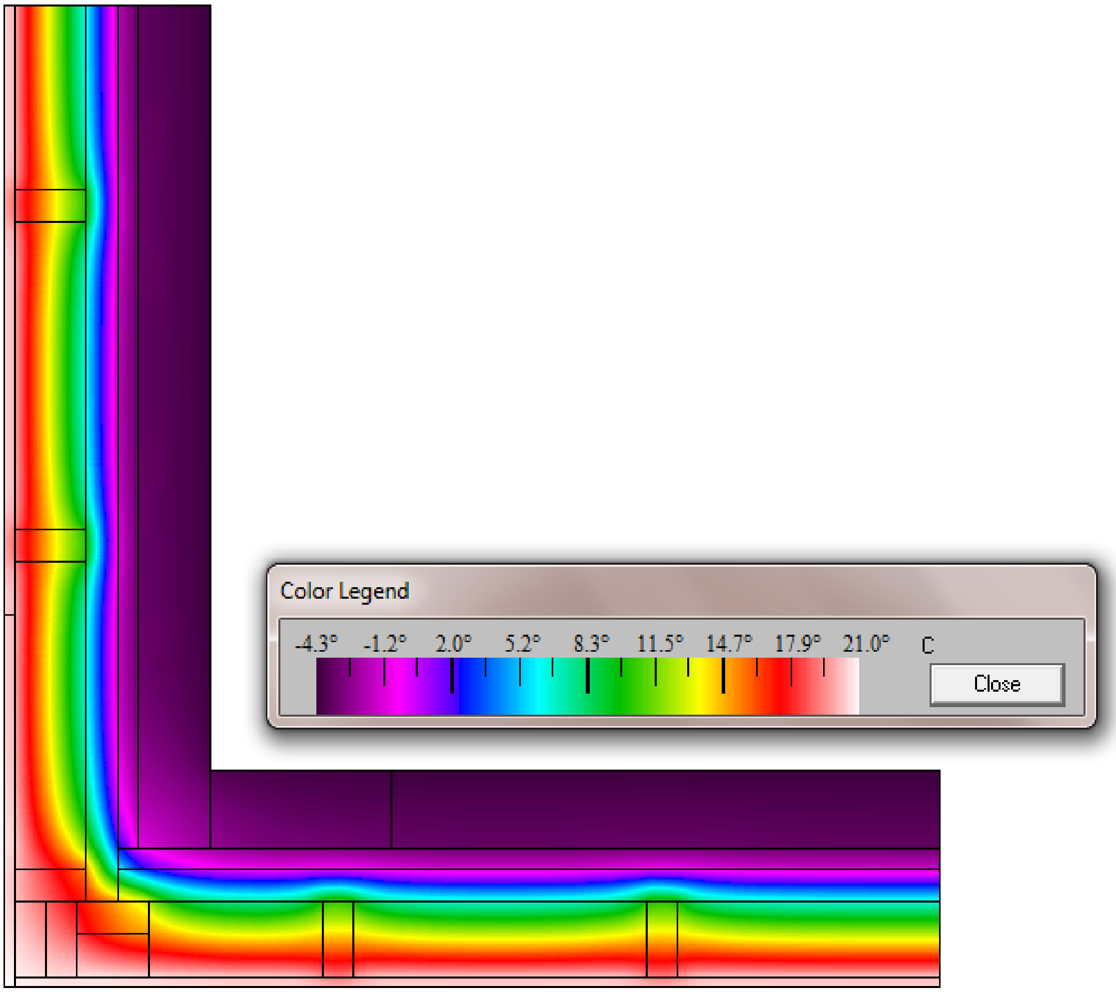


Figure K- 2: 38 x 89 mm (2x4) OBC 2012 Inside Corner

38 x 140 mm (2x6) 2006-

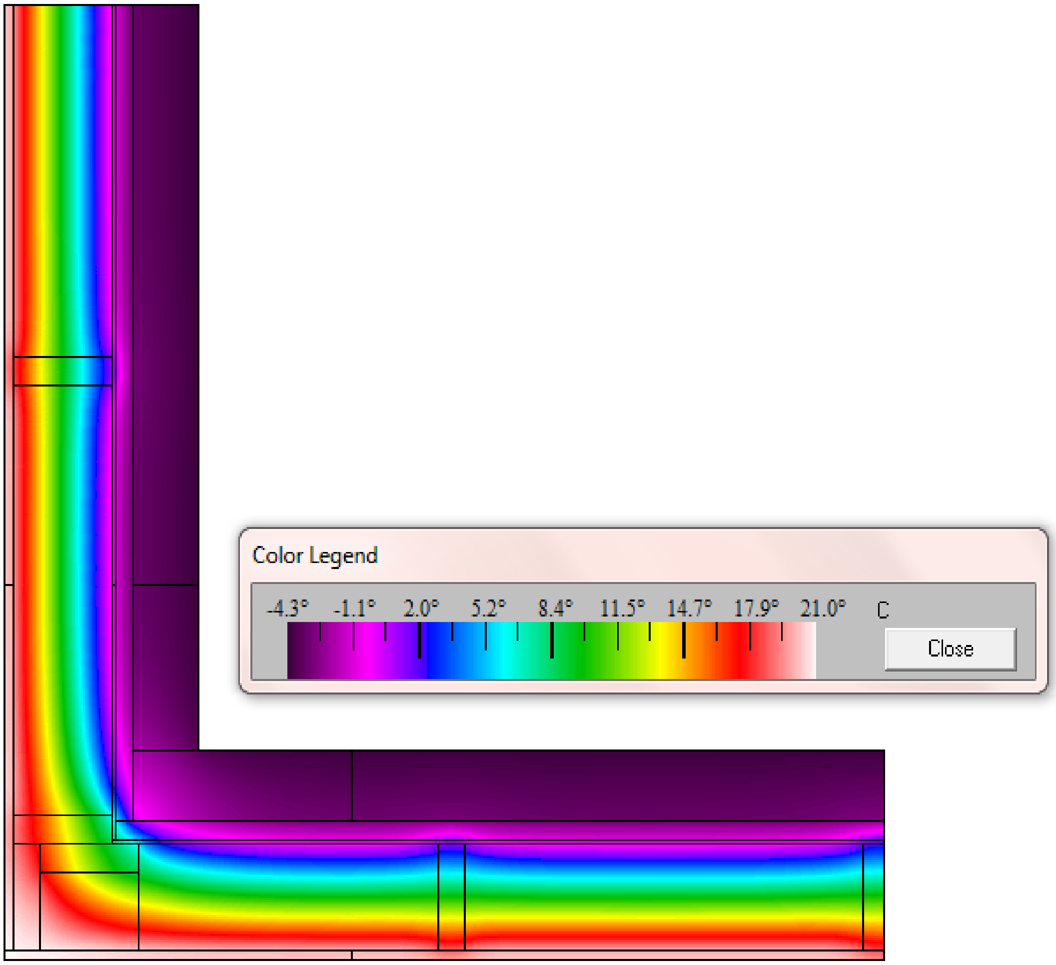


Figure K- 3: 38 x 140 mm OBC 2006 Inside Corner

38 x 89 mm (2x4) 2006-

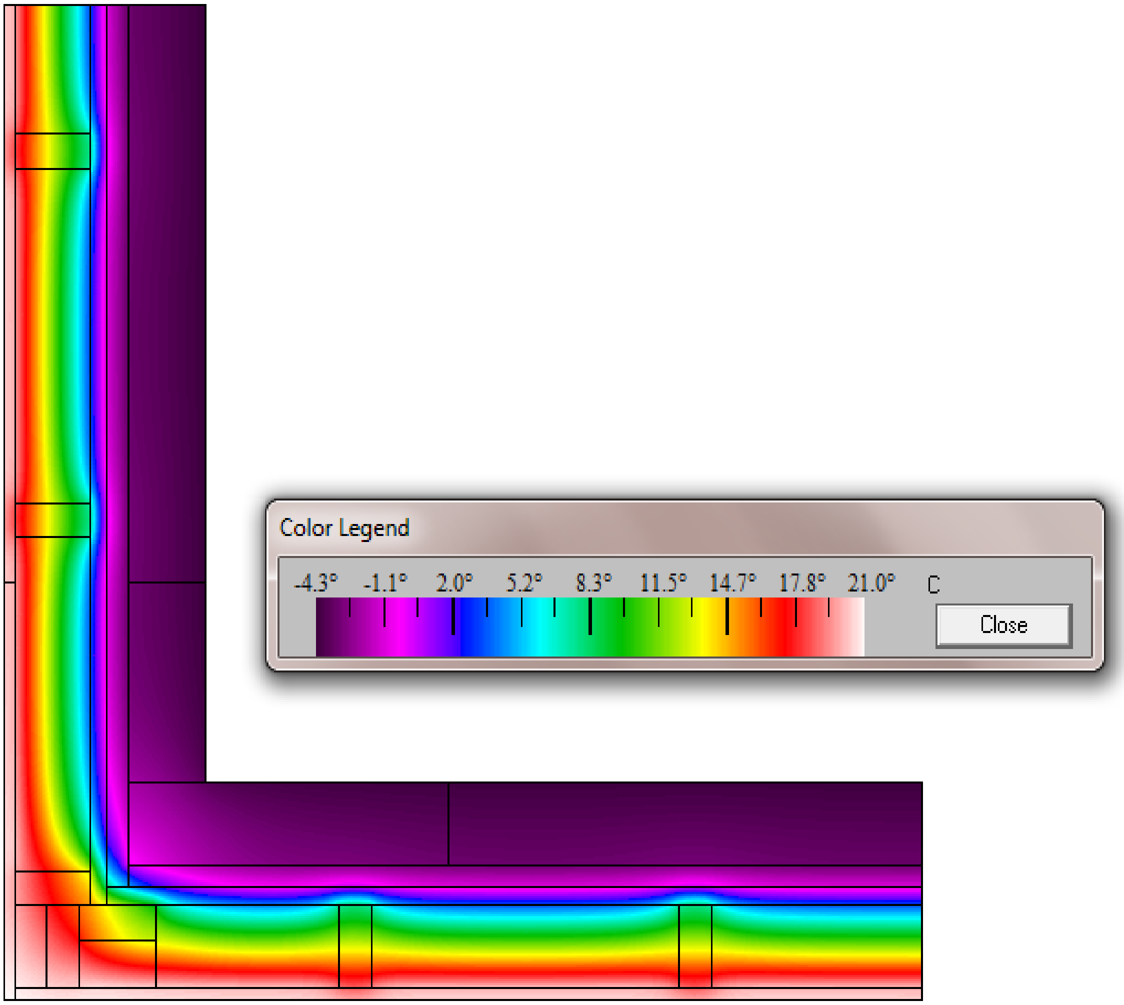


Figure K- 4: 38 x 89 OBC 2006 Inside Corner

Outside Corner:

38 x 89 mm (2x6) 2012-

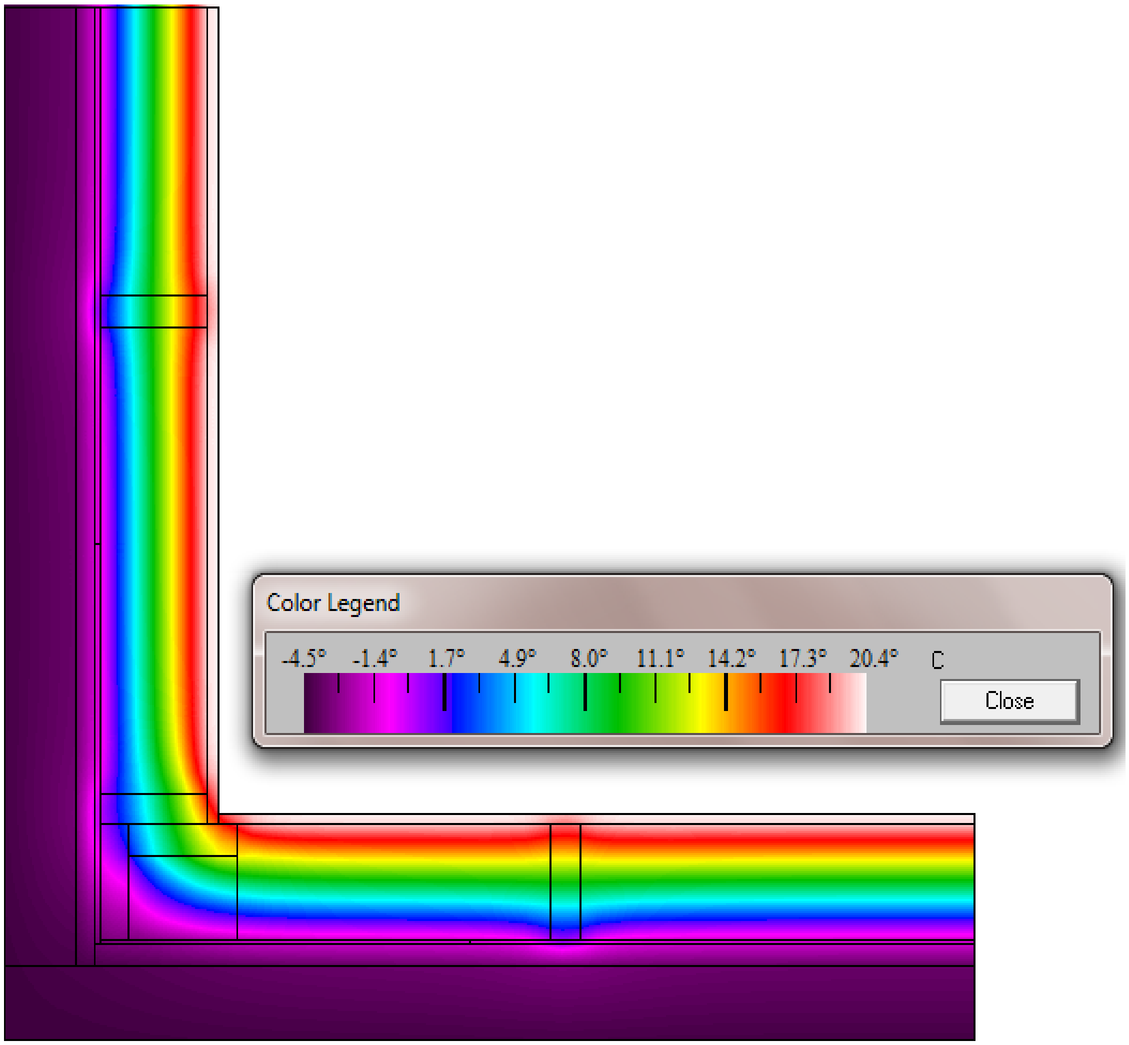


Figure K- 5: 38 x 140 mm OBC 2012 Outside Corner

38 x 89 mm (2x4) 2012-

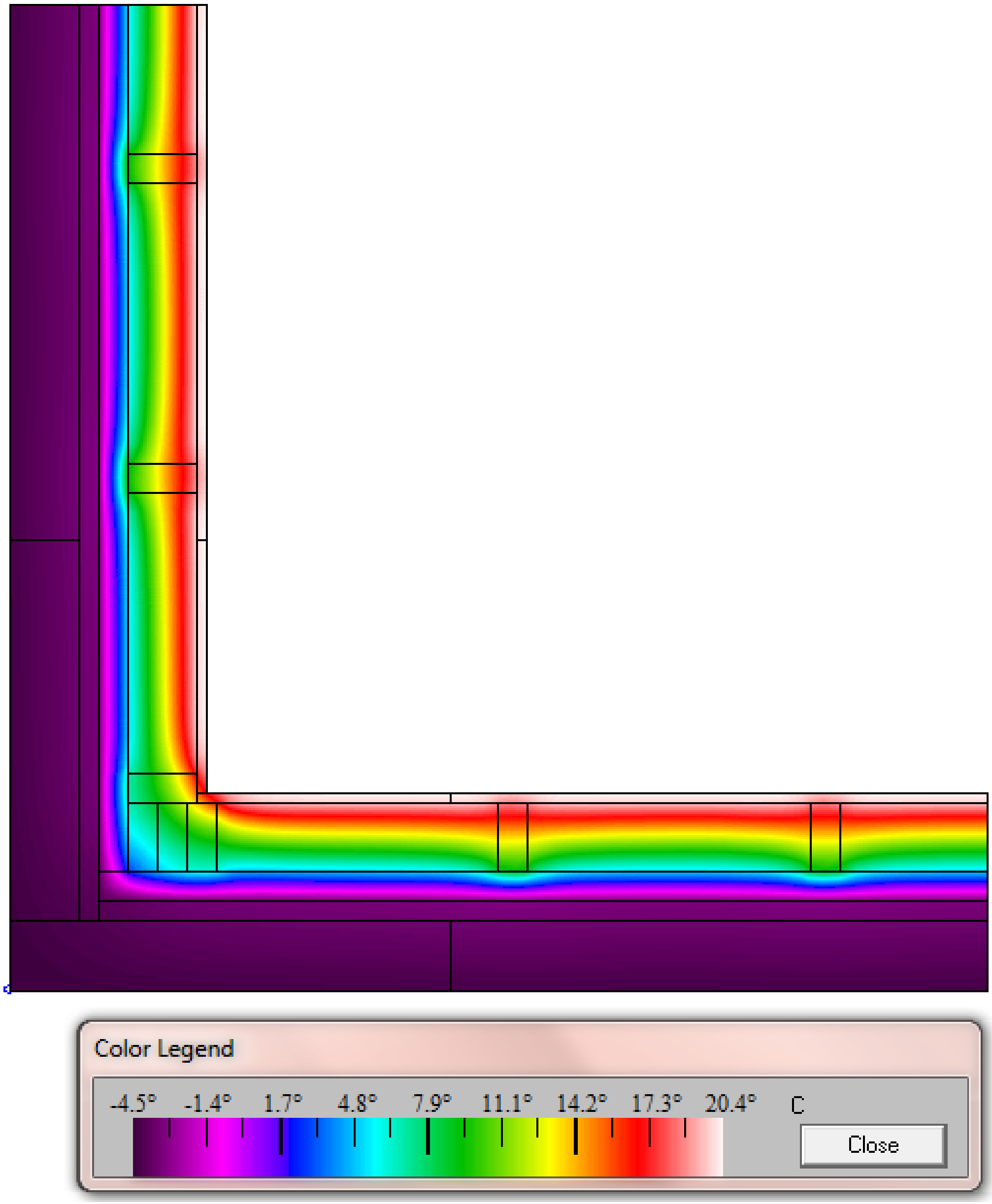


Figure K- 6: 38 x 89 mm OBC 2012 Outside Corner

38 x 140 mm (2x6) 2006-

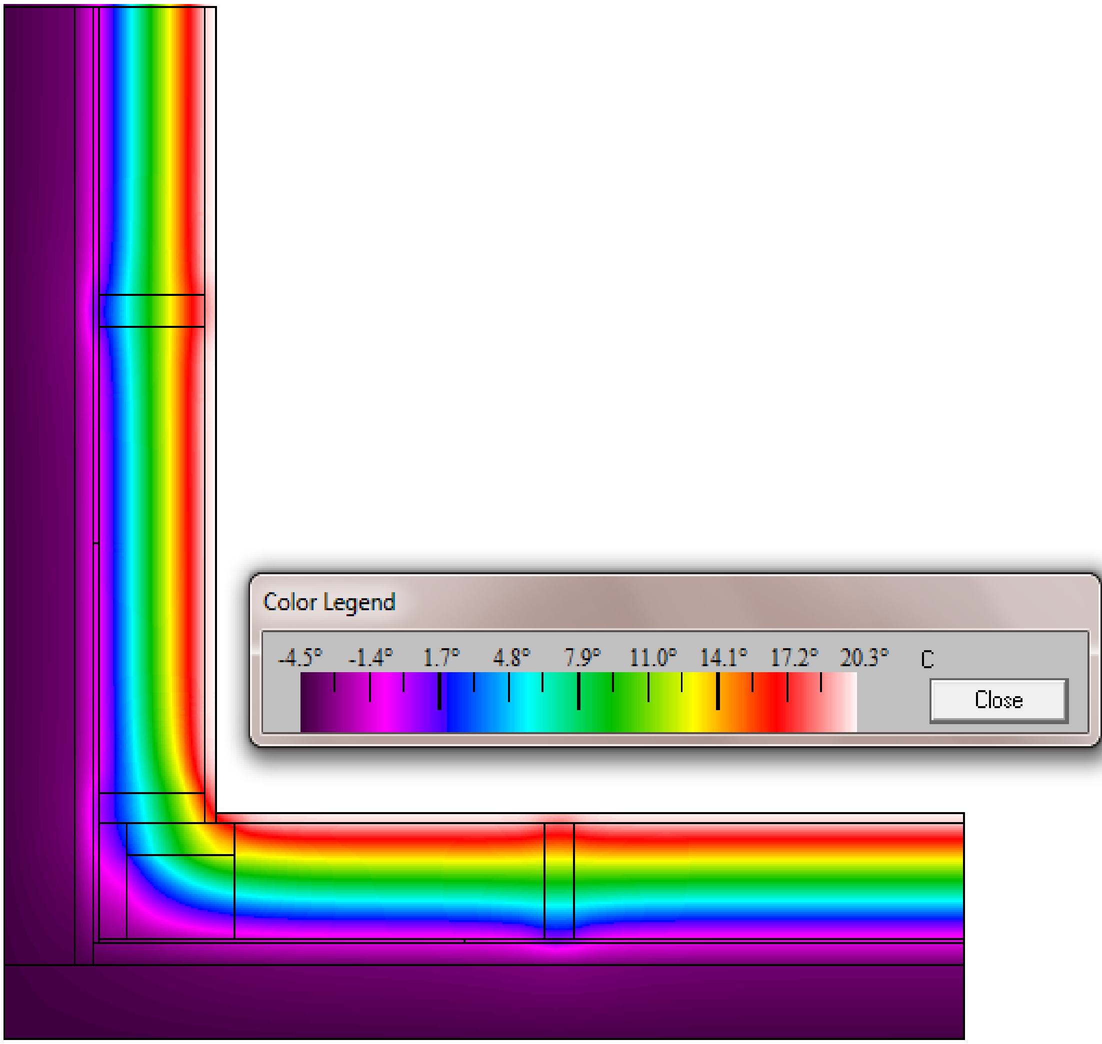


Figure K- 7: 38 x 140 mm OBC 2006 Outside Corner

38 x 89 mm (2x4) 2006-

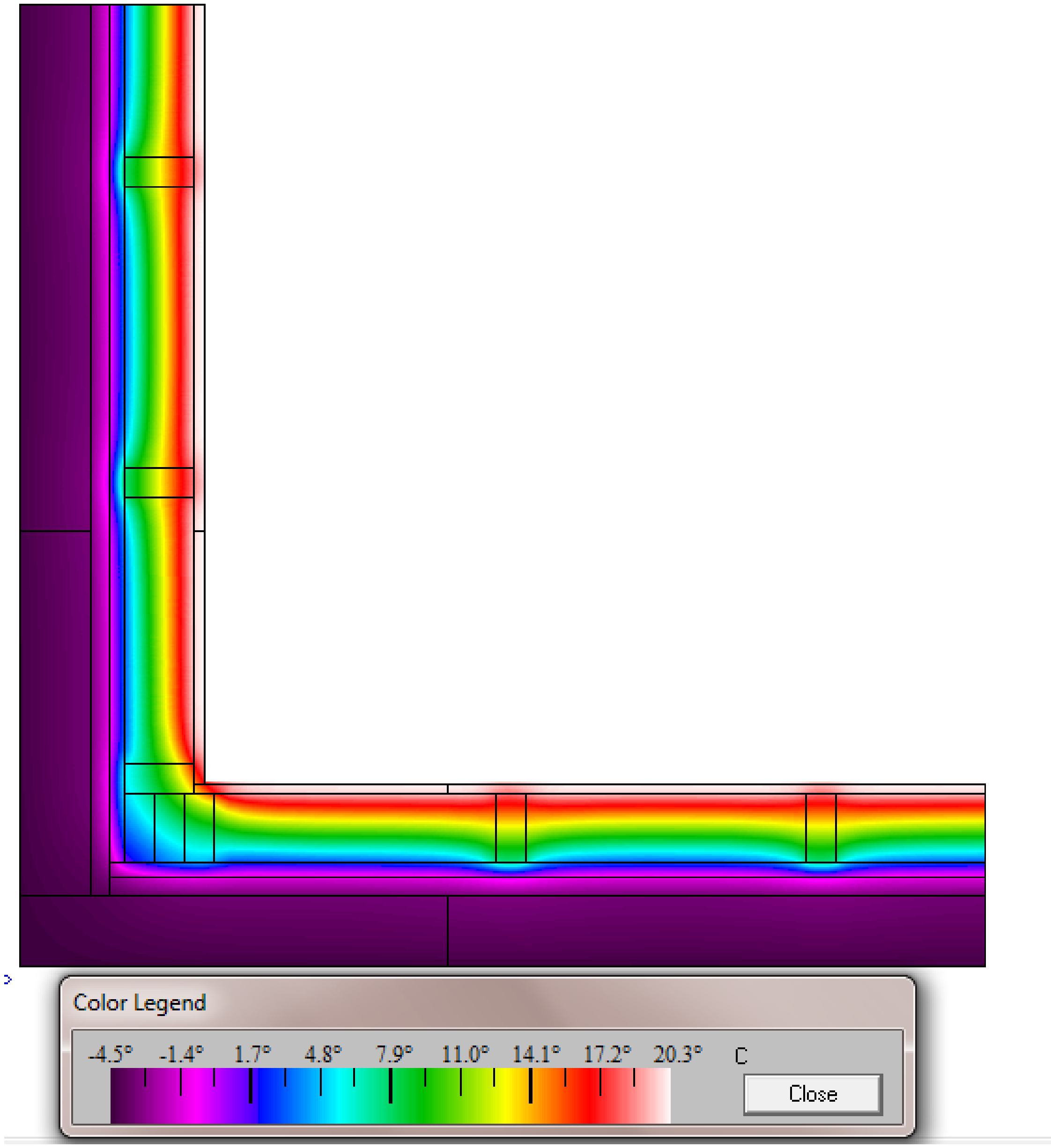


Figure K- 8: 38 x 89 mm OBC 2006 Outside Corner

Basement slab to Basement Wall Connection:

- Same for both 2006 and 2012 OBC

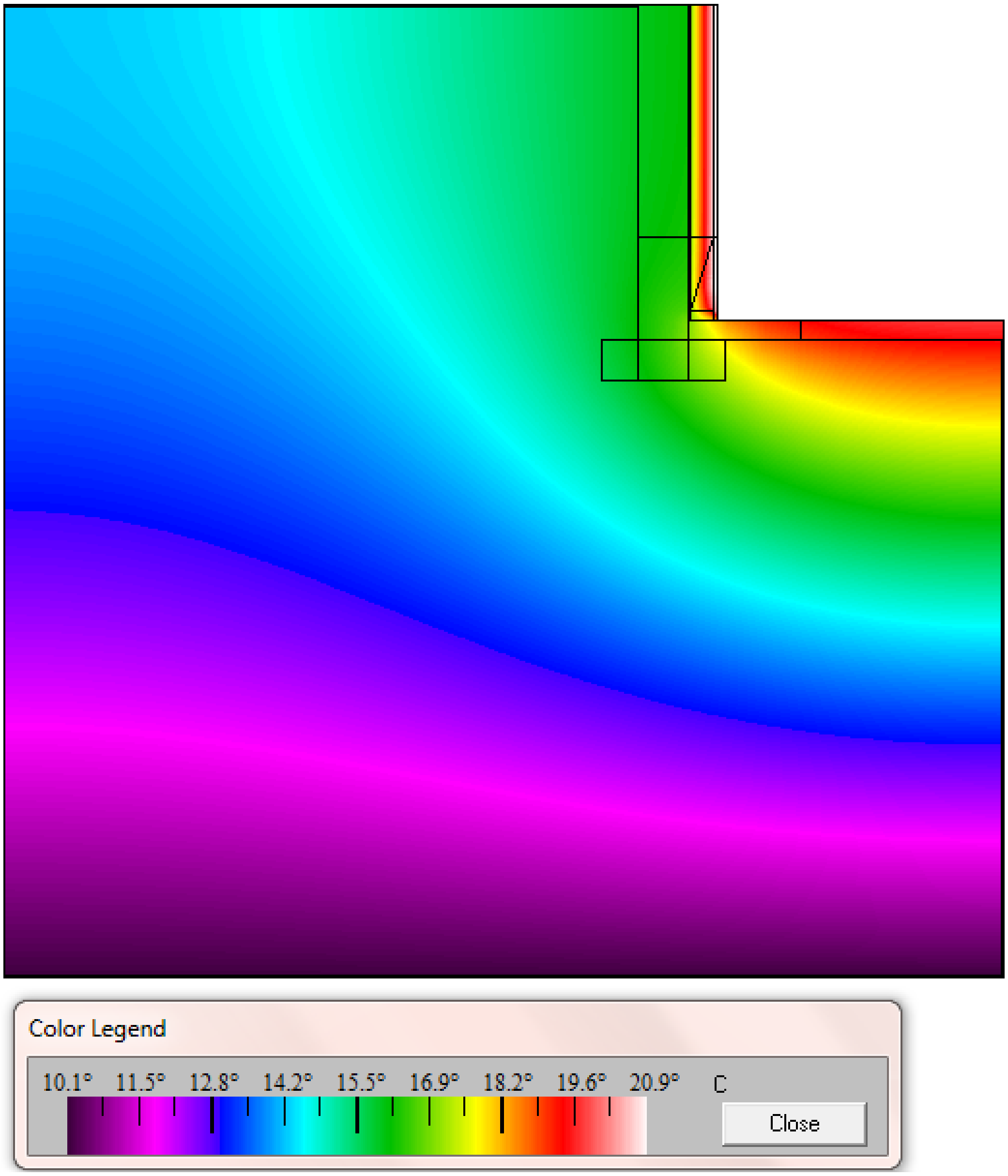


Figure K- 9: 2006 & 2012 OBC Basement Slab to Basement Wall Connection

38 x 140 mm (2x6) 2012-

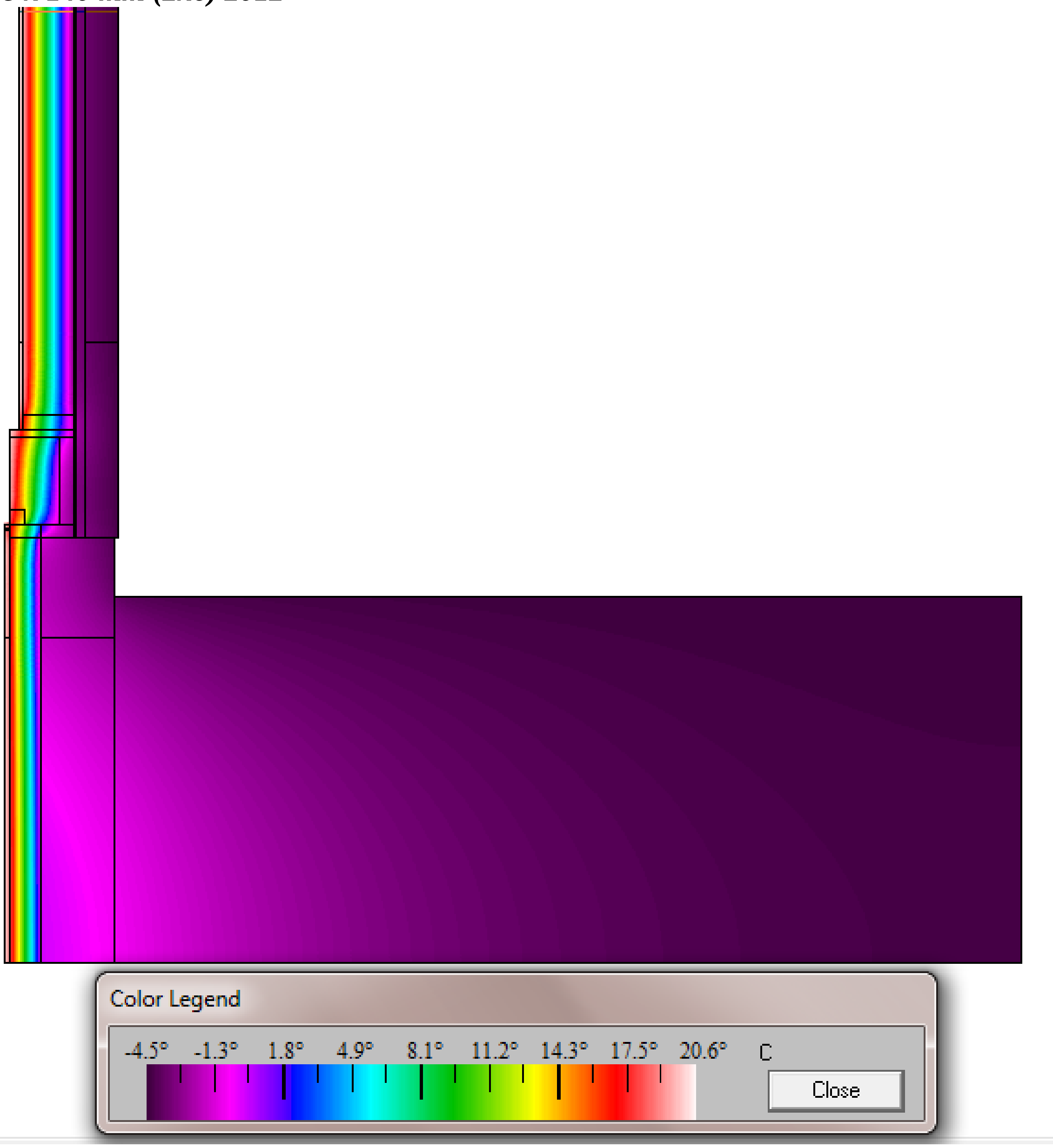


Figure K- 10: 38 x 140 mm OBC 2012 Basement Wall to Ground Floor to Ground Floor Wall Connection

38 x 89 mm (2x4) 2012-

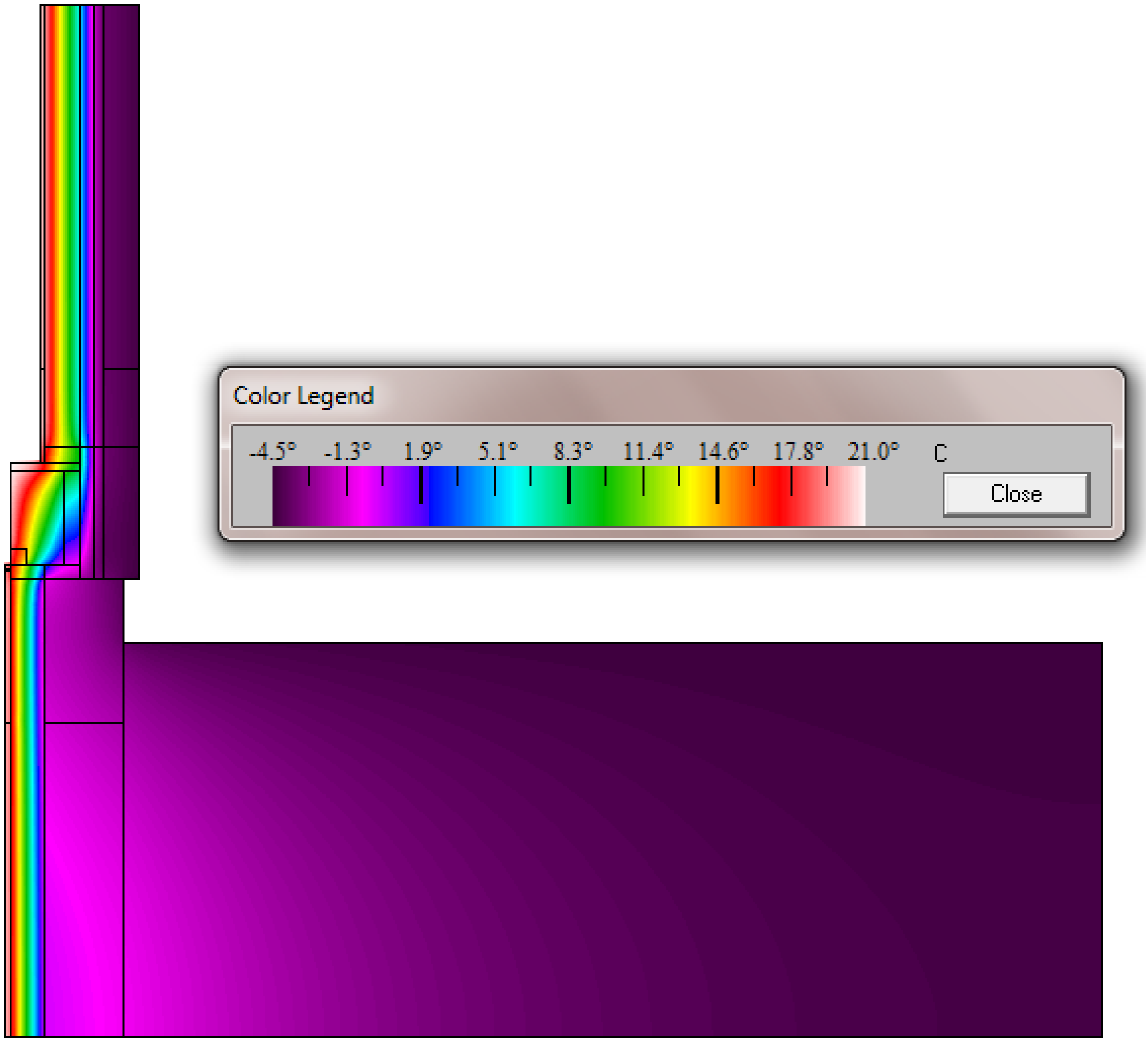


Figure K- 11: 38 x 89 mm OBC 2012 Basement Wall to Ground Floor to Ground Floor Wall Connection

38 x 140 (2x6) 2006-

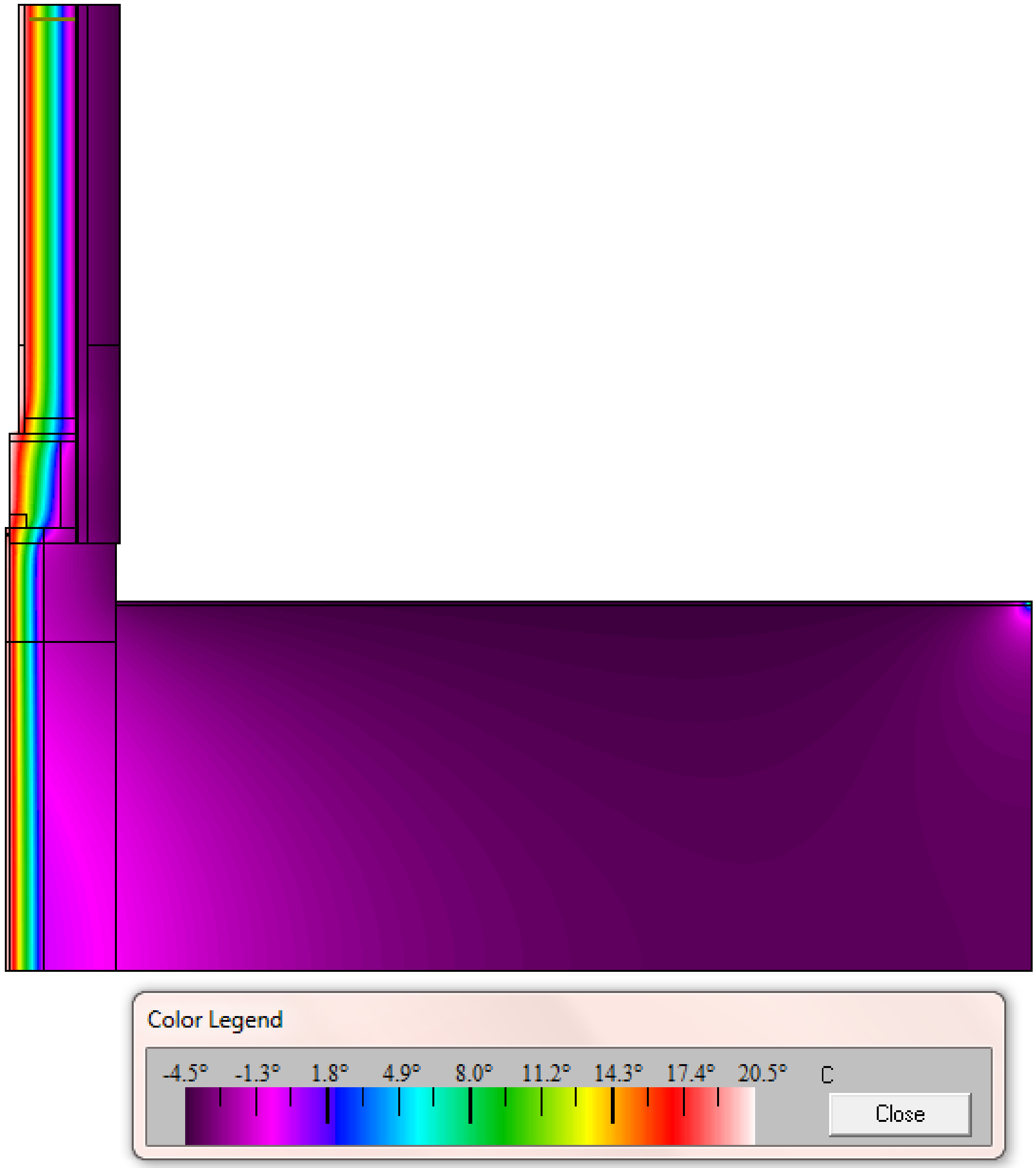


Figure K- 12: 38 x 140 mm OBC 2006 Basement Wall to Ground Floor to Ground Floor Wall Connection

38 x 89 mm (2x4) 2006-

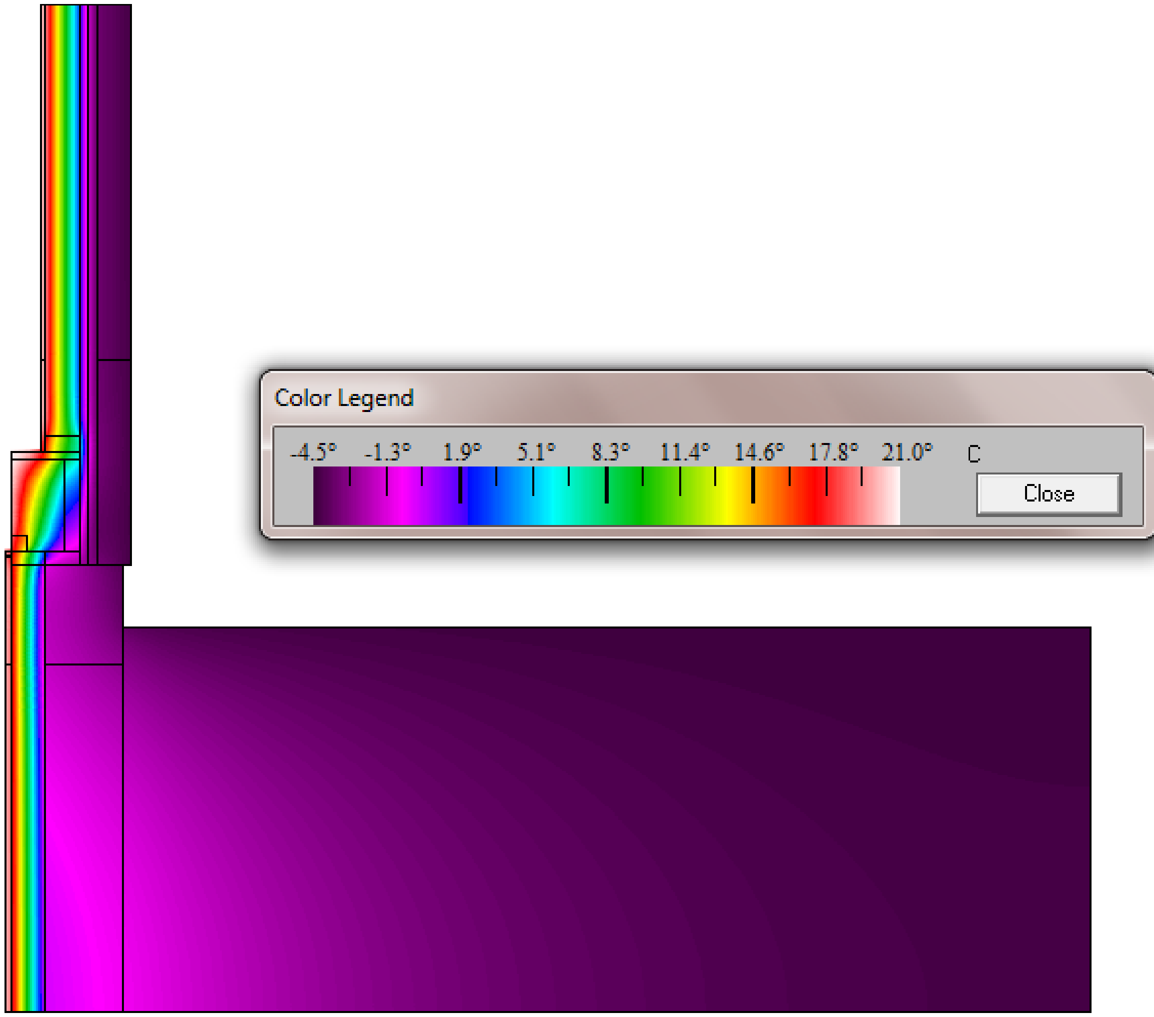


Figure K- 13: 38 x 89 mm OBC 2006 Basement Wall to Ground Floor to Ground Floor Wall Connection

38 x 140 mm (2x6) 2012

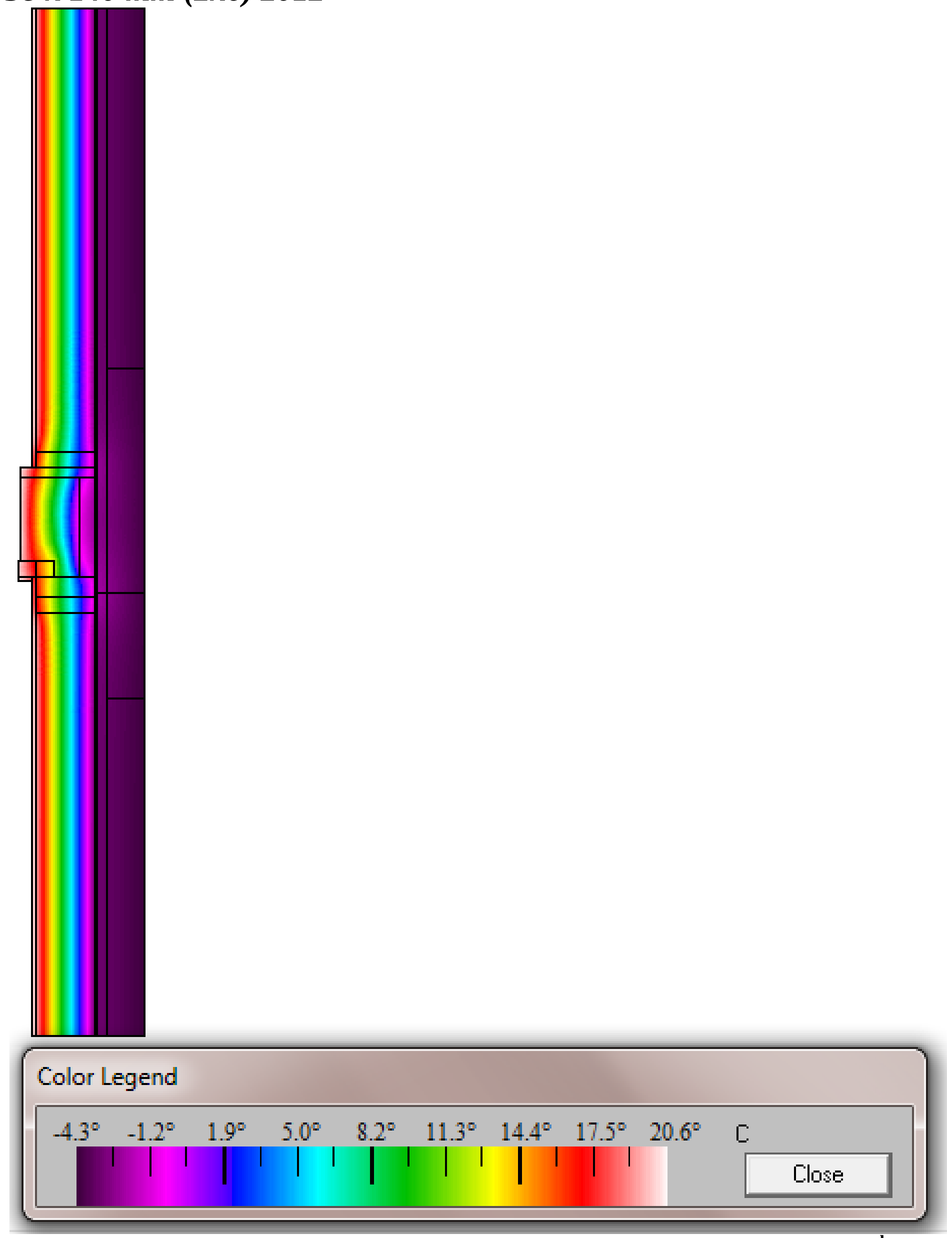


Figure K- 14: 38 x 140 mm OBC 2012 Ground Floor Wall Connection to 2nd Floor to 2nd Floor Wall Connection

38 x 89 mm (2x4) 2012

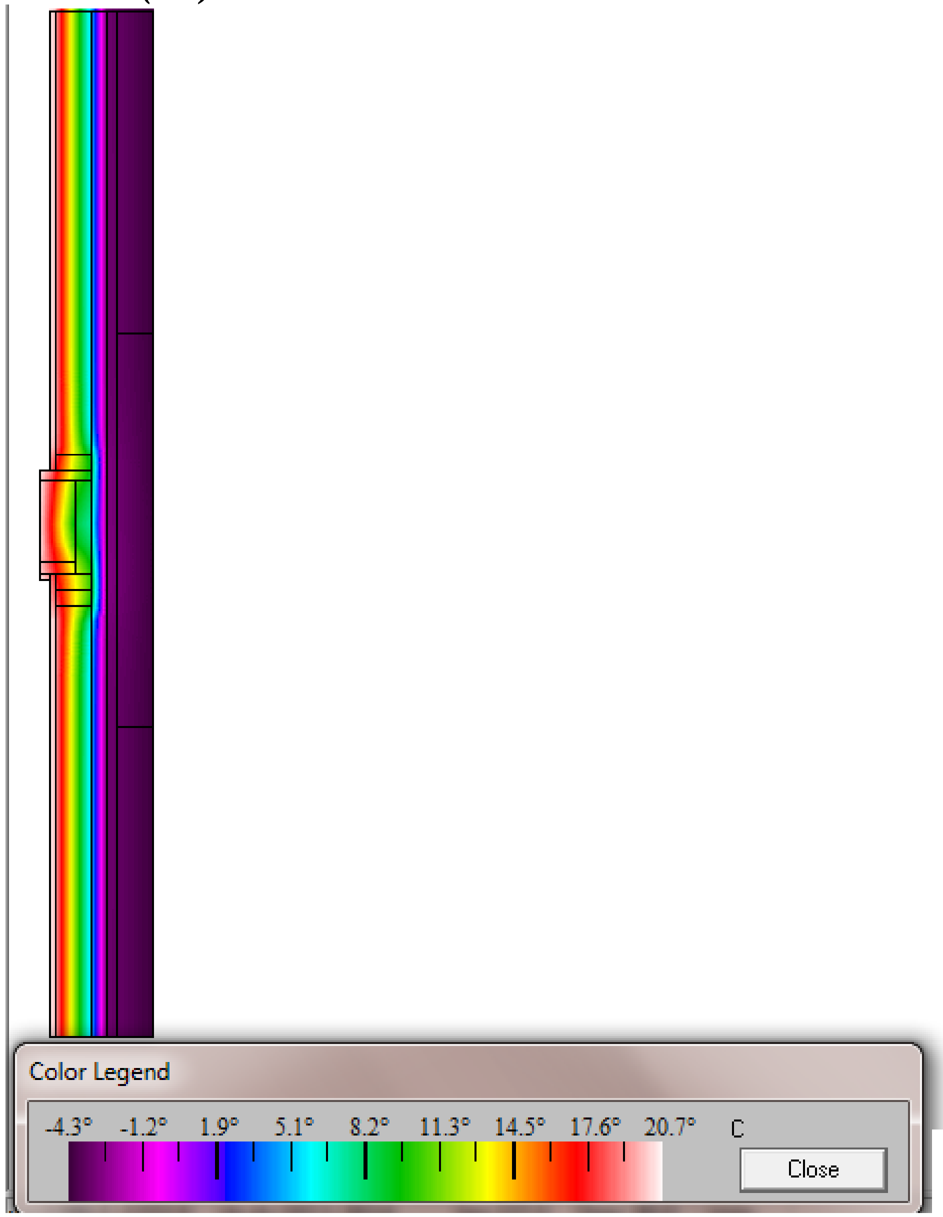


Figure K- 15: 38 x 89 mm OBC 2012 Ground Floor Wall Connection to 2nd Floor to 2nd Floor Wall Connection

38 x 140 mm (2x6) 2006-

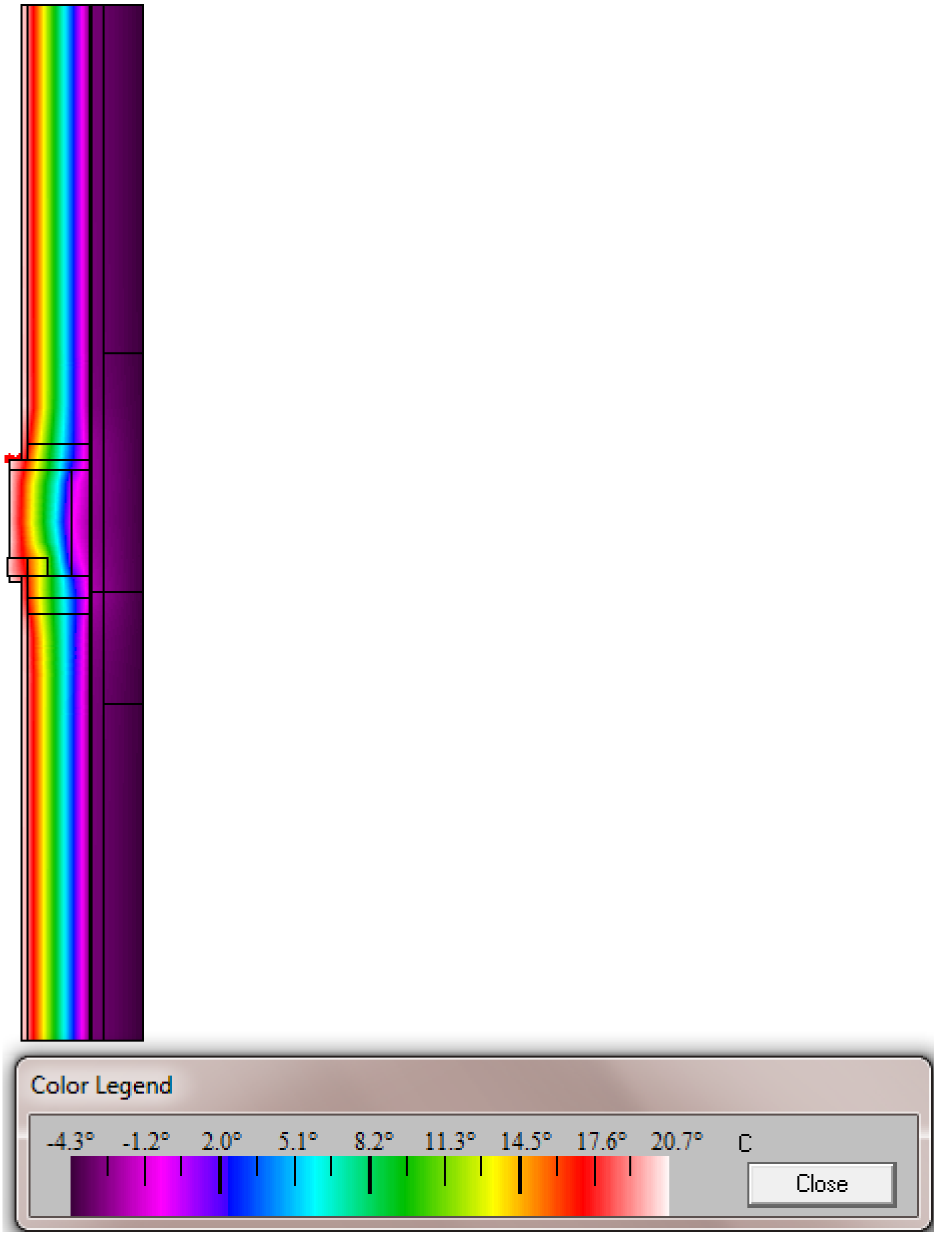


Figure K- 16: 38 x 140 mm OBC 2006 Ground Floor Wall Connection to 2nd Floor to 2nd Floor Wall Connection

38 x 89 mm (2x4) 2006-

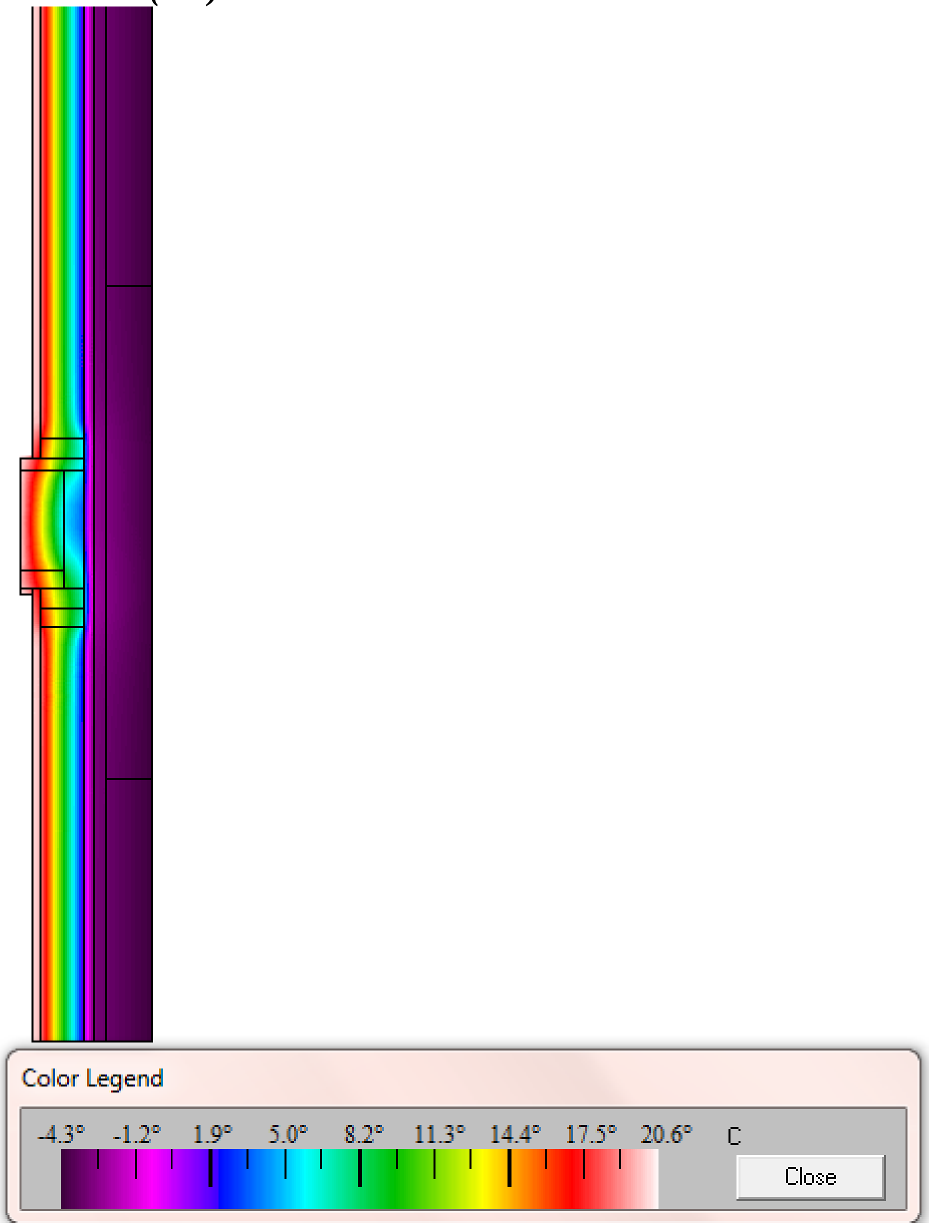


Figure K- 17: 38 x 89 mm OBC 2006 Ground Floor Wall Connection to 2nd Floor to 2nd Floor Wall Connection

2nd Floor to Roof Connections

38 x 140 mm (2x6) 2012 –

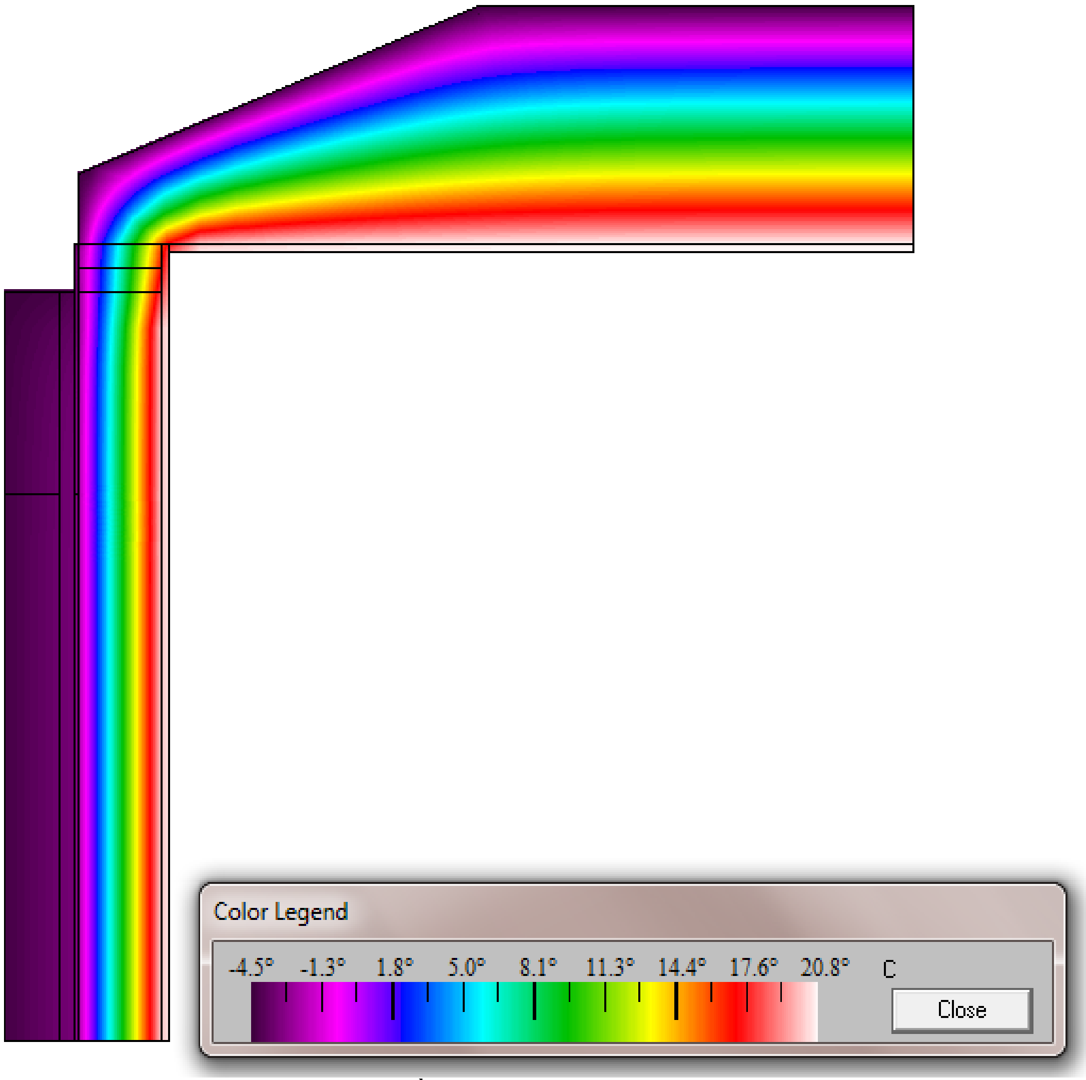


Figure K- 18: 38 x 140 mm OBC 2012 2nd Floor Wall Connection to Roof Connection

38 x 89 mm (2x4) 2012-

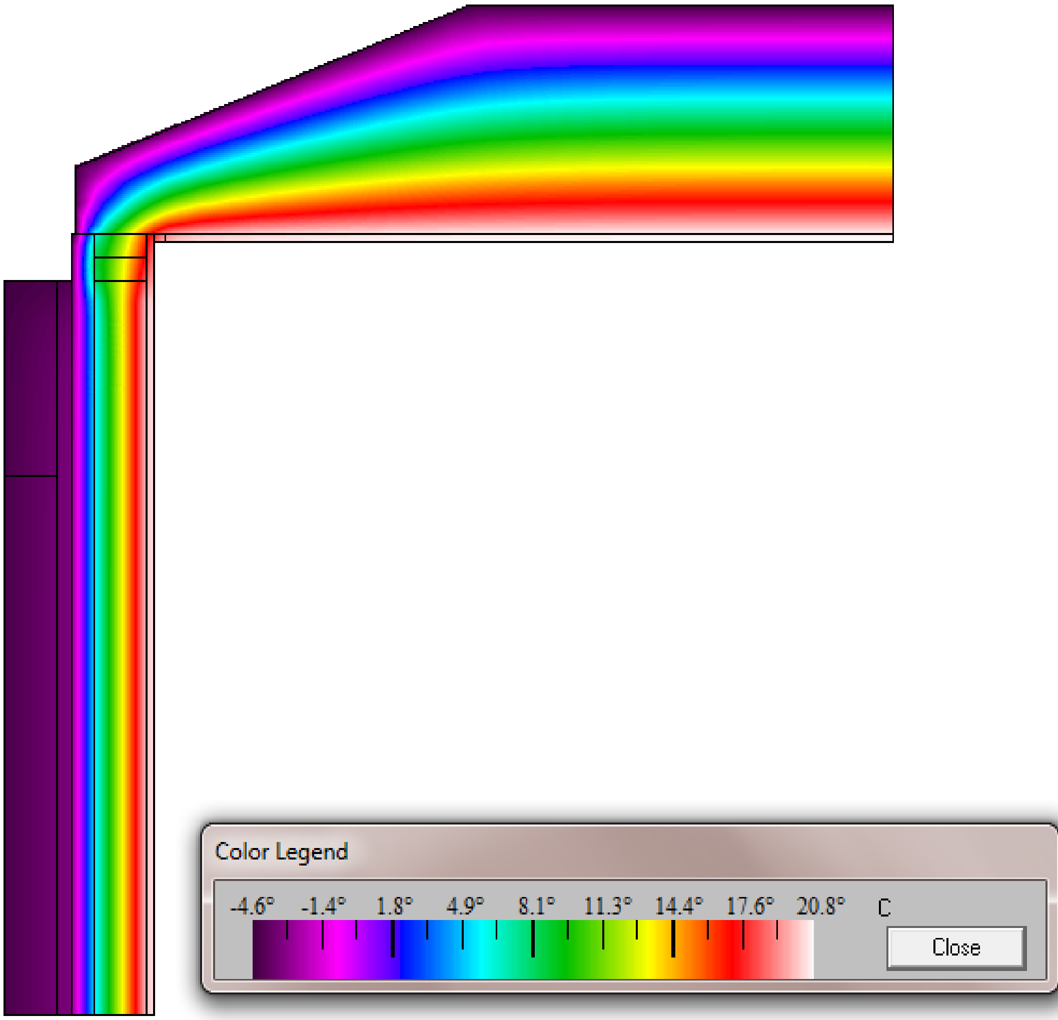
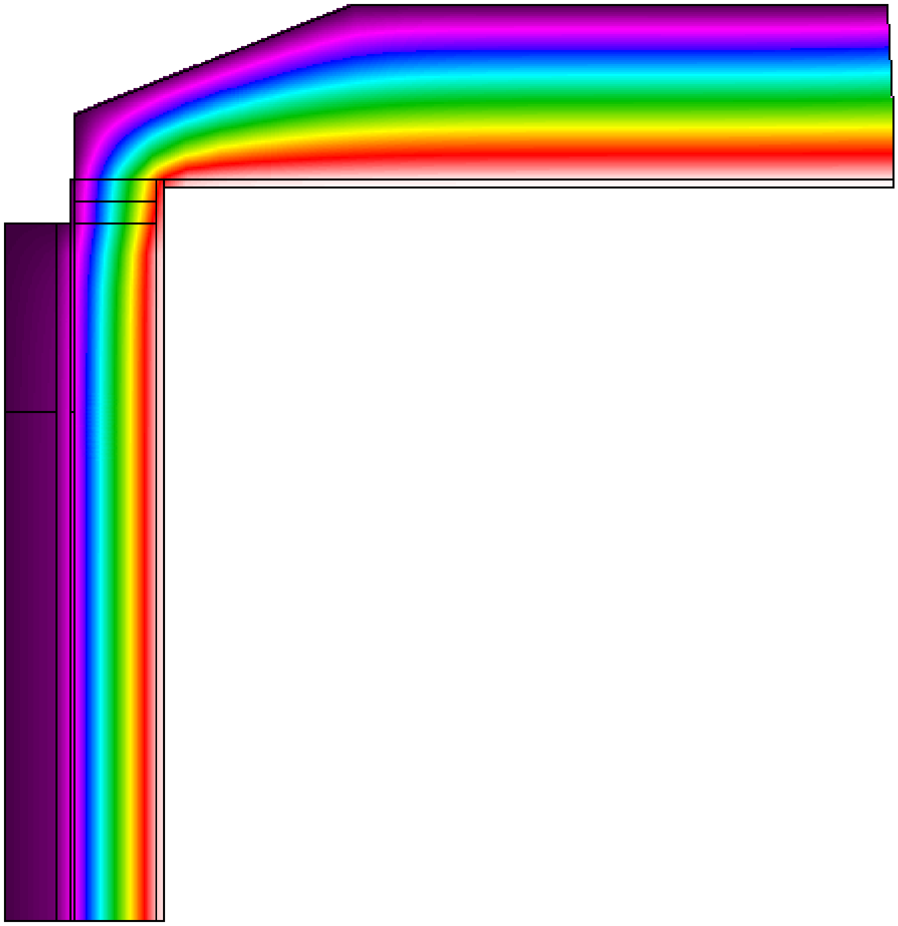


Figure K- 19: 38 x 89 mm OBC 2012 2nd Floor Wall Connection to Roof Connection

38 x 140 (2x6) 2006-



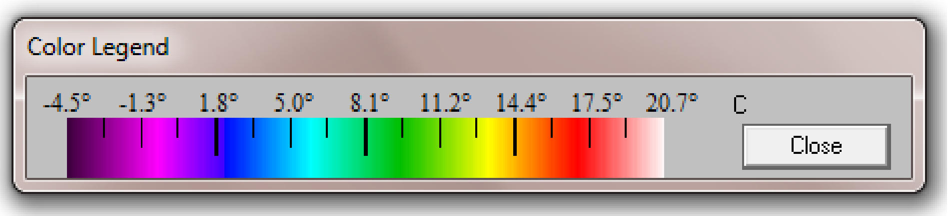


Figure K- 20: 38 x 140 mm OBC 2006 2nd Floor Wall Connection to Roof Connection

38 x 89 mm (2x4) 2006-

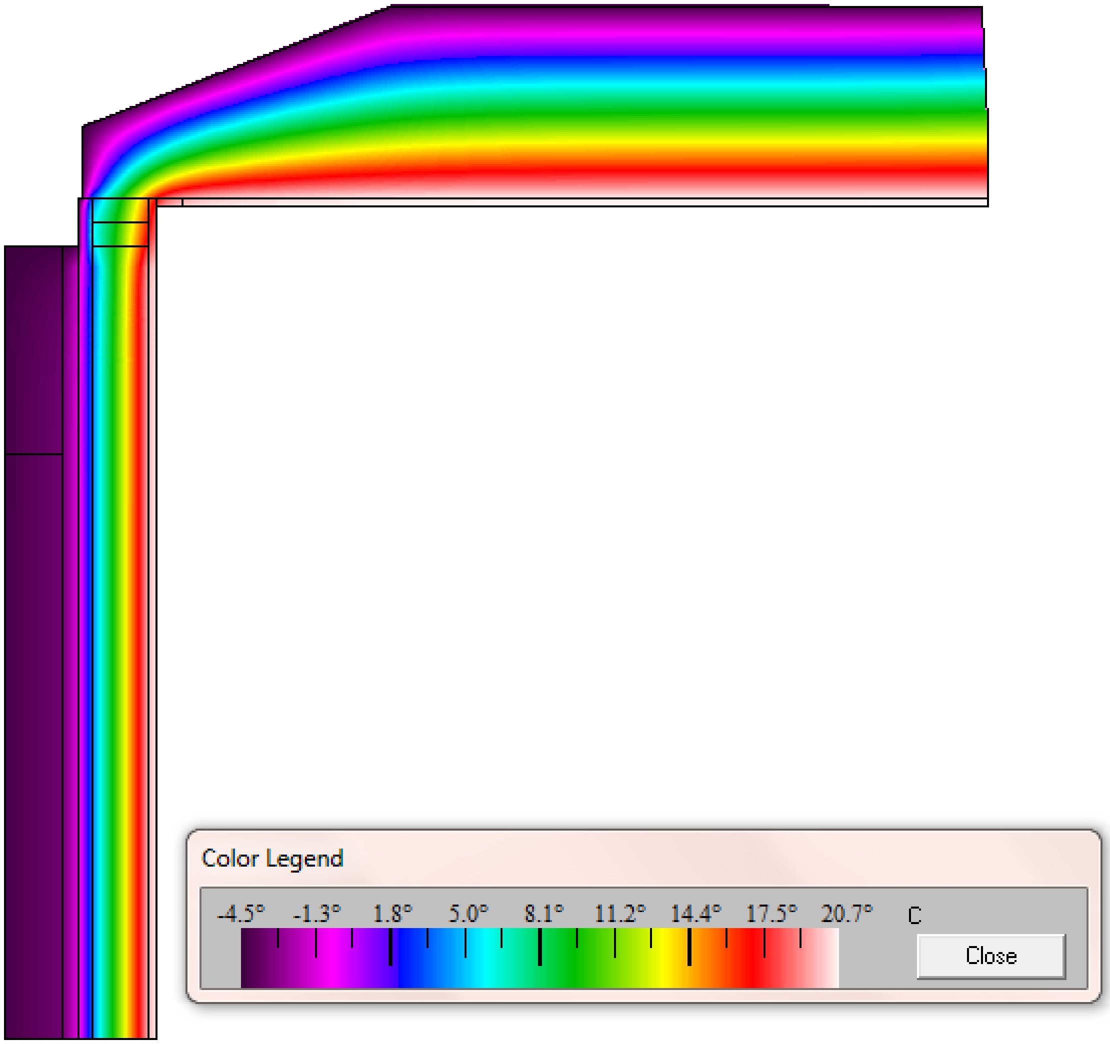


Figure K- 21: 38 x 89 mm OBC 2006 2nd Floor Wall Connection to Roof Connection

Appendix L - Denmark THERM Results:

To view the assumptions that were input into the simulations, reference Appendix E. These building envelope sections are courtesy of Danish Timber Information (Danish Timber Information 2008).

Typical Danish Outside Corner

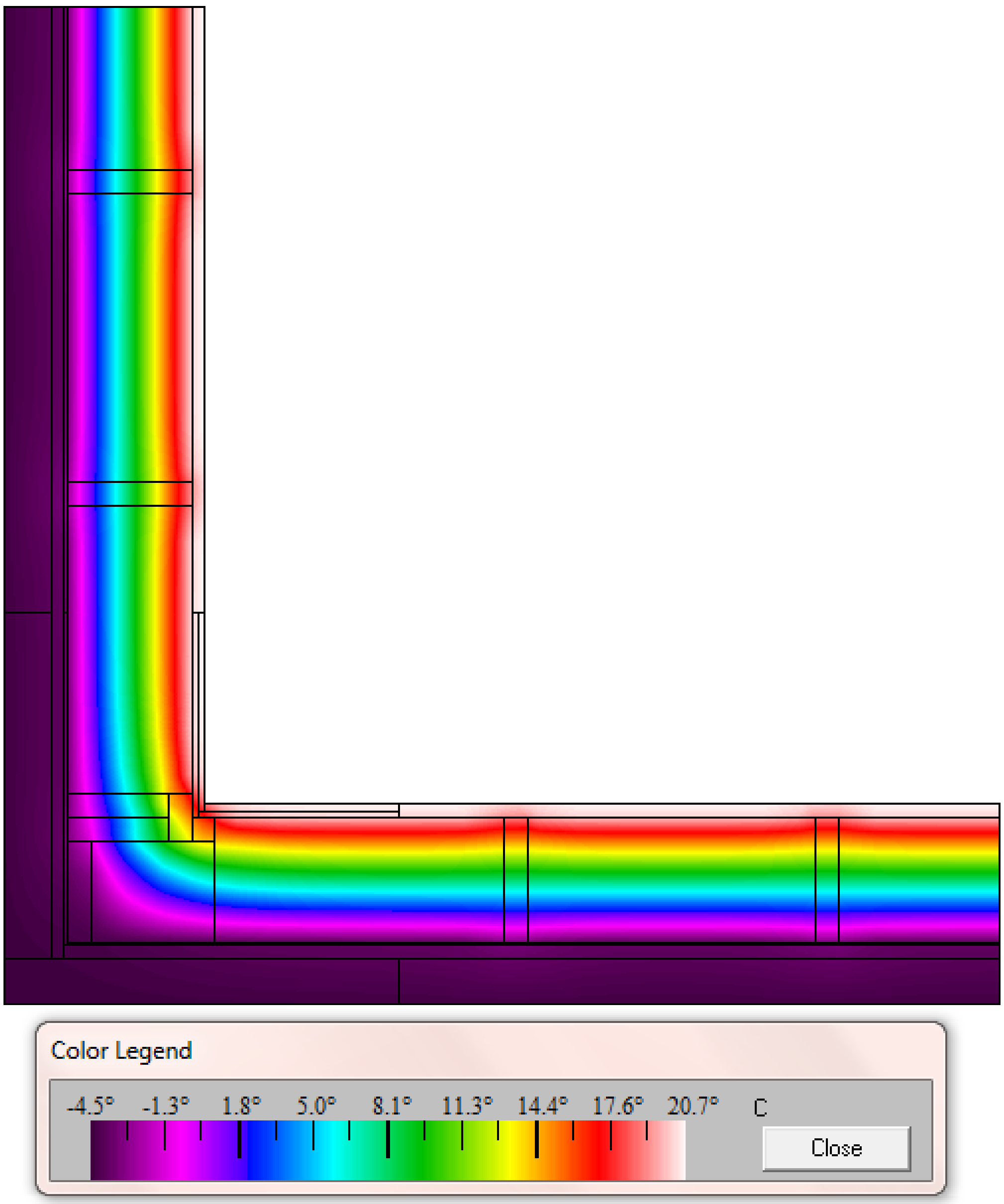


Figure L- 1: Typical Danish Outside Corner

Typical Danish Inside Corner

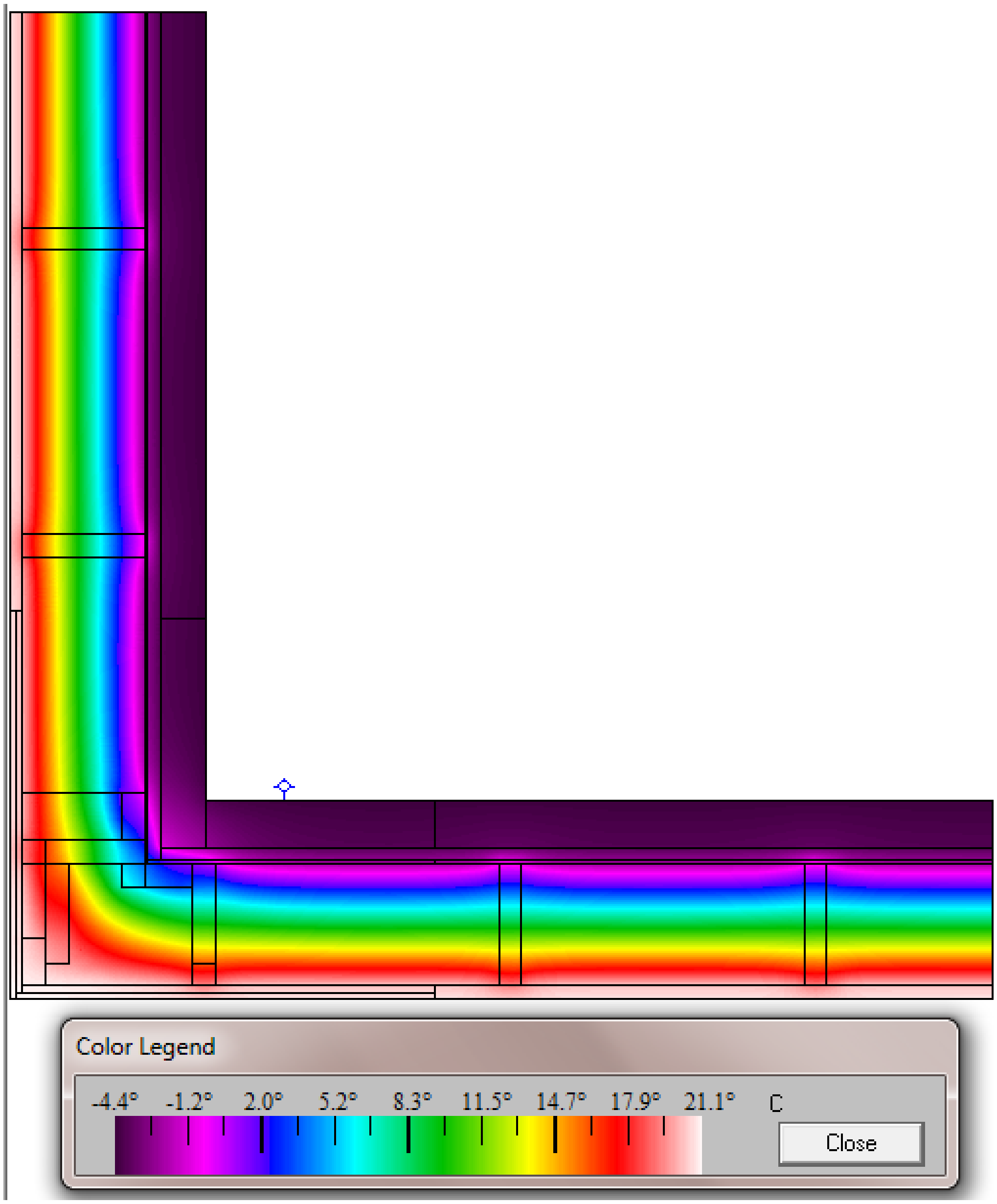


Figure L- 2: Typical Danish inside Corner

Typical Danish Basement Wall to Ground Floor Connection

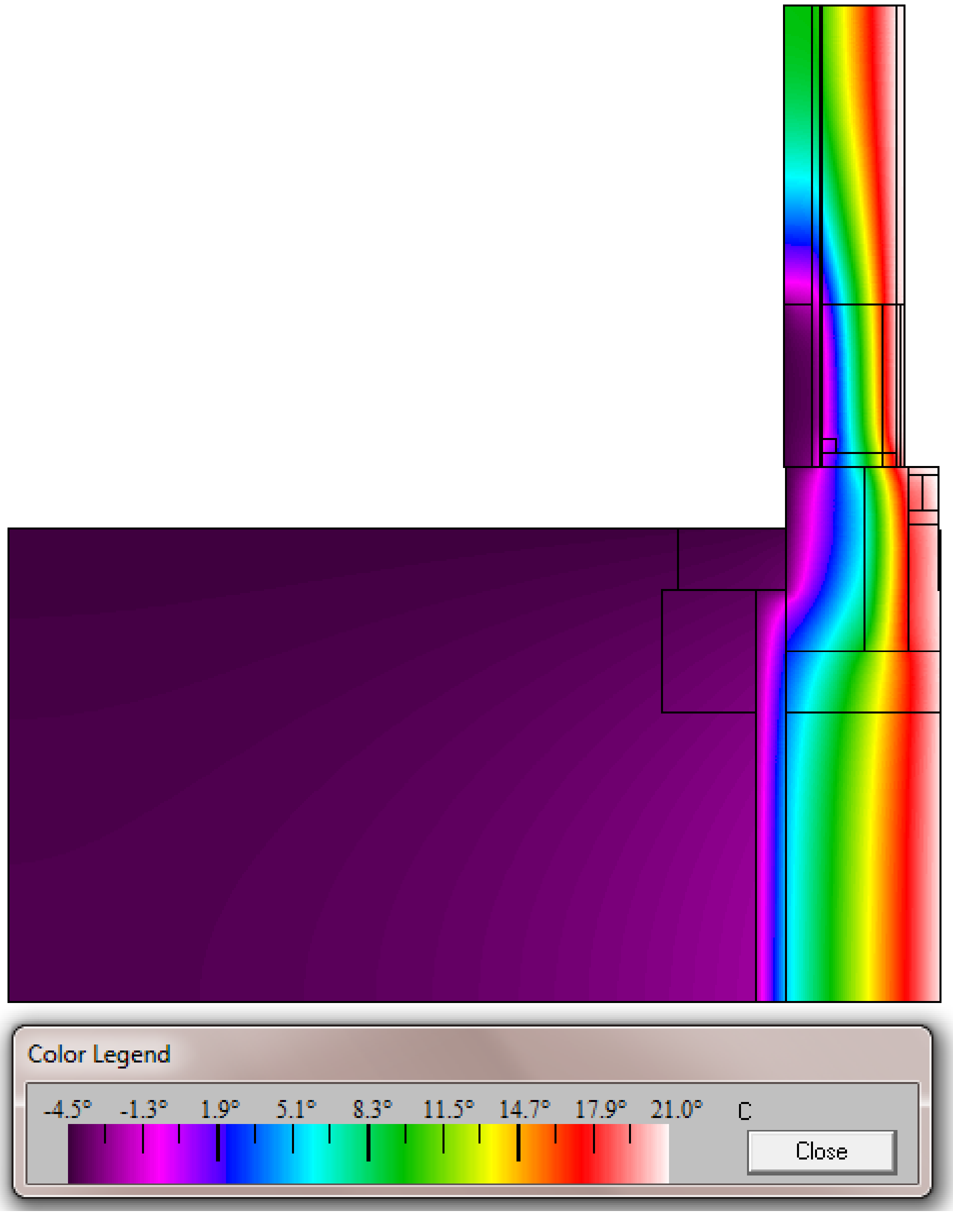


Figure L- 3: Typical Danish Basement Wall to Ground Floor Connection

Typical Danish Ground Floor Wall Connection to 1st Floor and 2nd Floor Wall

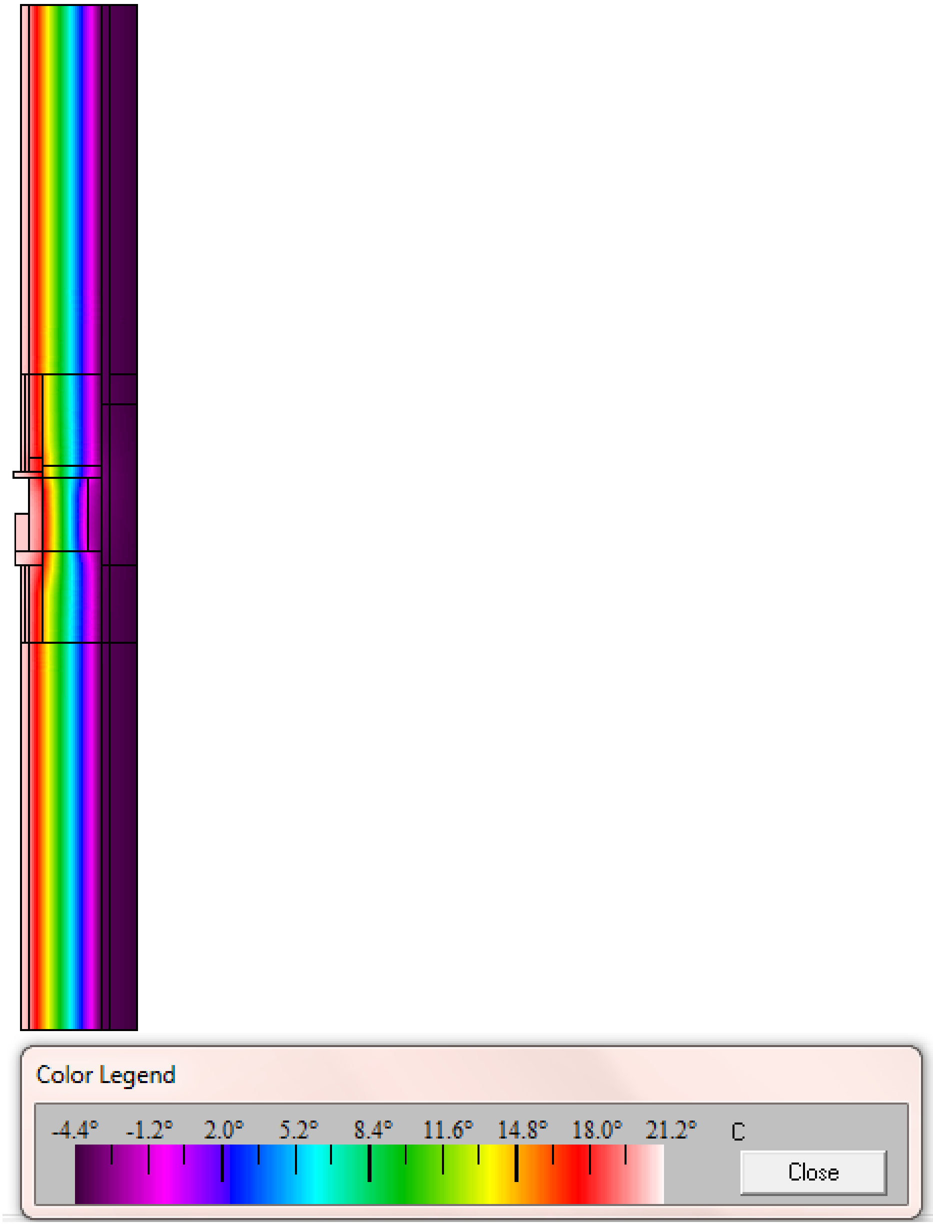


Figure L- 4: Typical Danish Ground Floor Wall Connection to 1st Floor and 2nd Floor Wall

Typical Danish Roof connection

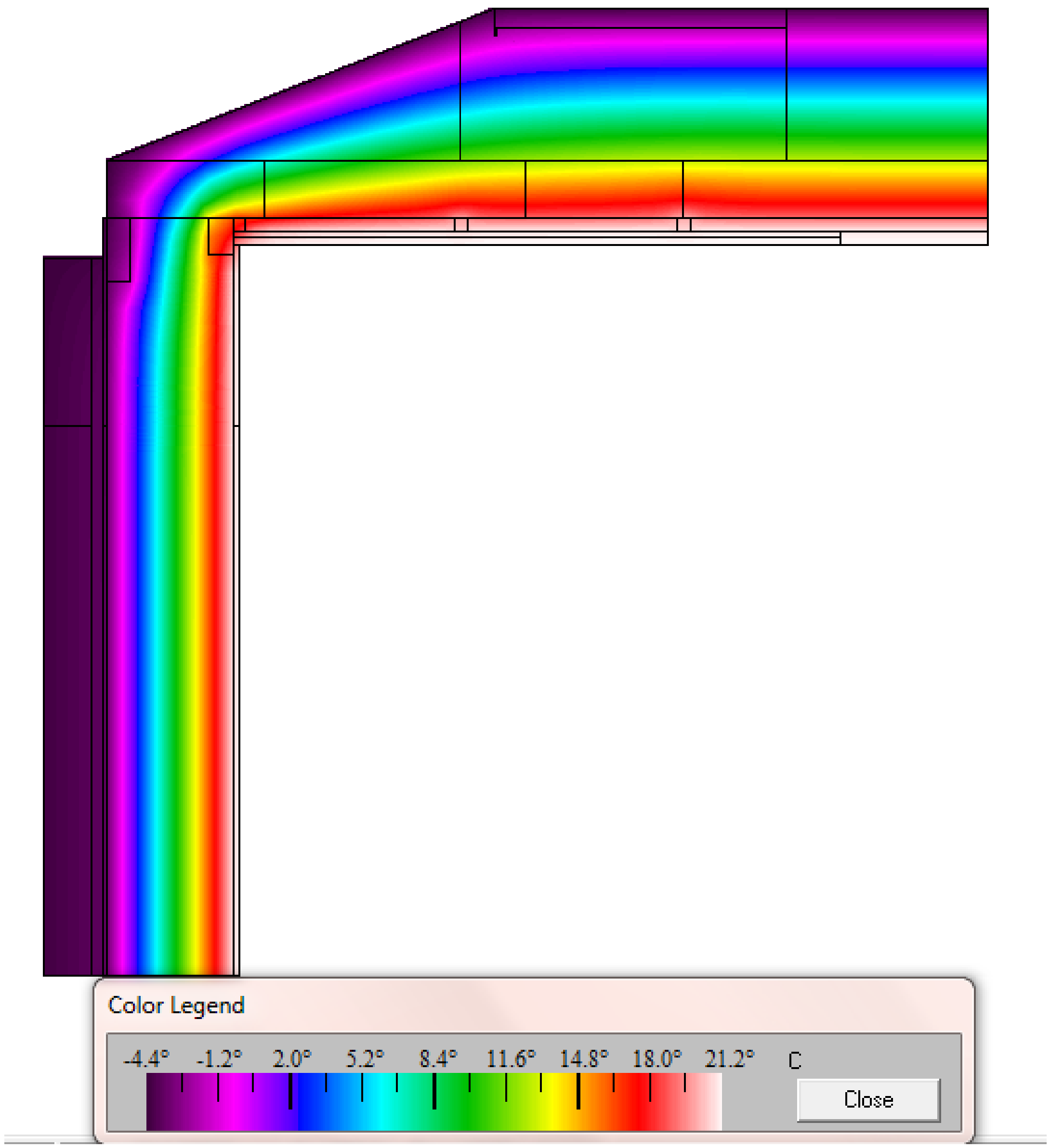


Figure L- 5: Typical Danish Wall Connection to Roof

Typical Danish Basement Wall to Basement Slab Connection

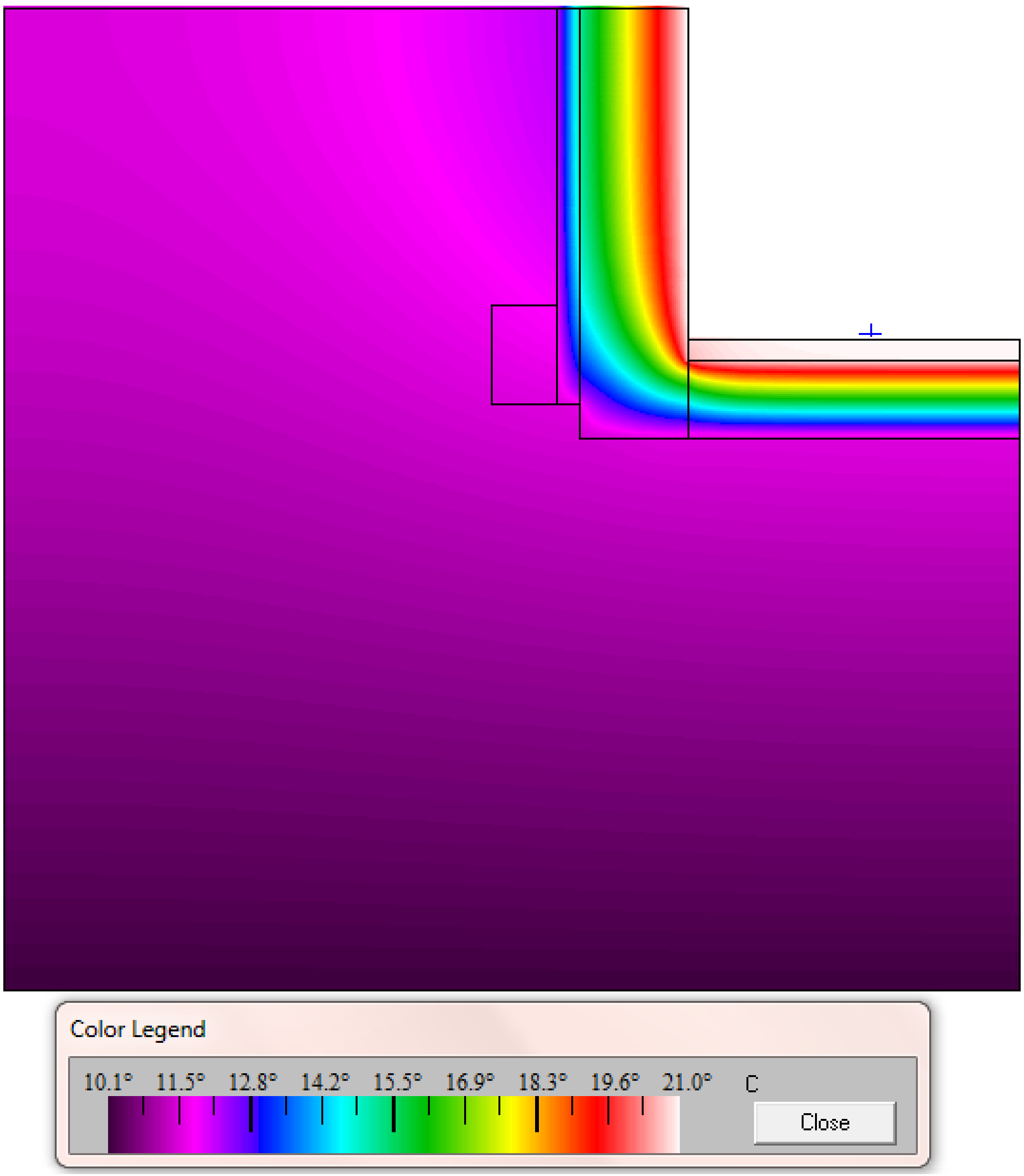


Figure L- 6: Typical Danish Basement Wall to Basement Slab Connection

Appendix M- Germany THERM Results:

To view the assumptions that were input into the simulations, reference Appendix E. All these building envelope connection details are courtesy of Hanse House (Hanse House 2010).

Typical German Outside Corner

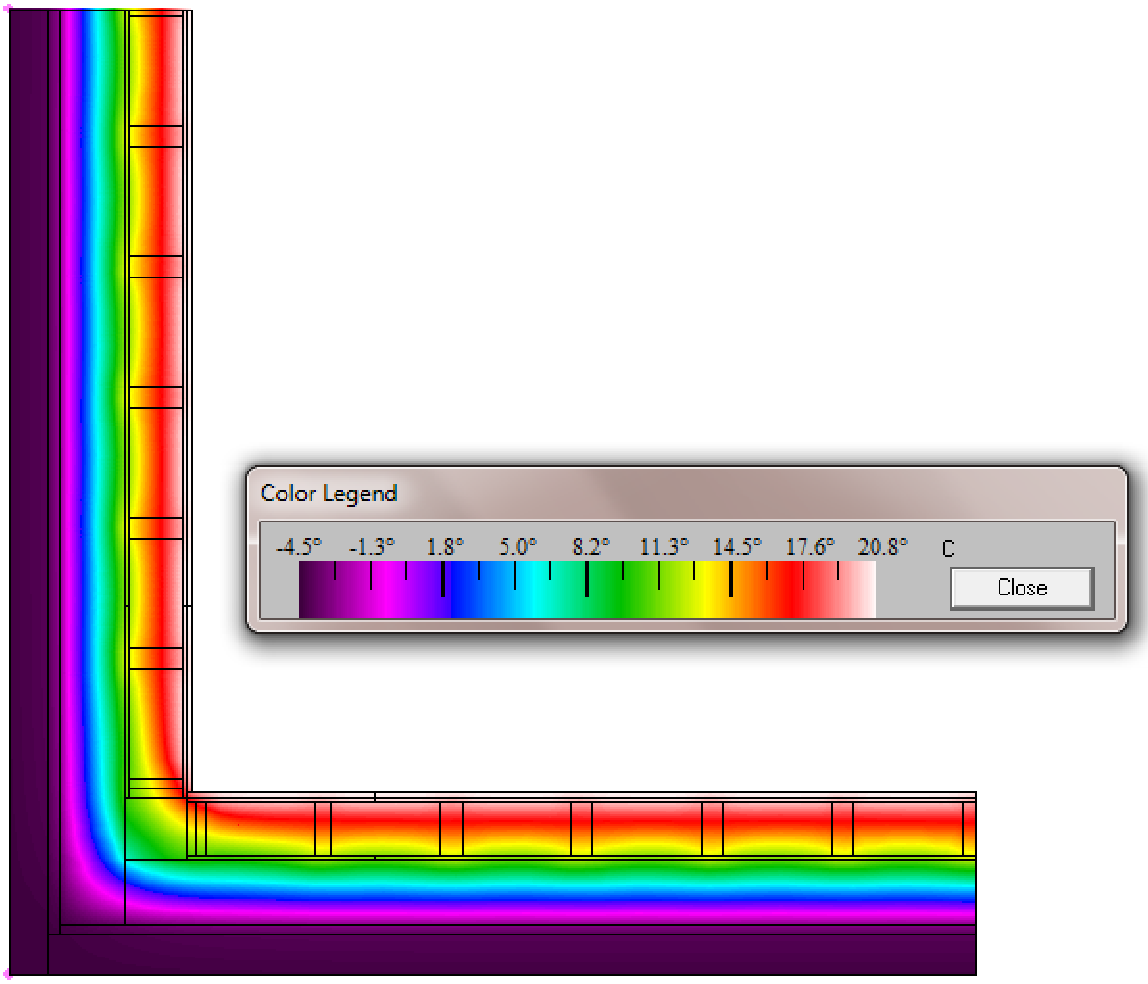


Figure M- 1: Typical German Outside Corner

Typical German Inside Corner

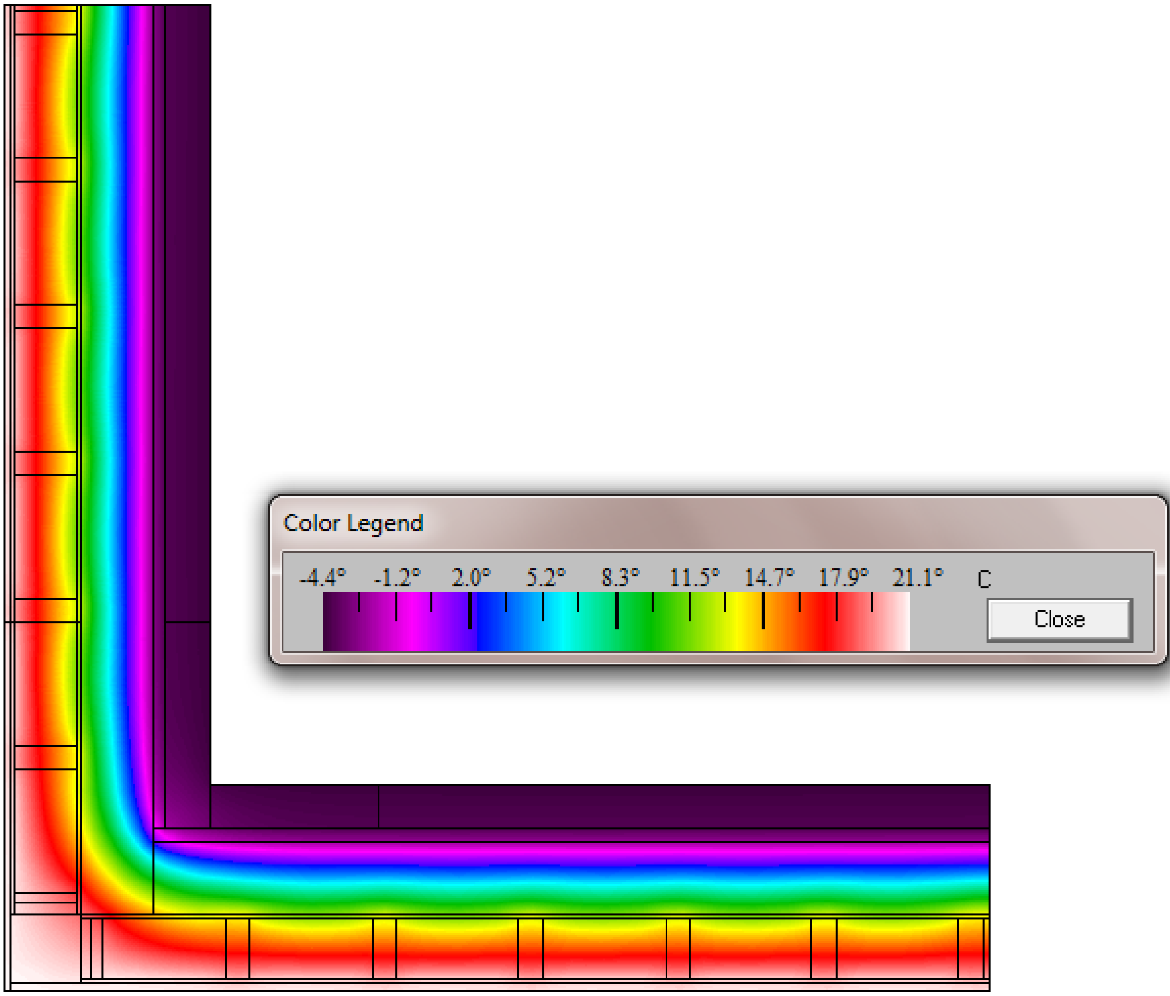


Figure M- 2: Typical German Inside Corner

Typical German Basement Wall to Basement Slab Connection

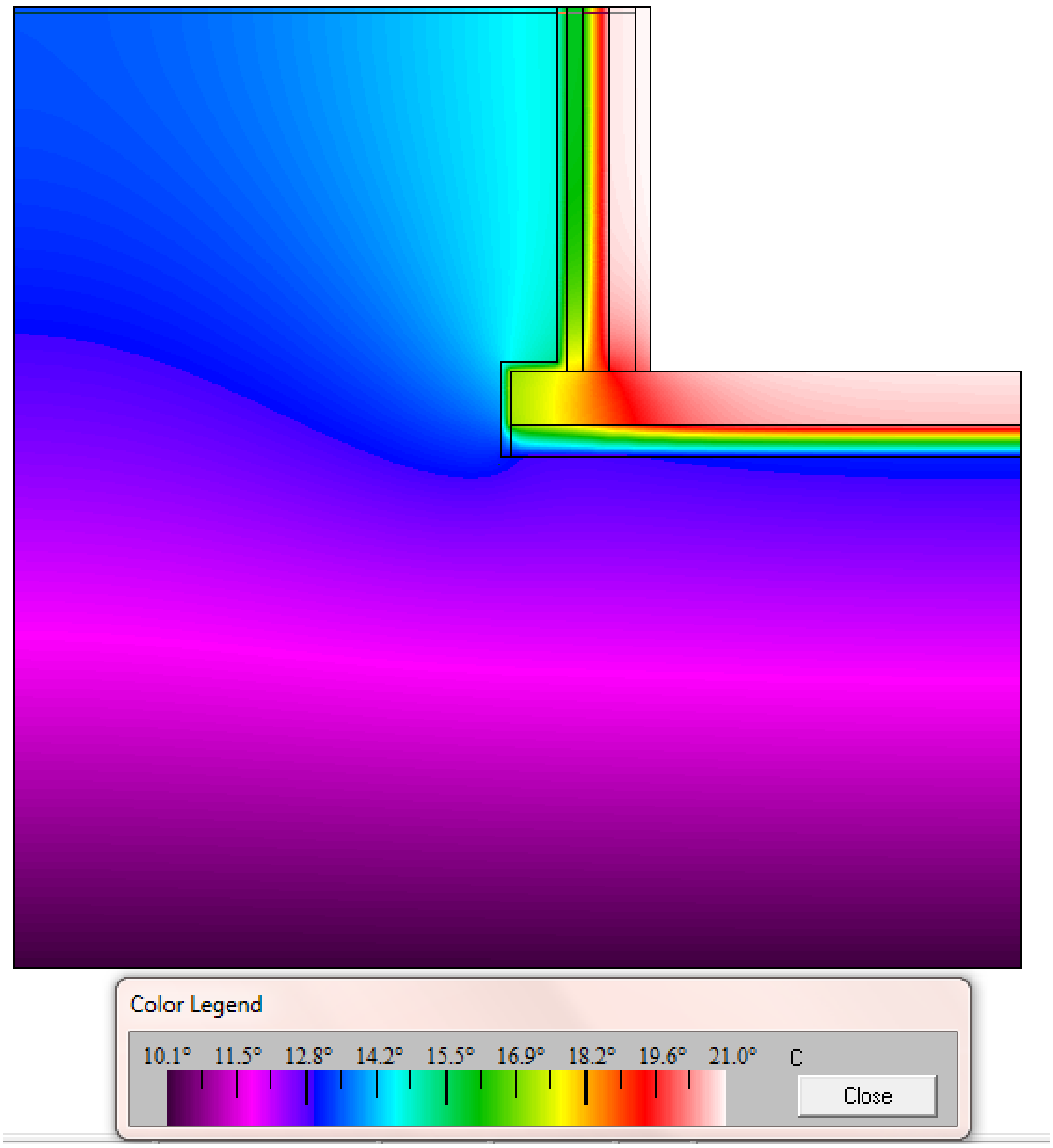


Figure M- 3: Typical German Basement Wall to Basement Slab Connection

Typical German Basement Wall to Ground Floor Wall Connection

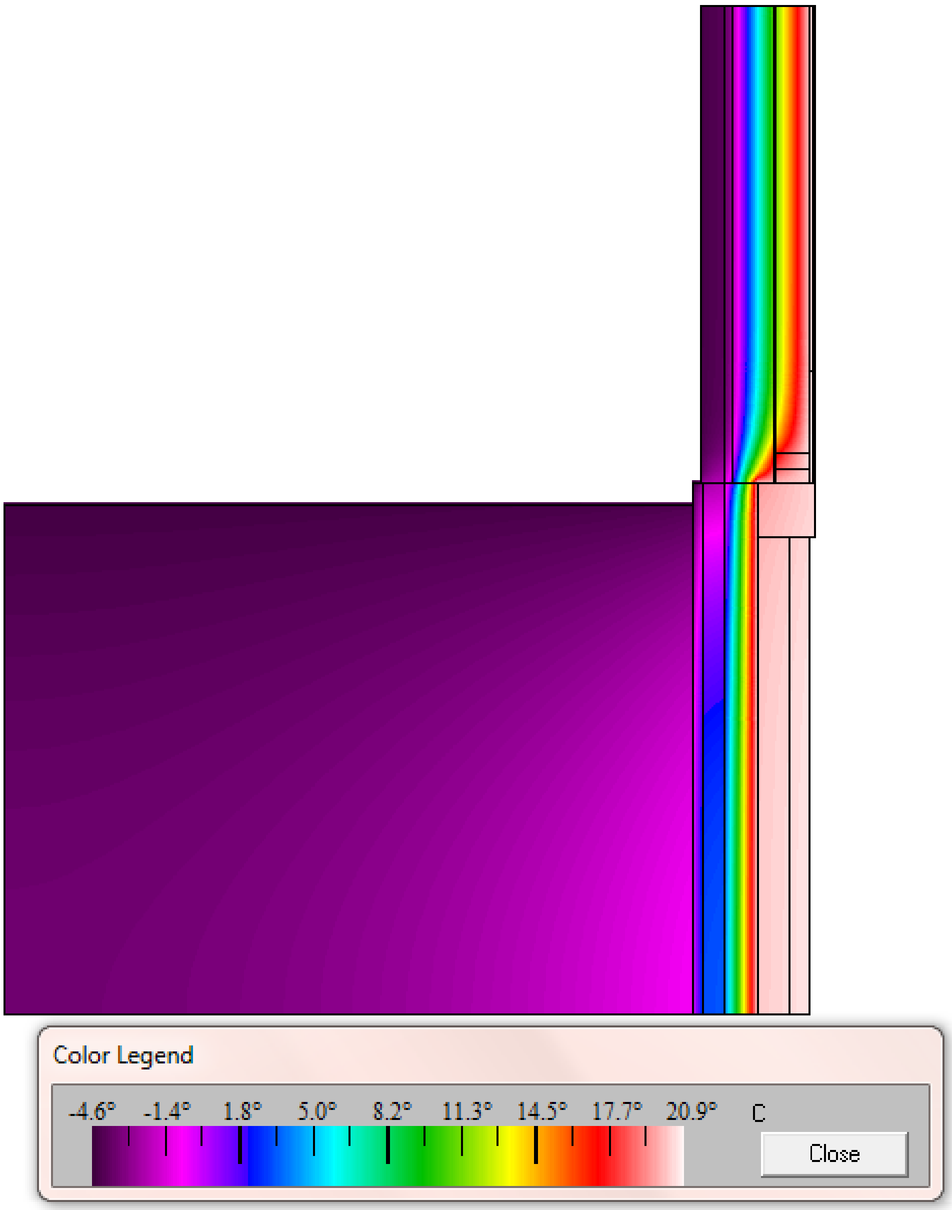


Figure M- 4: Typical German Basement Wall to Ground Floor Wall Connection

Typical German Ground Floor Wall to Basement Wall Connection

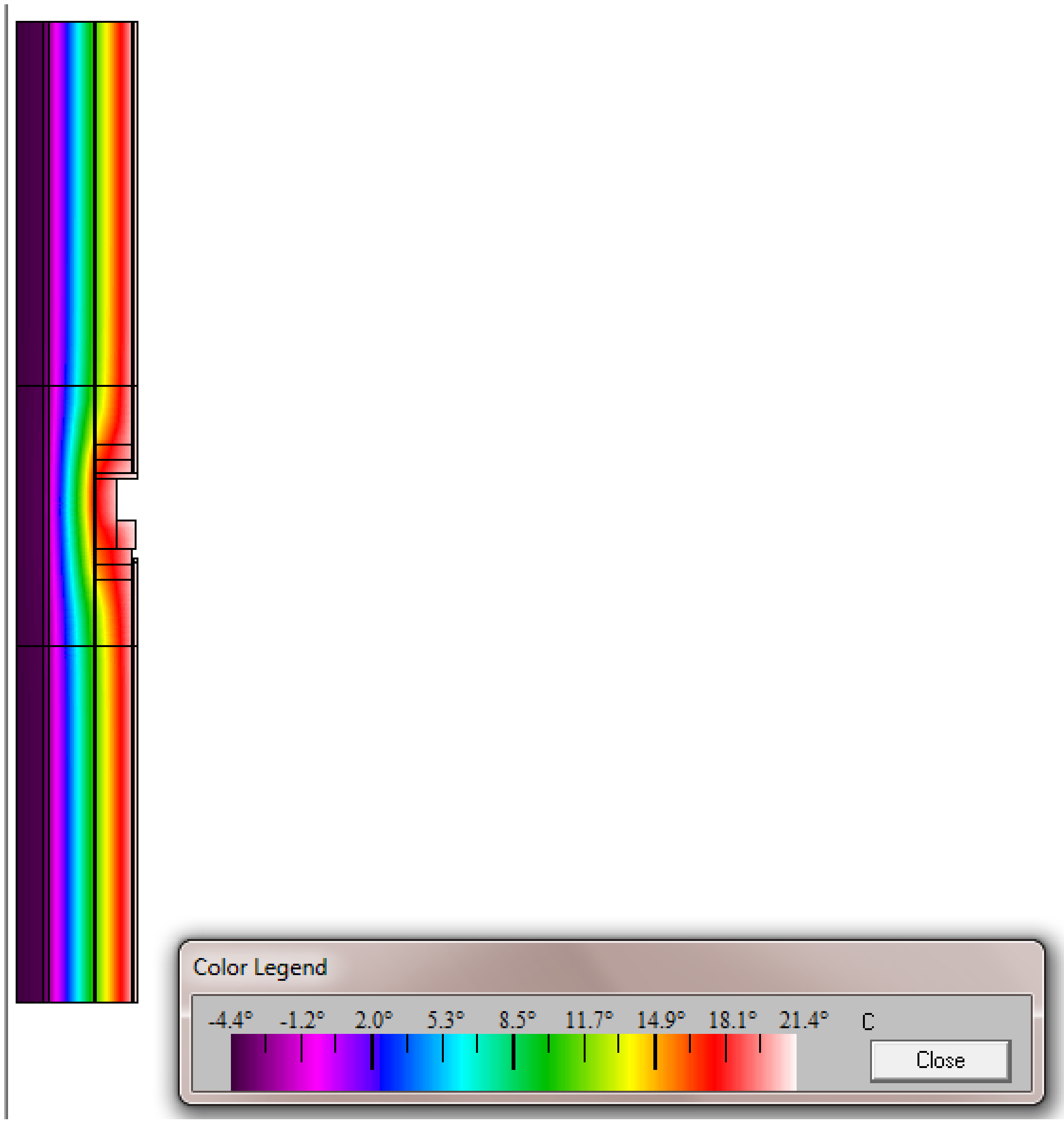


Figure M- 5: Typical German Ground Floor Wall to Basement Wall Connection

Typical German 2nd Floor to Roof Connection

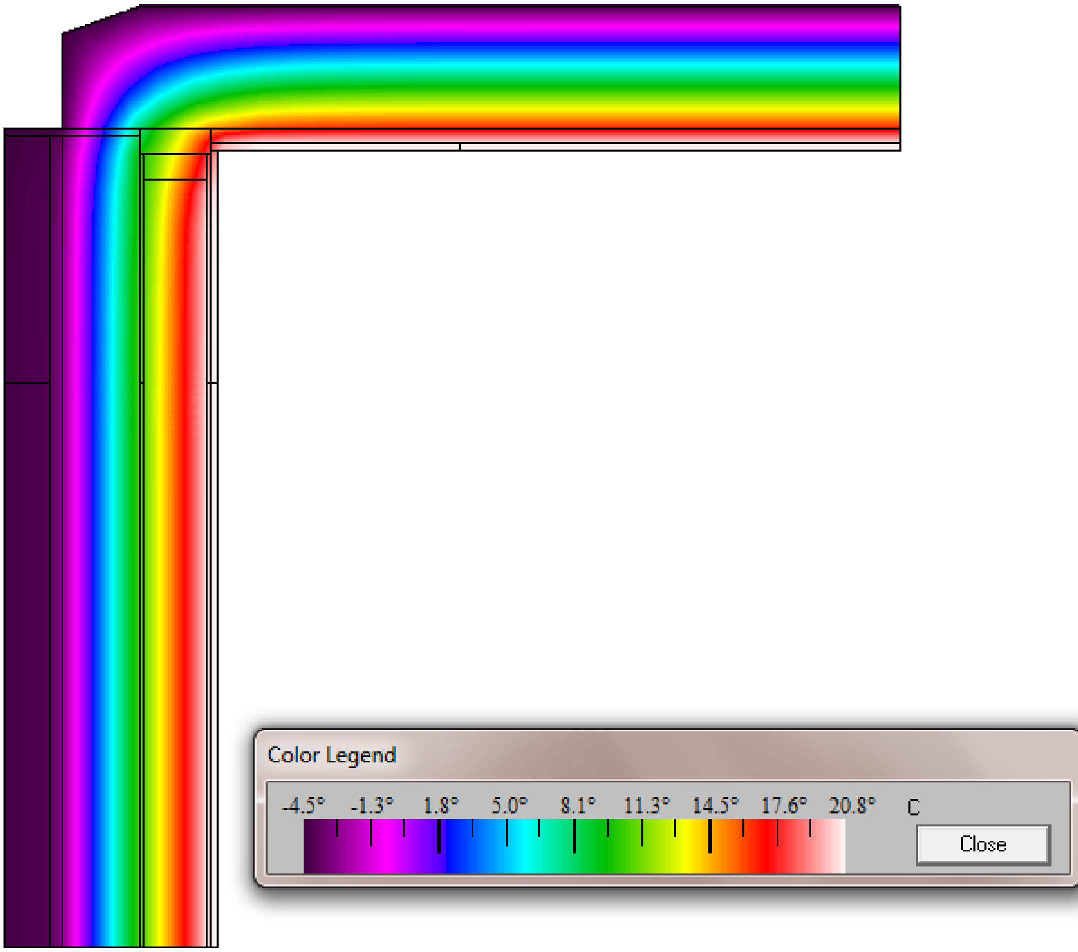


Figure M- 6: Typical German 2nd Floor to Roof Connection

Appendix N- Passive House THERM Results:

To view the THERM assumptions for these simulations go to Appendix E. Also note that some of the building envelope connections were altered slightly so they could be incorporated on an Ontario home. These building envelope connections were courtesy of Mark Yanowitz of Verdeco Design (Yanowitz, Beaton House- Verdeco Designs 2009).

Passive House Outside Corner 2nd Floor

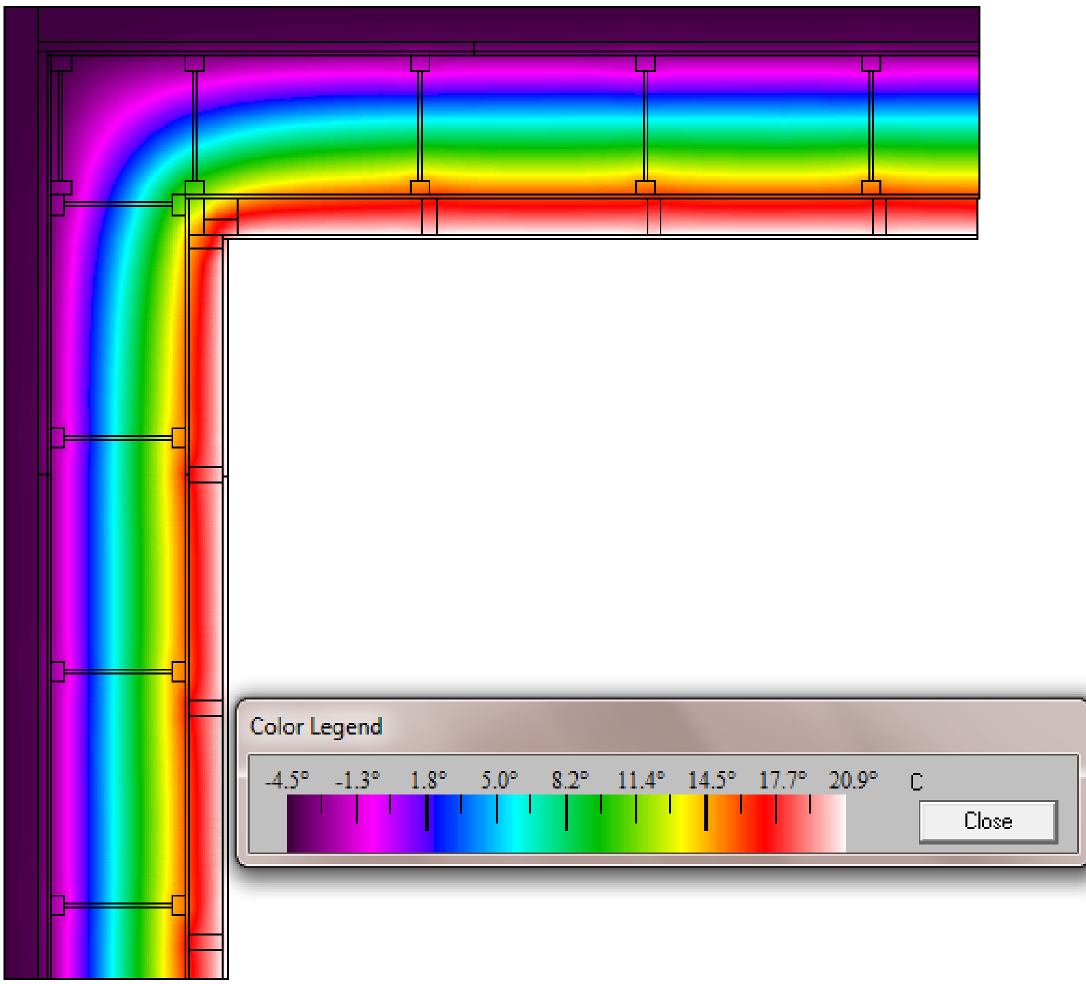


Figure N- 1: Passive House Outside Corner 2nd Floor

Passive House Outside Corner Ground Floor

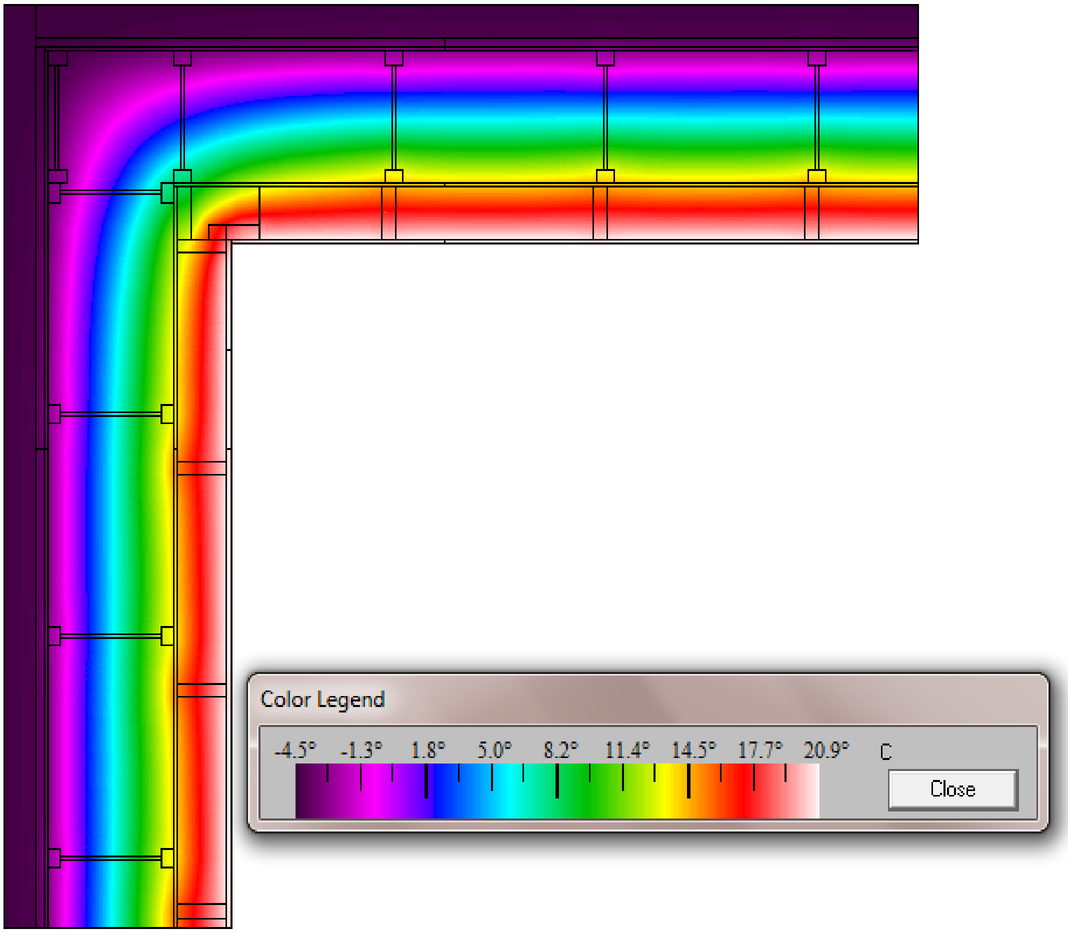


Figure N- 2: Passive House Outside Corner Ground Floor

Passive House Inside Corner 2nd Floor

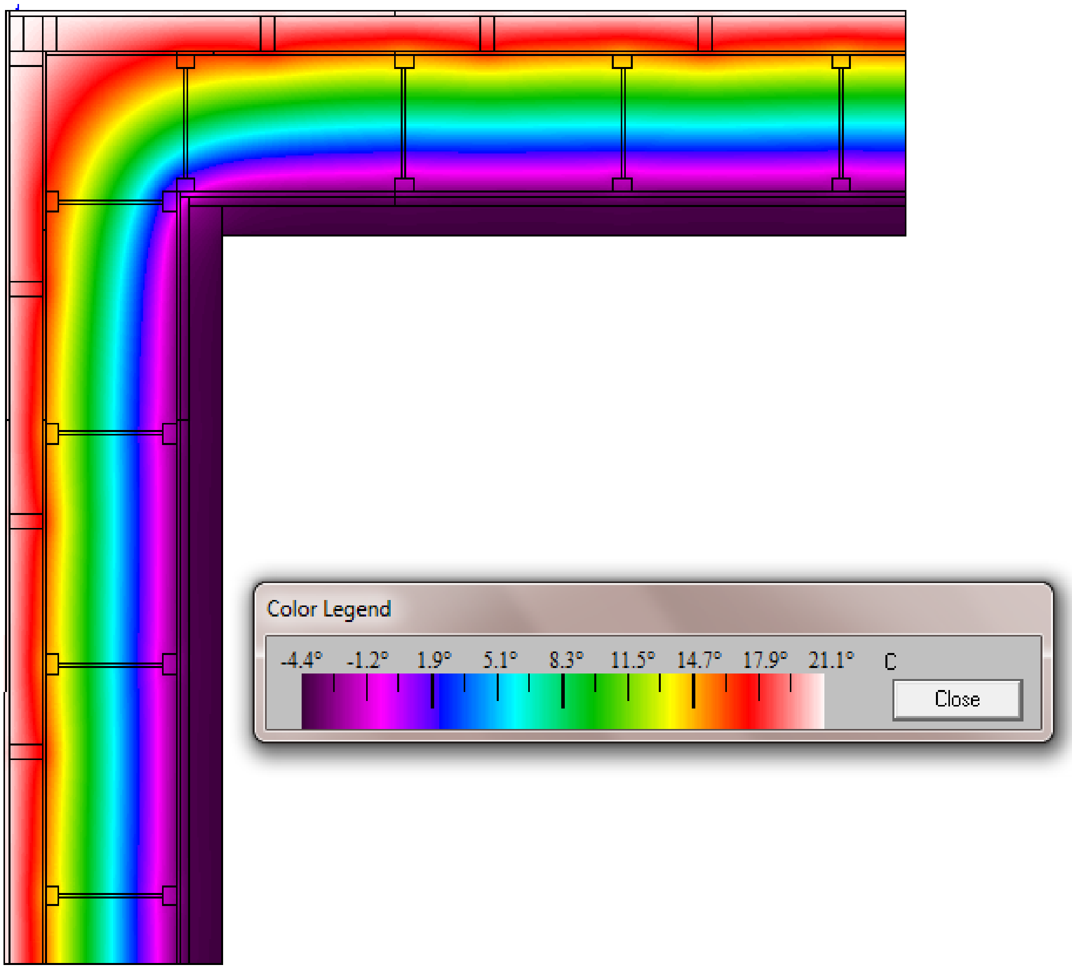


Figure N- 3: Passive House Inside Corner 2nd Floor

Passive House Inside Corner Ground Floor

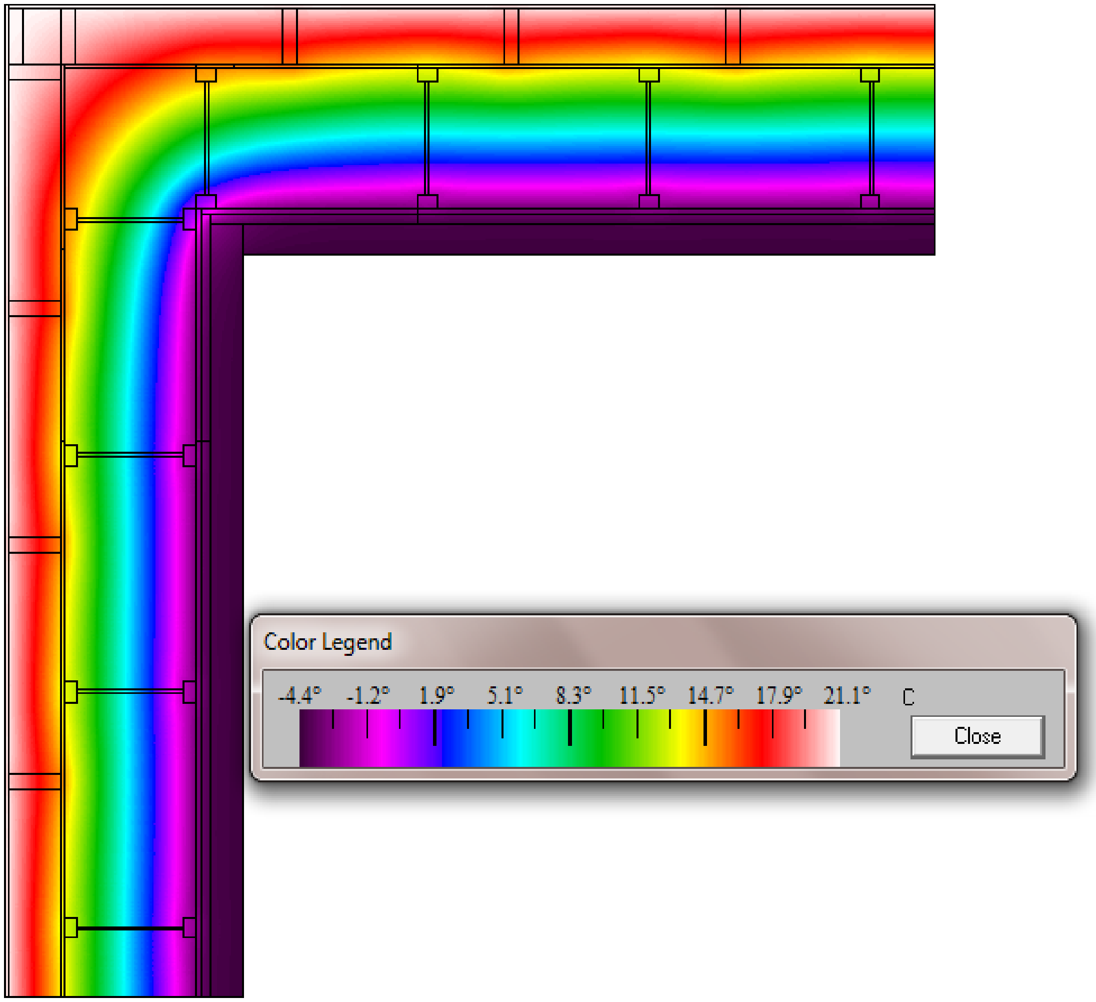


Figure N- 4: Passive House Inside Corner Ground Floor

Passive House Basement Wall to Basement Slab Connection

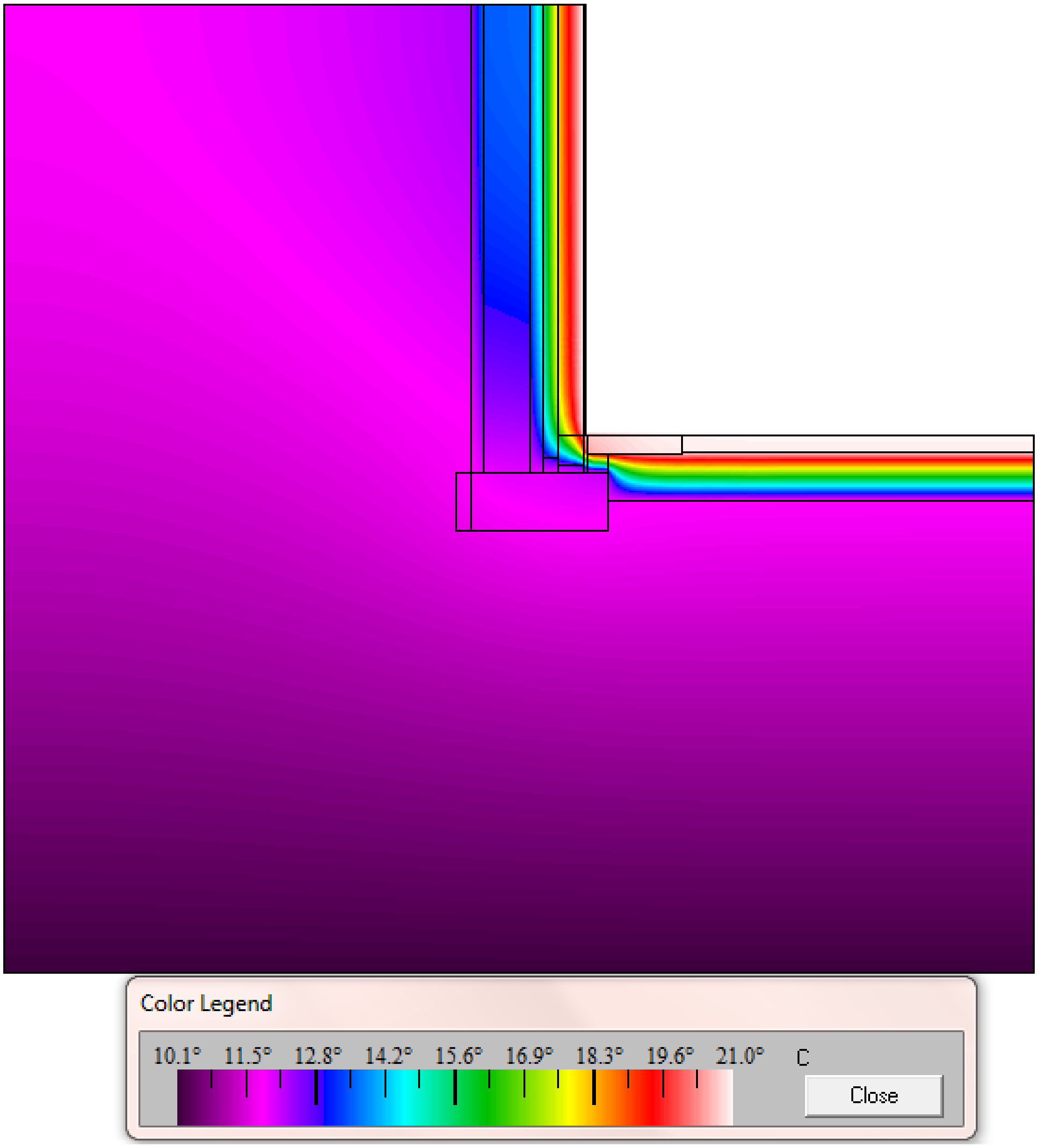


Figure N- 5: Passive House Basement Wall to Basement Slab Connection

Passive House Basement Wall to Ground Floor Wall Connection

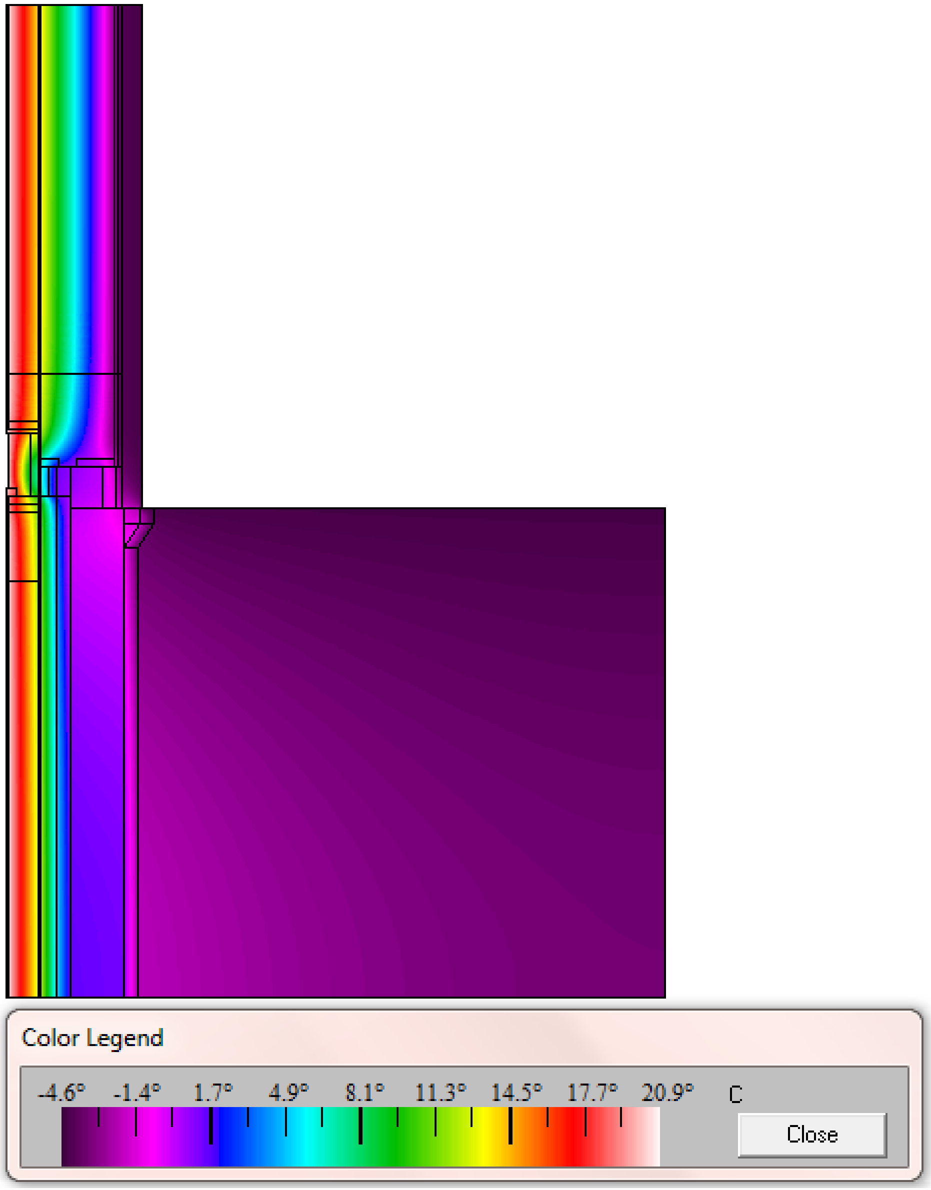


Figure N- 6: Passive House Basement Wall to Ground Floor Wall Connection

Passive House Ground Floor Wall to 2nd Floor Wall Connection

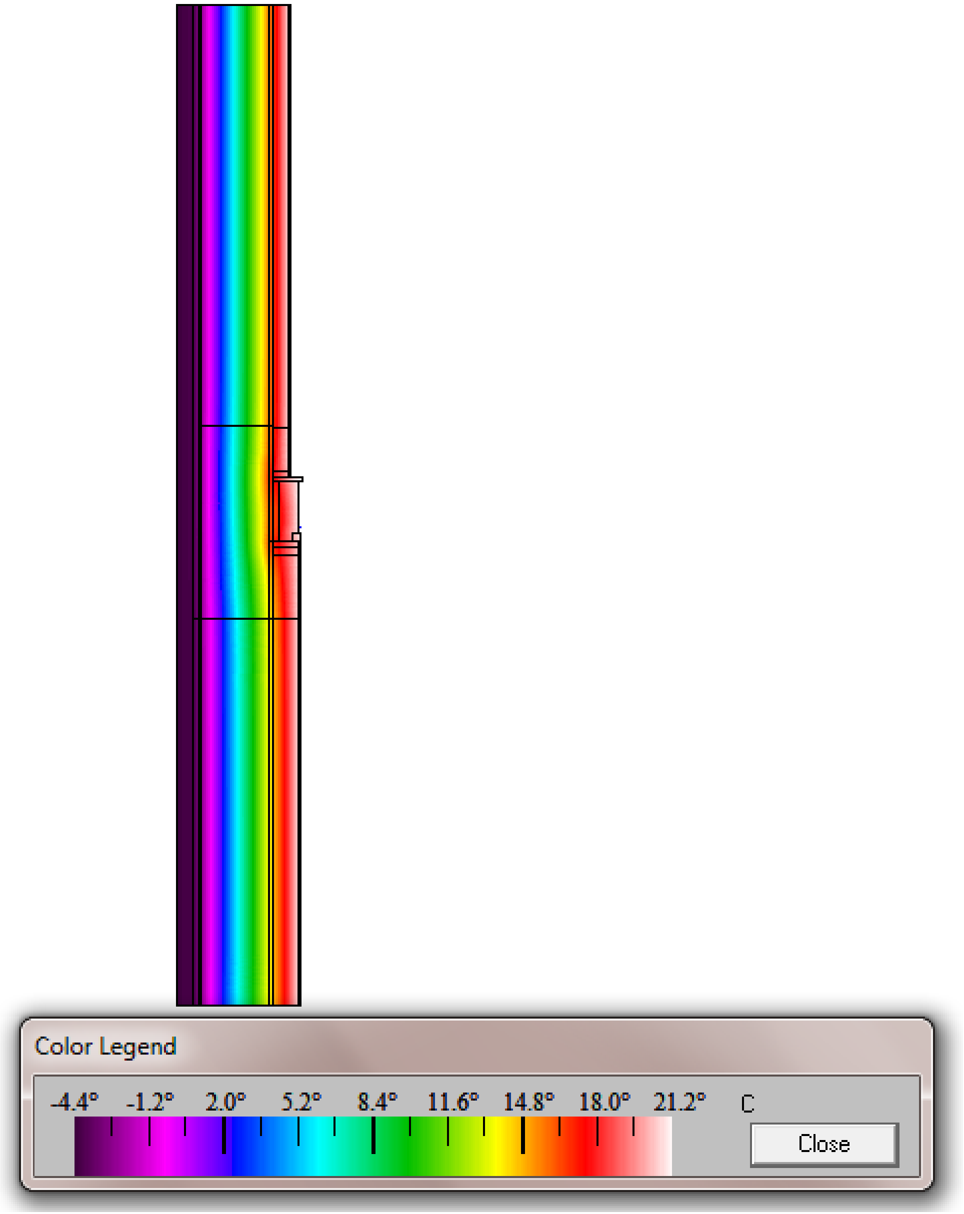


Figure N- 7: Passive House Ground Floor Wall Connection to 2nd Floor Wall Connection

Passive House 2nd Floor Wall to Roof Connection

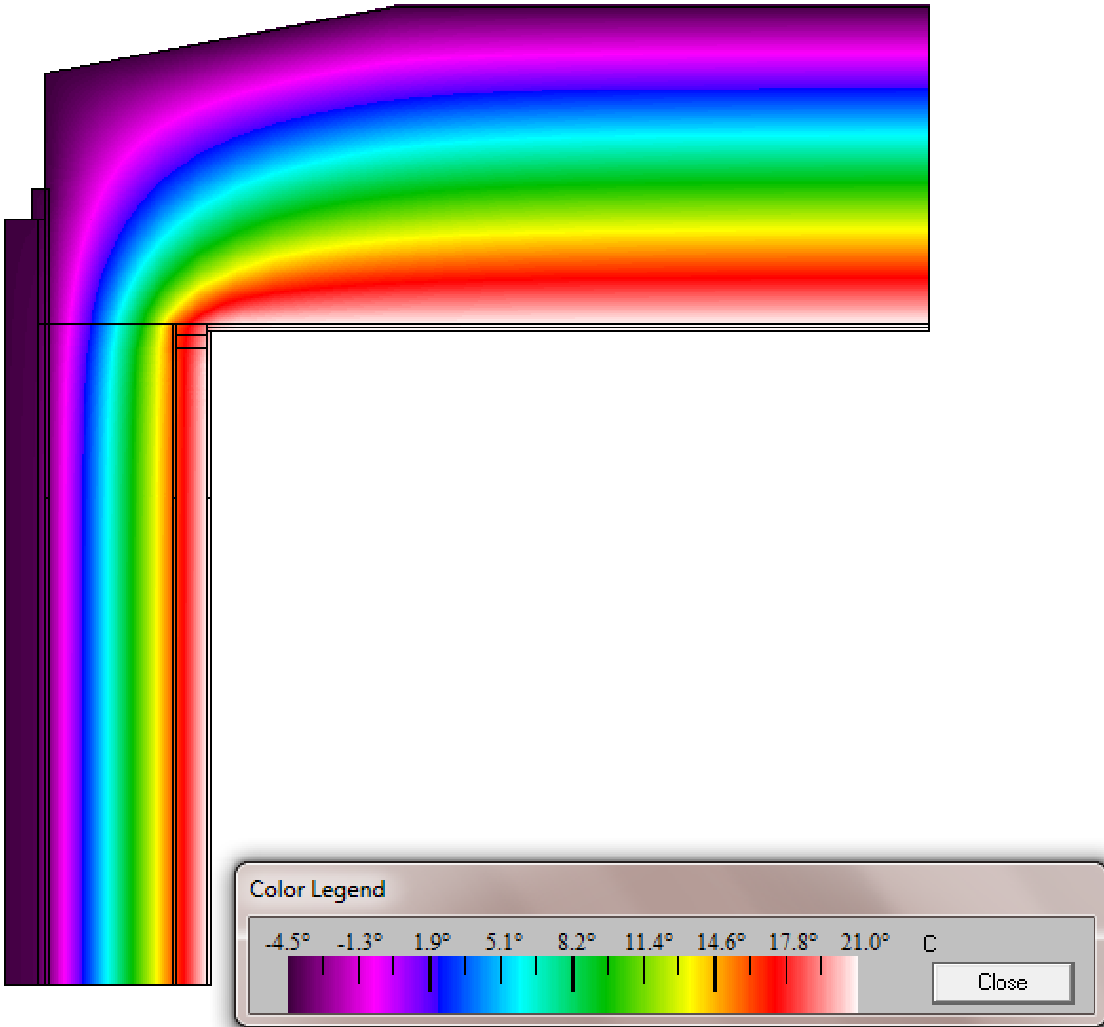


Figure N- 8: Passive House 2nd Floor Wall to Roof Connection

Appendix O - HOT2000 Calculated Building Envelope Values:

Table O- 1: Typical Homes HOT2000 Generated Building Envelope Components

Typical Homes HOT2000 Generated Building Envelope Components							
Urban							
Typical Building Envelope	**Case A-2006**	**Case B-2006**	**Case A-2012**	**Case B-2012**	**Germany**	**Denmark**	**Passive House**
Walls (RSI)	3.34	3.52	3.94	3.82	7.6	6.46	11.35
Basement walls (RSI)	2.13	2.13	2.13	2.13	5	4.7	7.75
Roof/ceilin g (RSI)	5.62	5.62	7.24	7.24	5.8	9.48	22.2
Slab (RSI)	0.07	0.07	0.07	0.07	3.59	7.1	8.9
ACH	2.5	2.5	2.5	2.5	1.5	1.93	0.6
Windows (U-value)	1.8	1.8	1.8	1.8	1	1.4	1.25
Suburban							
Typical Building Envelope	**Case A-2006**	**Case B-2006**	**Case A-2012**	**Case B-2012**	**Germany**	**Denmark**	**Passive House**
Walls (RSI)	3.32	3.51	3.94	3.81	7.6	6.44	11.35
Basement walls (RSI)	2.13	2.13	2.13	2.13	5	4.7	7.75
Roof/ceilin g (RSI)	6.06	6.06	7.77	7.77	5.9	10.02	22.2
Slab (RSI)	0.07	0.07	0.07	0.07	3.66	7.1	8.87
ACH	2.5	2.5	2.5	2.5	1.5	2.1	0.6
Windows (U-value)	1.8	1.8	1.8	1.8	1	1.4	1.25

Table O- 2: Minimum Requirements Homes HOT2000 Generated Building Envelope Components

Minimum Requirements Homes HOT2000 Generated Building Envelope Components				
Urban				
HOT2000 Minimum Requirements Inputs	**Case A-2012**	**Germany**	**Denmark**	**Passive House**
Walls (RSI)	3.94	3.03	5.8	11.35
Basement walls (RSI)	2.13	4	6.7	7.75
Roof/ceiling (RSI)	7.24	2.5	10	22.2
Slab (RSI)	0.07	2.5	10	8.9
ACH	2.5	1.5	1.93	0.6
Windows (U-value)	1.8	1.3	1.4	1.25
Suburban				
HOT2000 Minimum Requirements Inputs	**Ontario**	**Germany**	**Denmark**	**Passive House**
Walls (RSI)	3.94	3.03	5.8	11.35
Basement walls (RSI)	2.13	4	6.7	7.75
Roof/ceiling (RSI)	7.77	2.5	10	22.2
Slab (RSI)	0.07	2.5	10	8.87
ACH	2.5	1.5	2.1	0.6
Windows (U-value)	1.8	1.3	1.4	1.25