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Timber Framing Factor in Toronto Residential House Construction

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TIMBER FRAMING FACTOR IN TORONTO RESIDENTAL HOUSE CONSTRUCTION

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Abstract:

Achieving energy efficiency with thermal control in residential houses is crucial for the reduction in the energy consumption. Timber framing as the main structural component in the building envelope has a big influence on the effective R-value depending on the framing percentage, and this impacts the overall thermal performance of the building. This project, carried out in Canada, measured the typical framing percentages that are achieved in residential construction sites and compares them with code recommendations. It provides framing factors measured for 17 residential units under construction including detached, row-housing, and semi-detach dwelling units in three different locations in the Toronto area. Detailed on site measurements provide data for numerical calculation to evaluate the amount of framing within external walls, ceilings, and exposed floors. The overall framing factor calculated for each dwelling is found to exceed the recommended percentage by Canadian Model National Energy code for dwellings and ASHRAE Handbook- Fundamental. The research considers the impact that additional regular thermal bridging from the increased framing percentage will have on the effective R-value, and consequently, the impact on thermal effectiveness of the envelope leading to an increase in the overall energy above the expectations of the codes and standards.

Table of Contents

List of figures

List of Tables:

List of Abbreviations;

CEC: California Energy Commission

DHs: detached houses

$F.F_{f:}$ framing factor through the stud frame

F.F i: framing factor through the insulation

f: factor coefficient

IECC: the International Energy Conservation Code.

NBC: National Building Code

NBC: National Building Code

OBC: Ontario Building Code

OBC: Ontario Building Code

ORNL: Oak Ridge National Laboratories

Pf: framing factor

P_f: percentage of panel occupied by framing (decimal percentage)

R cw: clear wall R-value

$R_{effective}$: effective total R-value of the panel (degrees F.ft^2.hr/Btu)

$R_{f:}$ R-value of a panel section through the framing (degrees F.ft^2.hr/Btu)

R_f: R-value through the stud frame (m2.K)/ W

R i: R-value of a panel section through the insulation cavities (degrees F.ft2.hr/Btu)

R_i: R-value through the insulation (m2.K)/ W

R n: the center of cavity-R-value

R ww: whole wall R-value

RSI_f: R-value through the stud (m2.K)/ W

RSI_i: R-value through the insulation (wall cavity) (m2.K)/ W

RSI_T: total effective thermal resistance (m2.K)/ W

SDHs: semi-detached houses

TF: Timber Fraction

THs: town houses

U_T: the overall thermal transmittance

1. Introduction:

Wood framing has been used in building construction for many years in North America. It continues to be the main type of framing for the residential house construction in cold climates. It is also sometimes used in low rise commercial buildings. Standard framing construction with 25.4mm x 152.4mm studs or 25.4mmx 101.6mm studs, at 0.41m c/c are the predominant types used in low rise residential houses in Canada. Some "advanced framing" methods advocate for 0.61m on centers, which are often used in other countries like USA.

Platform wood frame construction is now the main type for wood framed building construction used in North America. It was developed from balloon framing (Appendix A) which requires full length studs to run continuously for two stories from foundation to roof with elimination of the heavy beams. Balloon framing has many disadvantages present in difficulties of long two-story studs, hanging the 2nd floor platform on an anchored sill, and absence of fire stop the hollow spaces between the continuous studs act as multiple chimneys which helps spreading the fire quickly to the second floor (American Wood Council, 2001).

Platform wood framing (Appendix A) is more complex in its details but easy in its concept. Each floor is built individually; first floor walls carry the platform for the second level and walls of the second level are constructed and built on the top of that platform. In this type of framing, the vertical hollow spaces in each walls works as fire stopper by preventing heat from escape to the upper floor. Therefore platform framing is now considered as the universal standard for wood frame construction (American Wood Council, 2001).

In Canada, 30 % of energy use is consumed in buildings(Home Owner Protection Office, 2010) and 60 % of the energy consumed by a single family home is used for space heating to provide comfortable internal temperatures- usually around 20 degrees Celsius as ambient temperature, (Green Building, 2012, or Canadian Geo-Exchange Coalition, 2010). Therefore, interest in achieving energy efficiency for buildings to reduce the energy consumption for space heating is spreading. These issues have a big relation with the function of building enclosure, which lead to a huge influence on increasing the insulation level in the building envelope. They also have a big impact on changes of some Building Codes such as the Ontario Building Code (OBC 2012) and the National Building Code (NBC 2012). These building codes are being modified in order to achieve better levels of thermal control in buildings than before, leading to cost savings for the occupants, CO_2 emission savings, and improved comfort level. As a result, more accurate methods of design and construction are required for upgrading the performance of building envelopes. Furthermore, new buildings should meet or exceed a specific R-value depending on the building code for that region (Carpenter, 2003).

R-values for the wall, ceiling, and floor can be calculated by setting up a set of calculations that add up the thermal performance for each layer of the envelope components (Carpenter and Stephan, 2003). In R-value calculations for a wooden frame wall, two parallel-paths for heat transfer occur in the envelope because of having two major different materials within the thickness of the structural frame. One path passes through the wood studs and the other goes through the insulation layer. The parallel path calculation method calculates the R-value through both and then each area is weighted (Carpenter and Stephan, 2003).

It is crucial to correctly measure the amount of wood used in framing and its thermal impact on the envelope; wood studs have higher thermal conductivity compared with the insulation filling the spaces between them. Calculating the total R-value for the wall by adding the R-value for each material can overestimate the actual R-value. The “effective R-value” has been proposed as a more accurate way of measuring heat flow: this includes the effects of framing and other regular thermal bridging (Siegenthaler, 2004). Calculating the effective R-value gives more accurate results in heat transfer calculations. A better estimation for the framing percentage gives more accurate prediction of effective R-value and thus better prediction of thermal performance including size for the heating system components. Therefore, in the typical residential and light commercial construction, some energy codes and standards require using the effective R-value in any calculation of different building components to avoid overrating the actual thermal performance of the whole wall system; some heat load estimating soft-wares are also adjusted for the presence of the wood framing for these buildings (Siegenthaler, 2004).

Residential wood frame systems are commonly constructed with 25.4mm x 152.4mm or 25.4mmx 101.6mm timber studs distributed vertically with equal distances of 0.41m between centers of studs. These wood elements are generally considered as a natural thermal insulator but their thermal conductivity is higher compared with the surrounding materials in the envelope components. The thermal conductivity for lumber studs is 0.140 (W/m K) while it is 0.042 (W/m K) for fibreglass batt insulation (Straube, 2009). These studs form a better path for heat to escape from the building to outside, and therefore act as thermal bridges. Therefore, the thermal performance of the envelope results from the combination of the effects of the framing elements and the insulation layers which form the envelope system.

Figure 1.1 shows a typical simple wood framed wall assembly, 12.2m x 2.7m., with 25.4mm x 152.4mm wood studs distributed equally with a distance of 0.41m center to center. Double top and single bottom plates are also used in the wall assembly.

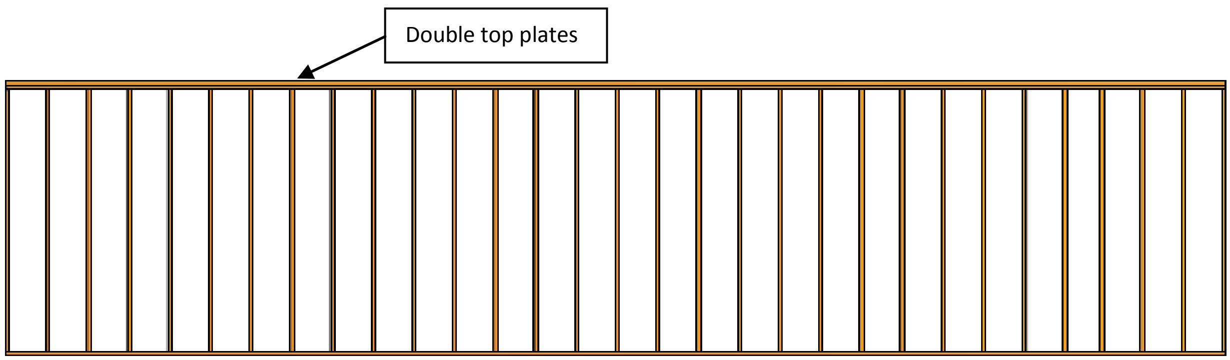


Figure 1.1: Standard wall framing- opaque

This standard wall includes 31 studs and 30 sections of insulation material, the amount of the wall that can be insulated is 87% and the framing percentage calculated for that wall is 13%.

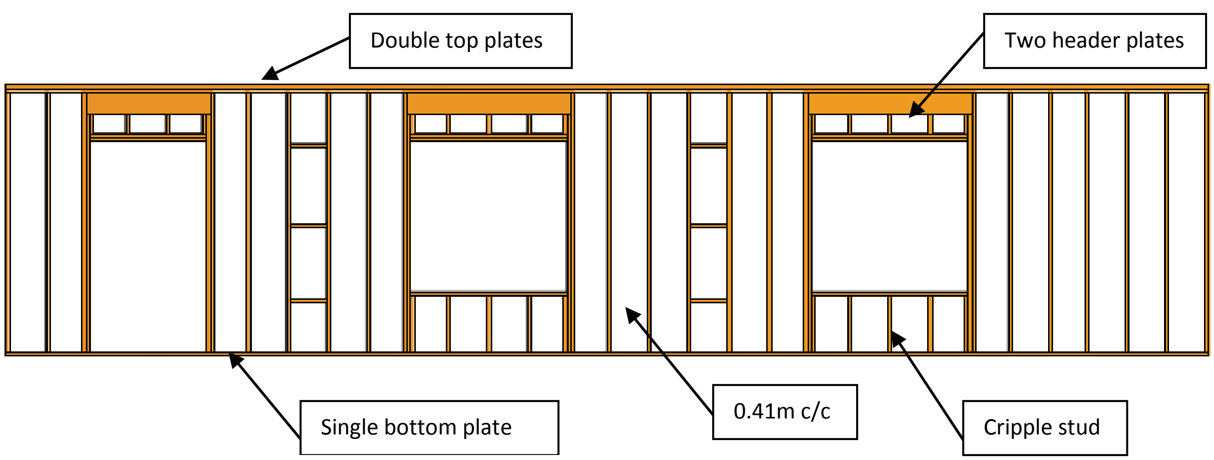


Figure 1.2: Standard wall framing- with openings

When openings like a door and two windows, and additional elements like headers and cripple studs are added to the same wall assembly as shown in Figure 1.2, it will contain 29 studs and 44 sections of insulation. In this modified wall, the insulation area is reduced to 60% and the framing percentage increased to 18.3% of the total wall area or 23.3% of the opaque wall area, while the openings area (including the door and the two windows) occupies 21.7% of the wall. This example presents the impact of framing percentage on the amount of insulation used in the wall. Framing percentage increases even further with the junctions between walls or with floors and ceilings are considered. Furthermore, additional (often unnecessary) framing is sometimes added on site by the framing contractor.

Calculating the framing factor for a wood framed residential building seems to be easy since studs are distributed with an equal distance between them but in reality it is far more complicated because of having additional studs added to the frame around windows doors and corner, even in area which includes pipes and exhausting fans.

It is common to identify the R- value of the wall according to the type of insulation installed between studs, for instance, installing R13 fibreglass batt insulation in a wall system does not give the performance of R13 because of ignoring the top and bottom plates, rim joist, and studs around windows and doors. Although soft wood works as a good insulating material, it has higher thermal conductivity comparing with the surrounding insulating materials in the envelope. Timber elements participate in reducing the R-value of the wall because they act as weak spots- thermal bridging- which increase the opportunity for the heat to bridge around and over the thermal insulating materials and pass through the envelope to outside (Strauble and Smegal 2009). Figure 1.3 presents the thermal bridging through wood studs.

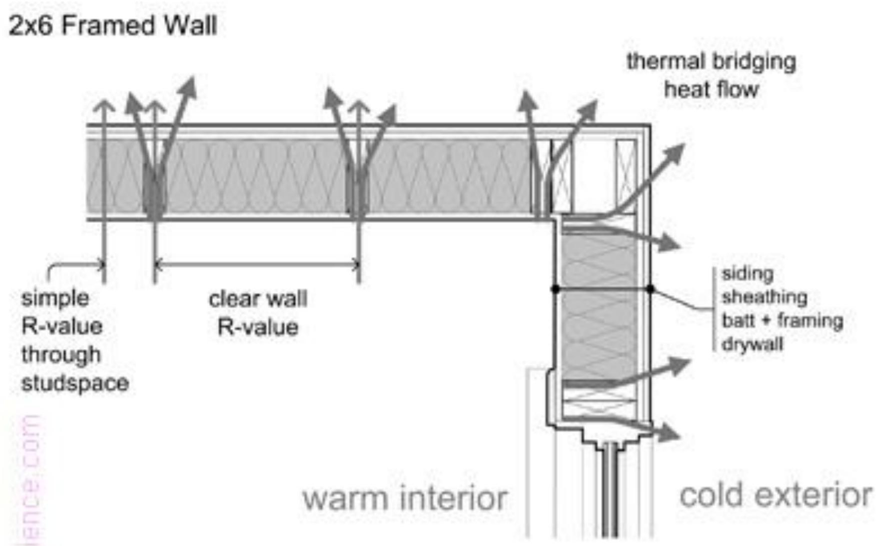


Figure 1.3: Thermal bridging through wood studs, (Straube, 2006)

The thermal conductivity of the framing components; studs, insulation material between studs, sheathing, and other materials used in framing construction play an important role in determining the overall wall R-value (ASHRAE 2001a). Table 1.1 shows some common construction materials with their thermal conductivity. It shows that the conductivity of framing lumber is four times higher than a typical insulation material alongside. Consequently, timber frame elements are the main elements that contribute to heat loss through the envelope and affect its thermal performance; lumber studs also occupy a noticeable area in the gross area of the envelope which can be used to calculate the framing factor.

Enclosure Component	Conductivity k [W/mK]	per inch [hr·°F·ft^2/Btu]
R14 Fiberglass Batt (3.5")	0.036	4.0
R21 Fiberglass Batt (5.5")	0.038	3.8
Blown Fiberglass	0.035	4.1
Extruded Polystyrene (XPS)	0.029	5.0
Expanded Polystyrene (EPS)	0.038	3.8
Framing lumber and sheathing	0.140	1.0
Cellulose Insulation	0.039	3.7
0.5 pcf spray foam	0.039	3.7
2.0 pcf spray foam	0.024	6.1

Table 1.1: Conductivity values used for two dimensional heat flow analysis, (Straube, 2009)

In the absences of Canadian studies on the framing factor, and the lack of measured data for Ontario region, little information is known and available about the values of the framing factor for Canada in general. So in this project, framing factors for different types of residential houses were measured on site to assess the real factors that are achieved in residential construction sites. These houses were chosen as examples of typical low residential building from different locations in the Greater Toronto Area. They were under construction at the time of measurement in order to allow for accurately counting and measuring the woods elements within the envelope. The resulting framing percentages are compared with the recommended percentage by codes and standards including ASHRAE Handbook of Fundamentals and Ontario Building Code and show the thermal impact of framing fraction on thermal performance of the building envelope. This project presents different ways to reduce the thermal impact of the framing factor by upgrading the wall system to improve the thermal performance of the as-built walls and reduce the thermal bridging effects in the envelope.

2. Objectives:

The purpose of this study is

1- Calculate the framing factor for residential buildings under construction in different locations in the GTA,
2- Compare the results generated from the calculation with the recommended framing factors by ASHRAE Standard of Fundamental and the NBC.
3- Calculate the effective R-value of the as built walls, floor, and ceiling
4- Study the effect of the calculated framing factor on the wall thermal resistance
5- Propose upgrades to as-built walls to reduce the impact of framing factor on the wall thermal performance and control the thermal bridging.

3. Literature Review

This literature review presents previous works done on framing factor measurement and the effect of framing factor on the thermal performance of the building envelope including the thermal bridging caused by the structural elements. It discusses various ways of calculating R-values used in the construction industry, and focuses on the way of calculating Whole Wall R-value.

Framing factor can be defined as a percentage of all framed area in an insulated envelope that bridges the insulation (including exterior walls, ceiling, and exposed floors) to the total area of the framed envelope (Carpenter & Schumacher2003). Theoretically, wooden or steel studs are distributed equally within the wall frame with usually 16 inches on center between each two studs. However, in reality, it is more complicated because of the additional framing components which are added where required, such as the areas around windows, doors, corners, between floors and bracings and blockings. Often framer will also add further components that may not be necessary.

It is crucial to accurately calculate the amount of wood used in the envelope in order to understand its influence on thermal performance of the envelope. According to (Carpenter & Schumacher, 2003), having the accurate framing percentage has many advantages; it has a significant impact on the total-assembly R-value because of having higher heat transfer through studs than insulation material. It is also necessary to know the framing factor to ensure that the building meets the recommended framing factor requirements of the local energy codes and standards.

In the UK researchers have started to estimate the actual amount of timber used in the building in order to understand the problem of thermal bridging in insulated timber walls. It is only since 1995 that problem has been considered by UK Building Regulation. At that time, in the UK framing factor was suggested to be 15 % for a typical wall with openings, 10% for wall with no opening, (Bell & Overend 2001) and 20 % for narrow walls with openings (CIBSE, 1999). However, the actual framing percentage recommended by the code was 6.3% for nominal stud spacing 600 mm and stud width 38mm (Bell & Overend 2001). On the other hand, This compares with ASHRAE 1993 recommendations to use framing factor between 22% and 25 % depending on the stud spacing (ASHRAE 1993).

In 2004, Siegenthaler also claimed that the framing factor (P_f) for the typical wood-framed residential and light commercial construction ranges between 10% framing factor for 0.61m center to center with insulated headers over windows and doors, while 20% framing factor is used for 0.41m center to center with solid headers, complex wall shapes also requir extra studs which leads to high framing factor.

Bell and Overend, (1997), at Leeds Metropolitan University carried out two case studies to measure the actual framing fraction in existing buildings in the UK, the first case study was a terrace of three bed rooms, three-story town house, while the second was a two-story development of student housing. Case 1 has 38mmx 89mm studs with a distance of 600mm on centers between studs. Case 2 has 38mm x 140mm studs with the same distance between studs. Table 3.1 shows the result of measured framing factor and the impact on U-value for case 1 and 2:

Timber fraction and U values

House type		Net wall area	Opening fraction	Area of timber	Timber fraction	U value (measured TF)	U value (6.3% TF)	U value (15% TF)
		m^2	%	m^2	%	W/m^2K	W/m^2K	W/m^2K
Case 1	End ter	114.91	16%	34.46	30.0%	0.51	0.38	0.43
Case 1	Mid ter	52.14	29%	20.72	39.7%	0.56	0.38	0.43
Case 2	End ter	84.77	13%	23.69	27.9%	0.35	0.26	0.30
Case 2	Mid ter	42.62	23%	16.13	37.8%	0.39	0.26	0.30

Table 3.1: Measured timber fraction and U-values in external walls, (Bell and Overend, 2001)

They showed that the framing factors were considerably higher than those available in design guidance and in the UK codes as set out in Approved Document, AD-L 1995 and the proposed framing factors for 2002 revisions to the codes (Bell and Overend, 2001). These building codes recommended framing factor to be 6.3% but the measured faction for the two case studies exceeds 4 to 6 times the recommended percentage in design guidance and proposed

Building Regulations Approved document, 1995-L. The framing percentage measured for each of these two buildings was fairly similar although they are different in design.

Another study was also done by Leeds Metropolitan University, UK on actual framing proportion in the walls of a terrace of 3 story wooden framed town house under construction. The resulting framing factors are 29%, 39%, 31% with an average of 32% (Bell et al 2001). These are similar to the results generated in the previous studies. These studies showed that the high timber framing factor resulted from extra framing around openings, additional head and sole plates, and having bay windows in the ground level which used 54% solid timber in the construction.

In order to estimate and develop a representative set of framing factor for low rise-residential buildings in the US including single family detached, single family attached, and low rise multi-family house, two projects were carried out for ASHRAE; one by (Enermodal Engineering, 2001) and the other by the California Energy Commission,(2003). These two projects aimed to assess the framing factor for 120 residential units in four non-seismic areas in US and 60 dwellings in two Seismic areas of California. These units vary between attached, detached, and multi-family dwellings with 0.41m wall stud spacing. The size and the style of dwelling in each area were chosen to represent the range in that region. It was found that the average wall framing factor in California region can reach 27% in order to meet the seismic requirements, (Enermodal Engineering, 2001) while it does not exceeds 25% (California Energy Commission, 2003) for the rest of North America low rise- residential buildings.

The results of these studies also reveal that the framing factors for the dwelling in the non-seismic region (US region without California zone) were generally similar to each other with very minimal regional differences. The same resulted of having almost similar values for the framing factor was also found in California zone. It was also found that the units which located in the western side of the US had lower framing factors because of having larger dwelling`s ceiling area which reduces the overall framing percentage. It mainly appears in the single story units while the low-rise multistory building had higher overall framing factor because of having smaller ceiling area, straight runs of wall and additional framing for support (Enermodal Engineering, 2001). Finally, the overall framing factors for all the three types of dwellings in California zone and the rest of the US zones are comparable, the only difference appeared in the walls framing factors (25% for non- seismic region and 27% for the seismic region), so it is recommended to calculate the framing factor for the walls, ceiling, and floor separately (Stephen et al, 2003).

3.1. Whole wall R-value calculation:

ASHRAE Handbook of Fundamentals contains the standard thermal resistance for most of the insulation materials used in construction. The parallel path method is also recommended by ASHRAE Handbook of Fundamentals to be used for calculating the thermal resistance for wood framing walls. This method works on the concept that heat flows in parallel path of different conductance because of the arrangement of the materials that compose the wall. ASHRAE Handbook of Fundamentals and the International Energy Conservation Code (IECC) standard requirements are based on results generated from AHSRAE and DOE research results, but all the thermal requirements come from ASHRAE considering the studs material, stud spacing, and stud depth for R-value calculation and neglecting the top and bottom plates. Consequently, this leads to lower and not accurate values for framing factors (Kosny, 2006).

3.1.1. Three different types of R-value are defined by Oak Ridge National Labs (ORNL) and used in calculating whole wall R-value;

3.1.1.1. Clear wall R-value (R cw)

R-value for exterior wall area that contains insulation with minimum necessary framing materials for an area without windows, doors, corners, columns or connections with other envelope elements such as roofs, foundations or other walls (Straube et Smegal, 2009 and Kosny et al 2006). This type of R-value does not give any indication how the building is built. It does not represent the effect of any additional construction or even how the roof and walls are jointed. Clear R-value can be determined by testing a section of 8'x8' framed wall with insulation in the hot box experiments (Christian and Kosny, 1998, Enermodal Engineering, 2001, and Chitwood Energy Management, 2001).

3.1.1.2. Center of cavity R-value (R cc)

It is an estimation of the R- value of the wall by adding the R-values for the materials at the center of the cavity, (i.e., through the insulation, this assumes 0% framing factor and it does not consider any thermal performance or thermal bridging in the wall assembly.

3.1.1.3 Total wall R-value (R ww)

The R-value for whole opaque wall includes all additional structural elements and typical envelope interface details including corners, wall to roof, wall to floor, wall to door, and wall to window connections (Straube et Smegal 2009 and Kosny et al 2006). Whole wall R-values can be 40% less than the clear wall R-value in a traditional wall assembly (Kosny et al, 1997). This type of R-value is more accurate because of including all of the interface details which have an impact on increased heat loss through the envelope.

Wall R-value is usually calculated for the conventional wood frame construction without taking into the account the effects of the additional structural elements around windows, doors, and corners. Using this method the actual thermal performance of the whole wall system is usually overrated (Kosny et al 1997).

ORNL worked on measuring the whole wall R-value for different wall systems including metal, concrete and timber framing walls to show the importance of using it to select the most energy-efficient wall system. Laboratory measurements and heat flow simulations were used to measure the whole wall R-value including clear wall R-value with the interface details in each wall types.

In 1997, Christian and Kosny worked on calculating the whole wall R-value. An 8 ft. x 8 ft. clear wall section was used in a secured hot box to be tested and results were compared with sophisticated heat conduction model predictions. Then, computer simulations for a clear wall area were carried out with insulation, structural elements, and eight interface details include wall/ wall, wall/roof, wall/ floor, wall/ door, and wall/window connections. Finally results were compared with a single whole wall steady- state R-value estimation (Kosny et al, 2006 and Kosny, 2002).

The following Table 3.2 shows the whole wall R-value data generated from the ORNL Hot Box tests and how much they vary from the clear wall R-value.

No.	System Description	Clear Wall R-Value (Rcw) M^2.k/W	Whole Wall R-Value (Rww) M^2.k/W	(Rww / R cw) x 100%
7.	**2x4 wood stud wall 16-in. (40-cm.) o.c., R-11 batts, -in. (1.3-cm.) plywood -exterior. -in. (1.3-cm.) gypsum board -interior.**	1.86	1.69	91%
8.	**2x4 wood stud wall 24-in. (60-cm.) o.c., R-11 batts, -in. (1.3-cm.) plywood -exterior. -in. (1.3-cm.) gypsum board -interior.**	1.91	1.74	91%
9.	**2x6 wood stud wall 24-in. (60-cm.) o.c., R-19 batts, -in. (1.3-cm.) plywood -exterior. -in. (1.3-cm.) gypsum board -interior.**	2.88	2.41	84%

Table 3.2: The whole wall R-value data based generated from the Hot Box tests, (Christian and Kosny, 1995 and Kosny and Christian, 1997)

Using the result generated from ORNL experiments on 18 different systems (steel, wood, and concrete framed wall systems), a comparison between clear R-value and whole wall R-value can be made; Most of the building with conventional wood framing wall have higher R cw than R ww.

An interface detail has an obvious influence on the whole wall R-value; experiment no. 9 had higher whole wall value comparing with experiments no. 7 &8. Rww for case no.9 (2x6 wood stud walls) was 2.41 M^2.k/W while experiment no.7 (2x4 wood stud wall) and experiment no. 8 (2x4 wood stud wall) achieved 1.69 M^2.k/W and 1.74 M^2.k/W respectively. In addition, the ratio of Rww/Rcw would be 91% for 2x4 stud walls (experiments 7 & 8). It is also higher than the ratio generated in experiment no.9 (2x6 wood stud walls) which is 84% because of having lower values for R ww. As a result, whole wall R-value can be changed with the change of any interface details. Whole wall R-value is also very important to be considered in the market place, and to be used in designer guidance, manufacturers, and buyers in order to choose more energy efficient wall systems (Christian and Kosny, 1997).

In 2009, Straube and Semgal did two dimensional heat flow simulations in order to calculate the total wall R-value. This simulation has included modeling for 2.5m timber wall section with 25% framing factor (Figure 3.1), 0.203m portion of the wall with top plates section (Figure 3.2), and the rim joist section (Figure 3.3) and (Figure 3.4).

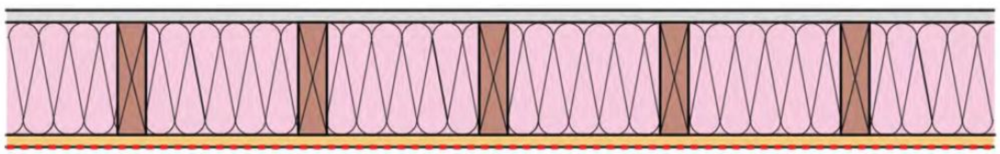


Figure 3.1: Plan view of wall section for THERM simulation (Straube, 2009)

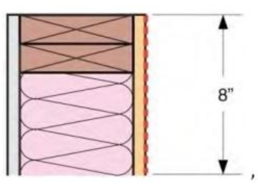


Figure 3.2: Top plate simulation with 8" of wall, (Straube, 2009)

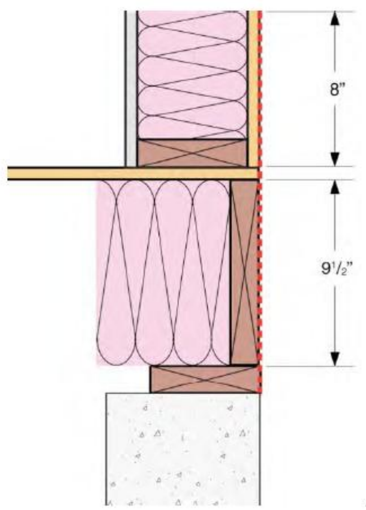


Figure 3:3: simulation with 8" of wall, (Straube, 2009)

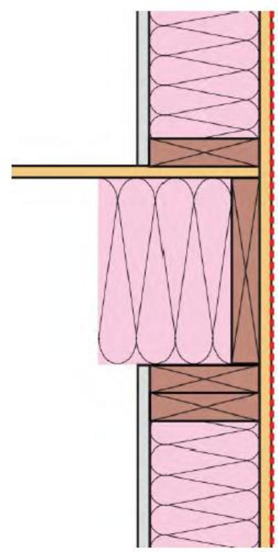


Figure 3.4: Rim joist simulation, (Straube, 2009)

When the R-values are simulated for each of these three sections, they could be applied in the following equation in order to calculate the whole wall R-value.

$$\text{Total wall R-value} = \text{R-value top plate} \times \frac{\text{height of top plate}}{\text{overall wall height}} + \text{R-value of rim joist} \times \frac{\text{height of rim joist}}{\text{overall wall height}} + \text{R-value of wall section} \times \frac{\text{height of wall section}}{\text{overall wall height}}$$

(Equation 3.1)

Source: Straube and Semgal, 2009

Where the height of the wall section is 2.33m and the overall wall height is 2.74 m.

According to Siegenthaler, 2004, having an accurate size for the hydronic heating system depends mainly on the best estimation for the building heat loss through the envelope. It can be evaluated by calculating the total R-value for the envelope enclosure that lays between heated and unheated zones.

3.1.1.4. Effective R-value

The “Effective R-value" calculation has been used to develop the way of calculating R-value in order to account for higher rates of heat transfer through wood-framed surface. “Effective R-value" depends on the type of the insulation, the depth and the spacing of the framing.

Effective R-value is also recommended by ASHRAE handbook Fundaments and Model National Energy Code Of Canada houses to be used in calculating the thermal resistance of a building envelope assembly containing wood framing. The effective R-value depends mainly on the parallel path heat flow for calculating two sums of the thermal resistance of a various materials combined in the assembly: along the line that passes through the stud and along the line that passes through the wall cavity. Then these 2 sums can be applied on the following equation in order to calculate the effective R-value for the wall assembly.

$$\mathbf{RSI_T} = \frac{\mathbf{100}}{\frac{\textbf{\%area with framing}}{\textbf{RSI f}} + \frac{\textbf{\%area}\frac{\textbf{w}}{\textbf{o}}\textbf{framing}}{\textbf{RSI i}}} \qquad \text{(equation 3.2)}$$

Where :

RSI $_T$: total effective thermal resistance **(m2.K)/ W**

RSI_f: R-value through the stud **(m2.K)/ W**

RSI_i: R-value through the insulation (wall cavity) **(m2.K)/ W**

And the overall thermal transmittance (U-factor) is $\boldsymbol{U_T = \frac{1}{RSI_T}}$ (Equation 3.3)

ASHRAE Handbook Fundamental (1997-2005) has also recommended the following equation to calculate the overall thermal transmittance for the wood framing wall

$$\mathbf{U_{AVGE} = (F.F_i \times U_i) + (F.F_f \times U_f)} \quad \text{(Equation 3.4)}$$

Where:

$F.F_{i:}$ framing factor through the insulation

R_i: R-value through the insulation (m2.K)/ W

$F.F_{f:}$ framing factor through the stud frame

R_f: R-value through the stud frame (m2.K)/ W

Alternatively using imperial units Ref can be calculated as follows:

$$\boldsymbol{x = \frac{R_i \times R_f}{p_f(R_i - R_f) + R_f}} \quad \text{(Equation 3.5)}$$

Where:

x= framing factor %

$R_{effective}$ = effective total R-value of the panel (degrees F.ft^2.hr/Btu)

P_f = percentage of panel occupied by framing (decimal percentage)

$R_{f=}$ R-value of a panel section through the framing (degrees F.ft^2.hr/Btu)

R_i == R-value of a panel section through the insulation cavities (degrees F.ft^2.hr/Btu)

3.2 Thermal bridging:

A building`s envelope plays an important role in reducing the heat loss in a cold climate zone. Highly insulated building enclosures provide thermal control and a comfortable environment for living. In 2004, Kosny demonstrates that 50 % of the heat loss in residential and small commercial building correlates with heat transfer and air leakage through building envelope component. The overall energy performance of the building envelope is also controlled by another factors such as floor plan, type of foundation, geometries of wall details, organizations of material in the envelope, surface physical properties etc. ORNL researches show that 10-15% of the US residential energy consumption is lost by thermal bridging (about 0.8 Quad a year or 0.84404472 exajoules (EJ)) (Kosny, Christian 1997, Kosny and Syed 2004, Kosny et al 2007). This energy is often not included in building loads analysis, sizing HVAC system, and whole building energy consumption calculation.

More than half of the opaque area can be affected by the interface details which can be defined as structural connections between envelope components. These interface details play a crucial role in the energy performance of the wall; poorly chosen connections can lead to additional thermal bridging causing heat loss and possible moisture condensation which helps mold growth and mildew (Kosny et al 1997).

In order to deal with the thermal bridging effect of timber and steel framing, various codes such as ASHRAE and OBC include recommended percentage of framing that should be included in the calculation of R-values.

Data has been published on framing factors for wood framed building by several sources, as summarised in Table 3.3 which presents the previous versions of publications done by ASHRAE handbook fundamentals, the California and, the Canadian energy codes on framing factor for wood framed units with 16 inches stud spacing construction:

Source	**Walls**	**Floors**	**Ceilings**	**Overall**
1985 and 1989 ASHRAE Handbook	15.0%	-	-	-
1993 and 1997 ASHRAE Handbook	25.0%	-	-	-
California Title 24	15.0%	10.0%	10.0%	12.5%
Canadian Model National Energy Code	19.0%	10.0%	10.0%	15.0%

Table 3.3: Published Framing Factor (for 16in. Stud Spacing), (Carpenter, 2003)

Straube and Semgal, 2009, carried out two dimensional heat flow simulation for R-value of a wall sections in order to calculate the total R-value (as mentioned in section 3.1.1.3) it is also done to study the thermal bridging effect of wall studs. The wall section in plan view was selected similar to a clear wall R-value with closer distance between studs to give the same image for the real number of studs used in the real wall.

Top plates and Rim joists were also modeled and simulated by taking a vertical section in a wall for a multistory building to show the effect of thermal bridging of the top plates, bottom plate, sill plate, and floor sheathing and rim joist. The simulation included a vertical wall section taken 0.20m above the floor finish, Figure 3.3. In this case, the concrete foundation underneath the rim joist was counted in the simulation to show the effect of thermal bridging on the insulation, but it was not part in the R-value calculation. While in the study that was carried out with the same researchers in 2010; a vertical section was taken from the middle of the top wall to the middle of the lower and the rim joist was placed directly at the top of the double plates, (Figure 3.2). Another horizontal section was simulated for the rim joist with insulation layer divided by the joists. This study shows important differences found in the wall designs; thermal bridging effects cause more than 30% differences between nominal and whole wall R- values (Straube & Smegal, 2009).

The best way to analyse building envelope assemblies containing thermal bridging is 3D simulation tools. For a simple light framed, 1D description created for a single building envelope details will not have a noticeable error in the whole energy consumption predictions but when the complexity of the building increases by having highly conductive structural elements and massive components, the error can reach 10% with the whole house energy consumption. Currently, 1D approximation is commonly used although it is inaccurate (Kosny 2004).

3.2.1. Thermal bridging in steel stud walls

In steel framing, steel studs and metal components work as the main part of heat loss through the wall because of their higher thermal conductivity (1,200) times higher than the fiberglass insulation material, (Environmental building news, 2012) and its higher density comparing with the surrounding insulating materials in the wall assembly (Straube, 2009). Steel also 300 times more conductive than wood (Sayed et al, 2006). These steel studs, which act as thermal bridging within the wall assembly, work on reducing the thermal resistance of the insulating materials by 50% to 80% comparing with wood framing which reduce the R-value of the insulating components by more than 20% (Straube, 2006). Straube also mentioned that filling the holes in the 12inches concrete block with R-15 insulating material will only increase the thermal resistance of the wall by around R-2. That means ineffectiveness of this wall system. As a result, wood can still be counted as a better insulating material than steel and concrete blocks.

Many studies have been done to improve the thermal performance of the timber-framed envelope. For instance, wrapping the building envelope with an exterior rigid insulation cuts off the thermal bridging presented by the framing elements. These lumber elements provide the heat flow with more paths to escape within the building envelope because of their higher thermal conductivity comparing with the surrounding insulating materials. So adding an extra continuous rigid insulation layer can reduce the effect of the thermal bridge and thus save energy, reduce condensation and risk of mold. The “perfect wall" is another solution to control the thermal bridging. This type of walls works on apply the insulation layer outside the structure to break the thermal bridging thorough the envelope (Straube, 2006).

3.3. The Effect of framing factor on clear R-value for wood wall

Framing factor or framing fraction in the wall assembly varies depending on the amount of lumber used in total framing. Currently, framing factor continues to be a debate issue in codes and standards. The framing factor calculated on the available construction drawings is usually lower than the real framing factor calculated on the site. Sometimes, it is also less than the percentage recommended in codes and standards (Steel Framing Alliance, 2008).

Framing elements were also one of the considerations in the THERM-simulation done by Straube and Smegal in 2009. When a cross section for a 2x4 stud wall, 0.41m center to center, was simulated the framing factor was found to be 9%- as a theoretical result. This results does not includes rim joists, double top plates corner and all the framing elements which present in the wall construction. While the same wall would have 23-25% framing factor on field study (Carpenter and Schumacher 2003) because of having additional framing elements. So this difference in framing factor values affect the total wall R-values; that difference decreased the total wall R-value from R12 to R10 when R13 batt insulation is installed between framing studs (Straube and Smegal ,2009).

When hot box has been used by North American labs (ORNL) to study the effect of framing factor on the Whole wall R-value,14% framing factor (for 16" stud spacing) and 11% (for 24" stud spacing)framing factor have been used as a percentage of framing factor for wood framed walls in the test. These are theoretical values and differ from the actual values that resulted in Ener-modal Engineering for California Energy Commission studies in 2001 for California region and ASHRAE studies for the rest of US region which is 27% and 25% respectively (CEC 2001A, CEC 2001B).

In 2007, Kosny presented a series of hot box test done in order to study the effect of framing factor on the wall R-value. This study includes 3 nominal (25.4mm x 101.6 mm stud) steel and wood walls, 0.40 c/c, with different configuration (Appendix B). The framing factor for all of these 3 walls was slightly greater than 24% and the insulating material was 76.2mm fiberglass batt insulation with R-13. The hot box results presented in the table below, Table 2.4, and showed that the test generated clear wall R-values were considerably lower than the nominal center- of- cavity R-values; clear wall R-values were 30% to 60% lower than the center of cavity R-values. It also shows that the walls with the same center of cavity R-values could have different clear wall R-values. So center of cavity R-values give inaccurate prescription on the whole wall thermal performance

Wall Configuration	**Wood Stud Wall** Base 16 in. (40 cm)	**Steel Stud Wall** Base 16 in. (40 cm)	**Steel Stud Wall** 0.75 in. (1.9 cm) XPS
Clear Wall R (Hot Box Test) (h·ft^2·°F/Btu [m^{2}K/W])	9.65 (1.69)	5.78 (1.02)	9.37 (1.65)
Center of Cavity R-Value (h·ft^2·°F/Btu [m^{2}K/W])	13.95 (1.76)	13.95 (1.76)	17.95 (3.16)
% Difference in R-Values	30.8%	58.6%	47.8%

Table 3.4: Hot-Box Test Results for Wood and Steel-Framed Wall Assemblies with Studs 16” o.c

Kosny et al, 2006, carried out another study by using the hot box test to study the effect of framing factor on the wall R-value and compare the change in R-value with the nominal in cavity R-value. Five different walls were used with different framing factors as presented in Table 2.5

Percentage framing	R-value h ft$^{2\circ}$F/BTU (m$^{2\circ}$K/W)		Framing effect coefficient, *f* (%)	
	Wood	Steel	Wood	Steel
5% framing	12.10 (2.13)	9.28 (1.64)	7.13	28.79
8% framing (≈24 in. o.c)	11.63 (2.05)	7.62 (1.34)	10.75	41.49
11% framing (≈16 in. o.c)	11.17 (1.97)	6.85 (1.21)	14.27	47.40
11% framing (≈24 in. o.c with track)	11.20 (1.97)	6.75 (1.19)	14.07	48.21
14% framing (≈16 in. o.c with track)	10.79 (1.90)	6.16 (1.09)	17.16	52.70

Table 3.5: R-values and framing effect coefficients for different percentage framing in timber and steel-framed walls.

The results showed that wall R-values decrease with the increase of the framing factor in both steel and wood framed walls and the increase in the framing effect coefficient correlates with the increase in the framing factor (Sayed and Kosny, 2006).

Many energy authorities recommend using the framing factors recommended by ASHRAE and CEC studies in 2001 to be as part of the local energy performance requirements (Sayed at Kosny 2006) because ASHRAE Handbook of Fundamental depends on stud materials, stud spacing, and stud depth for thermal calculation when the parallel path method is used without considering the top or the bottom plates in the calculation. This causes a reduction in actual the framing factor for the wall (Konsy et al 2007).

To solve that problem, Konsy and other researchers have done another experimental and numerical analysis on the thermal effect of framing intensity on the overall thermal performance of2x4 wooden and steel framed walls (3 wood stud walls and 3 steel stud walls). A series of hot box tests and thermal simulation were carried out. Each test has different locations and orders of the framing elements within the walls with a fixed framing amount of wood or steel. The framing factor chosen in that experiment was 27%. In one experiment, studs were located as cluster in the middle of the wall, other one has equally distributed of wood studs, and the third had stud distributed with sill and blocking between them(horizontal elements), and one with studs distributed with 2 inches between each. Appendix B shows these cases

Figure 3.5 presents the results for the R-values generated for wood and steel walls depending on the studs` distribution within the wall. in the three different way of arranging the wooden studs, the changes in wall R-value was only 2% between the higher and the lower reading. This is different from the changes happened for the steel studs cases which reached 8% in difference. (Syed et al 2006). The hot box results also revealed that the ratio of the steel stud wall R-values to the wood stud wall R-values was 0.47 (Kosny et al 2007), that shows that center of cavity R-value is notably higher than the clear wall R-value which is still used in some building codes.

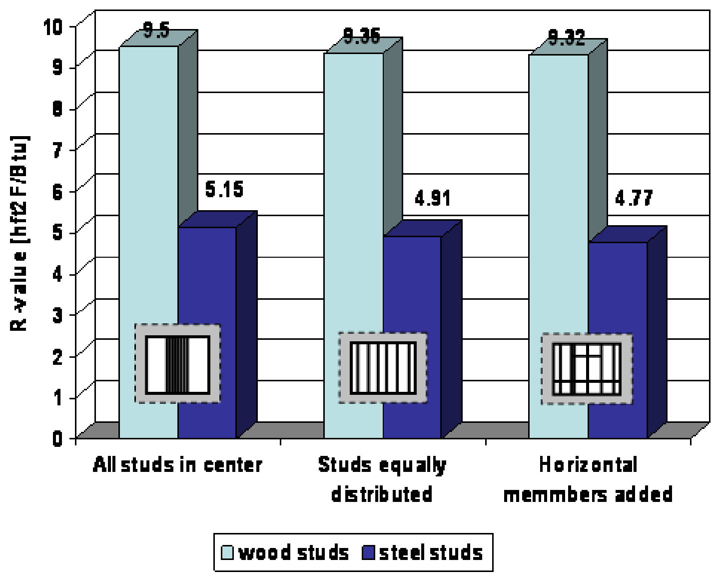
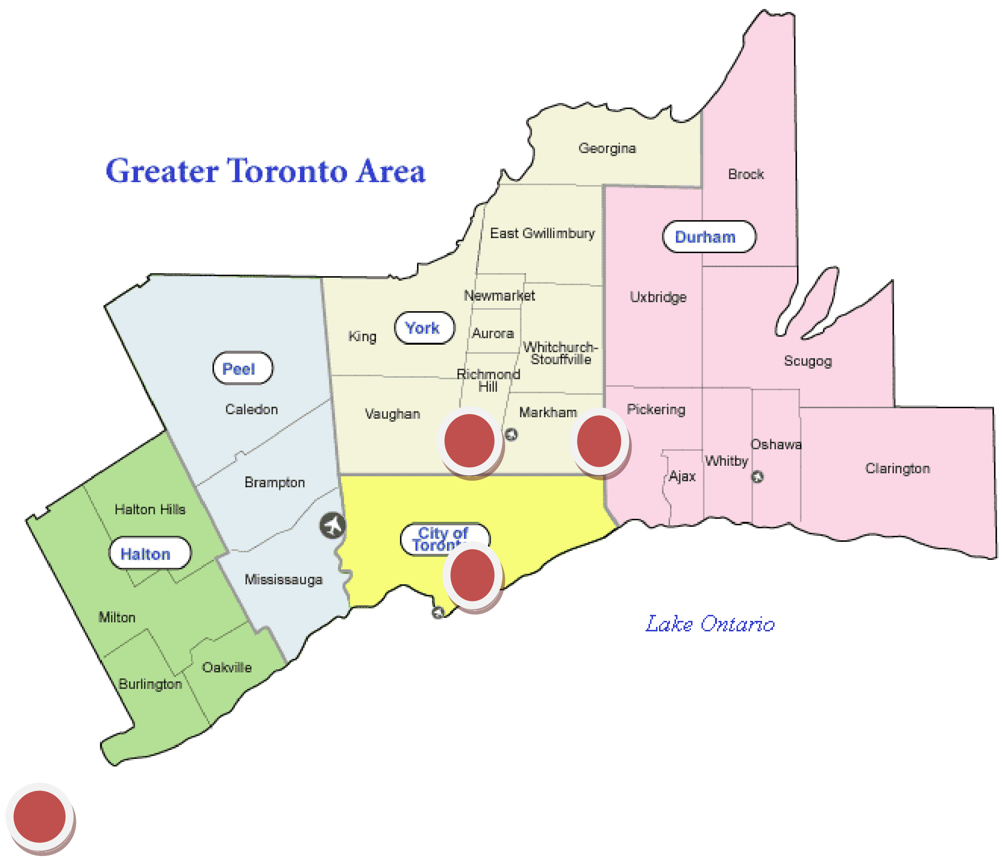


Figure 3.5: comparison of R-values for three Timber and Steel Walls (kosny et al, 2006).

This literature review presented information of previous framing factor values published by different sources inside and outside Canada. It also compared different types of wall R-value and the ways of calculating the effective and the whole wall R-values. The effect of framing factor on the wall R-value and its relation with the thermal bridging was also explained.

4. Approach/ Methodology;

In this project, seventeen residential dwellings were chosen to be studied including detached (DHs), semi-detached (SDHs), and town (THs) dwelling units. These units are located in three different locations in the GTA; East York (up town) Toronto, East Markham, and North York as shown in the following Figure 4.1



Study Areas

Figure 4.1: the location of the three units types –Detached, Semi Detached, and Town Houses, (Google map).

House type	Number of houses	Location
Detached Houses (DH)	4	North York
Semi-Detached Houses (SDH)	8	east Markham
Town Houses (TH)	5	East York (up town) Toronto

Total	17	

Table 4.1: Number, type, and location of houses used in the study

This study includes timber-framed, low-rise, residential buildings, and excludes the steel framed buildings to reduce the number of varieties. Table 4.2 summarizes the characteristics of the houses used in the study.

House Code	Location	Type	Floor Area M^2	No of floors	Basement
DH1	North York	Detached	215.8	2	Yes
DH2	North York	Detached	196.3	2	Yes
DH3	North York	Detached	220.0	2	Yes
DH4	North York	Detached	183.3	2	Yes
TH1	East York	Town House	214.2	3	Yes
TH2	East York	Town House	186.8	3	Yes
TH3	East York	Town House	214.2	3	No
TH4	East York	Town House	196.0	3	No
TH5	East York	Town House	195	3	No
SDH1	East Markham	Semi-Detached	186.8	2	Yes
SDH2	East Markham	Semi-Detached	173.9	2	Yes
SDH3	East Markham	Semi-Detached	153.1	2	Yes
SDH4	East Markham	Semi-Detached	154.4	2	Yes
SDH5	East Markham	Semi-Detached	173.9	2	Yes
SDH6	East Markham	Semi-Detached	186.6	2	Yes
SDH7	East Markham	Semi-Detached	210.2	3	Yes
SDH8	East Markham	Semi-Detached	211.3	3	Yes

Table 4.2: Characteristics of the houses used in the study

Detached houses chosen in the study (DH1 to DH4) consists of two story units with below grade basements, the net floor areas for these units are between 180 m^2 and 220 m^2. Town houses or row houses (TH1 to TH5) are divided into 2 categories; first one contains dwellings with two stories with a basement while the second category contains dwellings with three stories without basements. The net floor area for this type of houses is between 185m^2 and 215 m^2, while the net floor areas for the semi-detached houses (SMD1 to SMD8) range between 150 m^2

for the 2 stories houses and 215 m^2 for the houses with 3 stories. Each house plan is different, and so no house type is used more than one time except the row houses which have some repeated plans- without unique custom-built homes or unusual styles.

4.1. Data collection

Data collected on the amount of lumber used in the walls, floors, and ceilings for each unit were taken during the construction of the units. Additional data was taken from the overall buildings plans from the developers. The information was collected at the appropriate point in the construction process, which was after the framing was up and before wall insulation and drywall was installed. At this stage, all the additional framing which is not available on the drawing is revealed.

Photographs were also taken for the typical and unique construction details. Each unit was visited several times in order to count the framing members, measure the distance between the framing elements, and follow up with any additional framing added to the frame that did not exist on the drawing.

Using the data collected at the various sites, the real walls, floors and ceiling were re-drawn through Auto CAD software according to the existing dimensions on site. Then the EXCEL soft-ware program was used to calculate the surface area of the wood frame and to calculate the gross area for the walls, ceilings, and floors and finally compute the framing factor for each part of the envelope components.

This study focuses on the insulated parts of building envelope, including; external walls which locates between the conditioned zones and outside or with the unconditioned spaces like garages, and ceilings between heated space and unheated attic.

4.2. Framing Factor Calculation

Several research projects have been done and published about the framing percentage of the wood and steel frame buildings, and these have been used for the recommendation by ASHRAE Handbook and Fundamentals, California Title24, and The Canadian Model National Energy Code for houses (National Building Code NBC). These publications also present the way of calculating the framing factor. Two case studies done by Enermodal Engineering limited in association with Chitwood Energy Management (Carpenter, S. C., & Schumacher, C, 2003) on USA and California zones have presented a method for calculating the framing factor based on ASHRAE Handbook of Fundamentals (Carpenter, S. C., & Schumacher, C, 2003). Therefore, this project follows the same pattern used by these two case studies for defining the framing factor for the walls, roof, and ceiling and the overall framing factor for each unit as follows.

4.2. 1. Framing factor definitions:

-Wall framing factor:

"The ratios of the framing area in the insulated walls to the wall area (either gross or net). Framing includes headers, sill plates, studs, framing around doors and windows, corners, blocking and where floor joists penetrate the wall insulation layer. Framing that does not bridging the insulation is excluded (e.g., exterior or interior strapping, let-in bracing, rim joists)" (California Energy Commission, 2001 and ASHRAE 2001)

-Gross insulated wall area:

"The surface area (in the direction perpendicular to heat flow) of all insulated wall between conditioned spaces and the outside or unconditioned spaces (such as garages and porches). The wall area is based on exterior or outside dimensions; the wall width is to the outside of the framing. The wall height is from the bottom of the main floor to the inside of the ceiling framing including the height of any wall/ interior floors junctions (i.e. including rim joists). The area of any windows or doors is included". (California Energy Commission, 2001 and ASHRAE 2001)

- Net Insulated Wall Area:

"It is the gross wall area less the area of windows, doors. the net insulated wall area includes the area of rim joist". (California Energy Commission, 2001 and ASHRAE 2001)

-Ceiling framing factor:

It is "the ratio of framing area in insulated ceiling to the ceiling area (either gross or net). Framing includes joists, trusses, blocking and framing around skylights and attics hatches that partially or completely penetrate the insulation. Rim joists are not included" (California Energy Commission, 2001 and ASHRAE 2001)

-Gross insulated ceiling area:

"It is the surface area (in the direction perpendicular to heat flow) of all insulated ceiling between heated areas and the outside or unheated areas(such as attics).The ceiling area is based on exterior ceiling dimensions. the ceiling dimensions are to th outside of the framing and include the area of any skylights or attic hatches". (California Energy Commission, 2001 and ASHRAE 2001)

-Net Insulated Ceiling Area:

"It is the gross ceiling area less the area of any skylights or attic haches". (California Energy Commission, 2001 and ASHRAE 2001)

-Floor framing factor:

"The ratio of framing area in the insulated floors to the floor area (either gross or net). Framing includes joists, blocking and framing around access hatches that penetrate the insulation. Rim joists are excluded." (California Energy Commission, 2001 and ASHRAE 2001)

- Gross Insulated Floor Area:

"It is the surface area (in the direction perpendicular to heat flow) of all insulated floor between conditioned spaces and the outside or unconditioned spaces (such as crawlspaces and unheated basements).Non-framed floors such as concrete (e.g. slab on grade) floors are excluded. The floor area is based on the exterior or the outside floor dimensions. The floor dimensions are to the outside of the framing ". (California Energy Commission, 2001 and ASHRAE 2001)

- Net Insulated Floor Area:

"It is the gross floor area less the area of any floor hatches". (California Energy Commission, 2001 and ASHRAE 2001)

-Over all framing factor:

" the ratio of all framing area in the insulated floors, ceilings and walls to the total area of insulated floors, ceilings, and walls (either gross or net) non-framed floors, ceilings and walls are not included in the calculation " (California Energy Commission, 2001 and ASHRAE 2001).

- Window Area to Wall Area:

“Ratio of the rough window opening area to the gross wall area (including window and door areas). Swinging and sliding glass doors are considered doors” (California energy Commission, 2001 and ASHRAE 2001).

4.4. An example on how framing factor is calculated for each dwelling unit:

In this report, framing factor calculation followed the same process of calculating the framing factor used by ASHRAE and CEC researches in 2001 and 2003(California Energy Commission, 2001 and ASHRAE 2001). The process of computing was applied exactly the same for all the 17 units studied in the report. The following example for (DH 4) shows in details the process used in the calculation.

The first and the second floor plans of DH4 and each unit were re-drawn according the measurements taken from the site; studs used in the walls construction were also installed on the drawing according the actual as-built distances between them which were taken on site. The on-site measurements distances between studs were not fixed but varied between 0.23m to 0.41m. Figure 4.2 shows the first and the second floor plans with the available studs at the time of construction the walls.

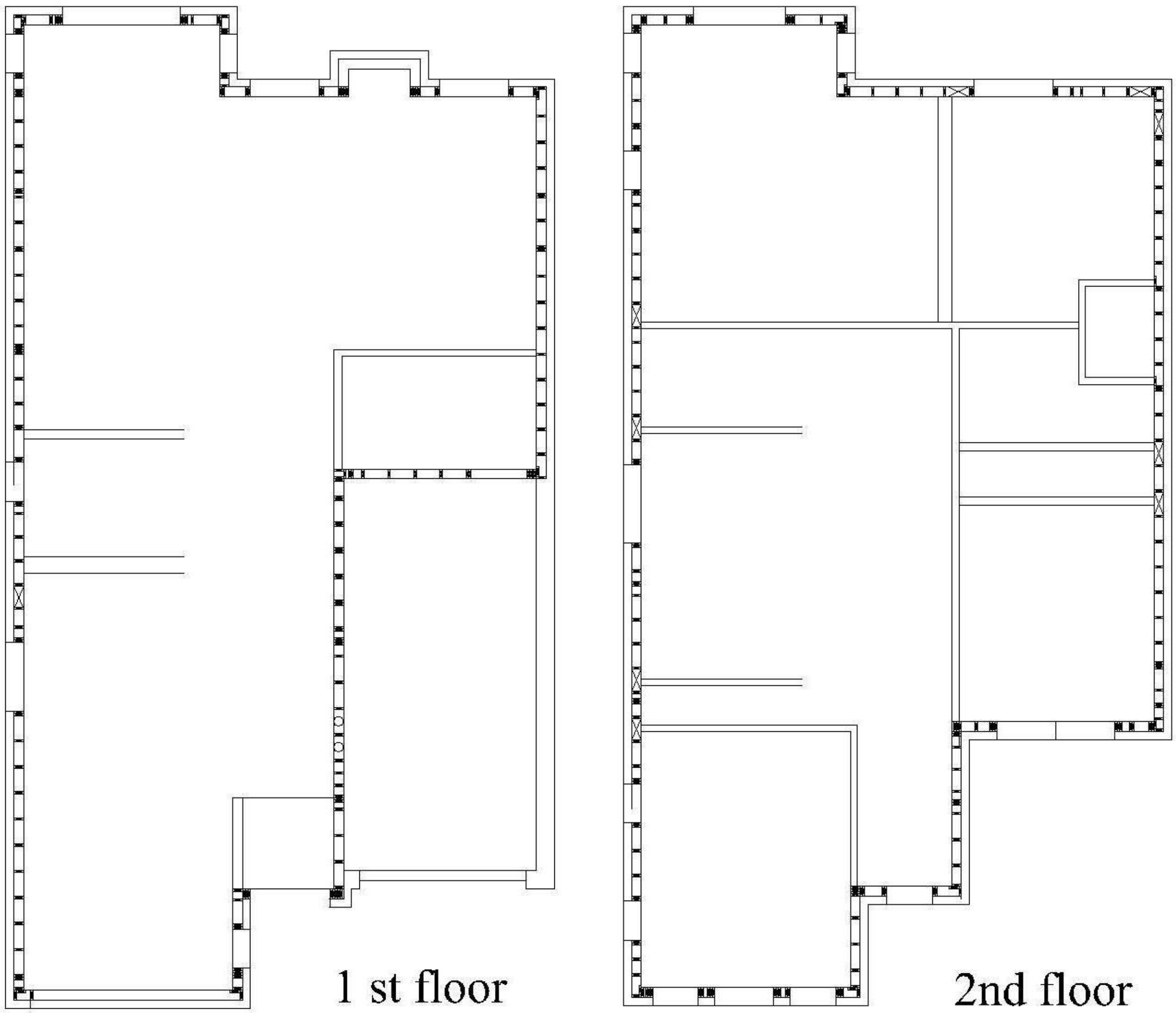


Figure 4.2: The first and the second floors for detached house (DH4) with the a built studs

The elevations for each wall showing the wooden frames were also drawn according to the on-site measurements with a floor to ceiling height of 2.7m for the first floor, 2.4m for the second floor, with a height of 0.24 m or 0.29 m for the rim joists as measured on site. Figures 4.3 to 4.6 present the timber framed elevations. Then the surface area of the timber frame which is perpendicular on the heat flow and fully penetrates the whole frame was computed through AutoCAD software, but the wooden elements that partially penetrate the frame and do not bridging the insulation were neglected and were not counted in the timber area.

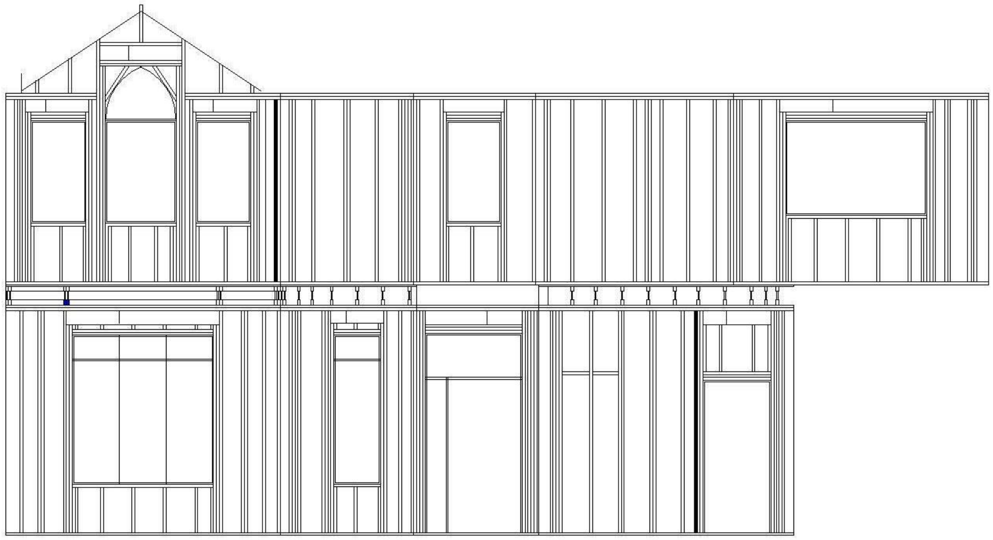


Figure 4.3: Detached house DH4 front (extended) elevation with the as-built studs installed on the first and second floors including the rim joist area.

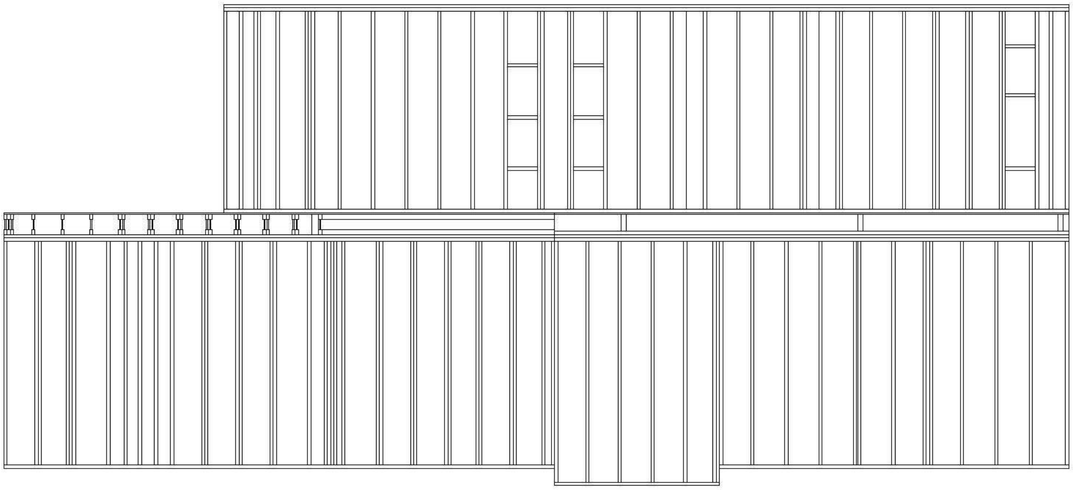


Figure 4.4: Detached house DH4 east-side elevation with the as-built studs installed on the first and second floors including the rim joist area.

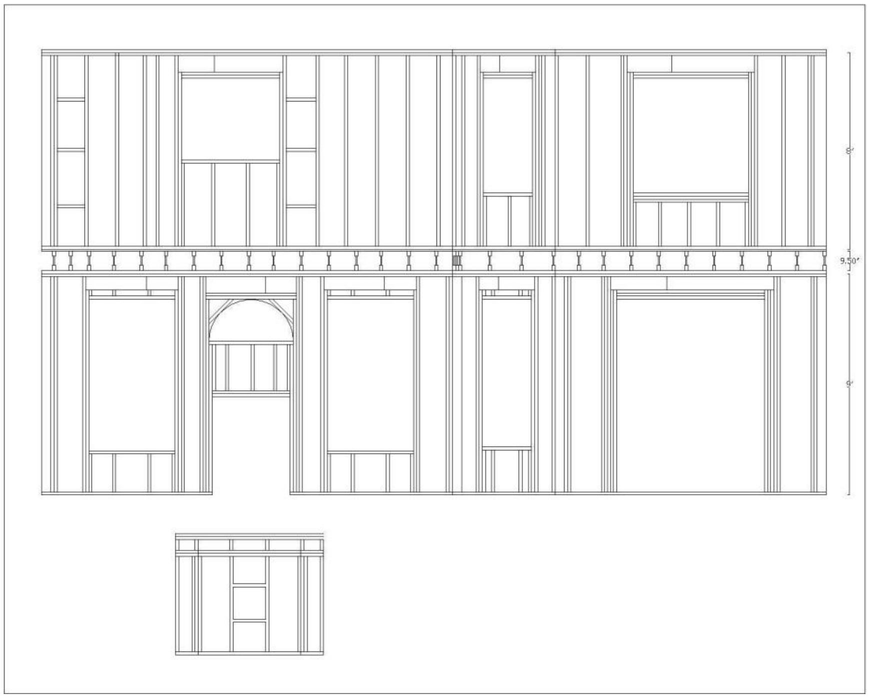


Figure 4.5: Detached house DH4 back-side (north) elevation with the as- built studs installed on the first and second floors including the rim joist area.

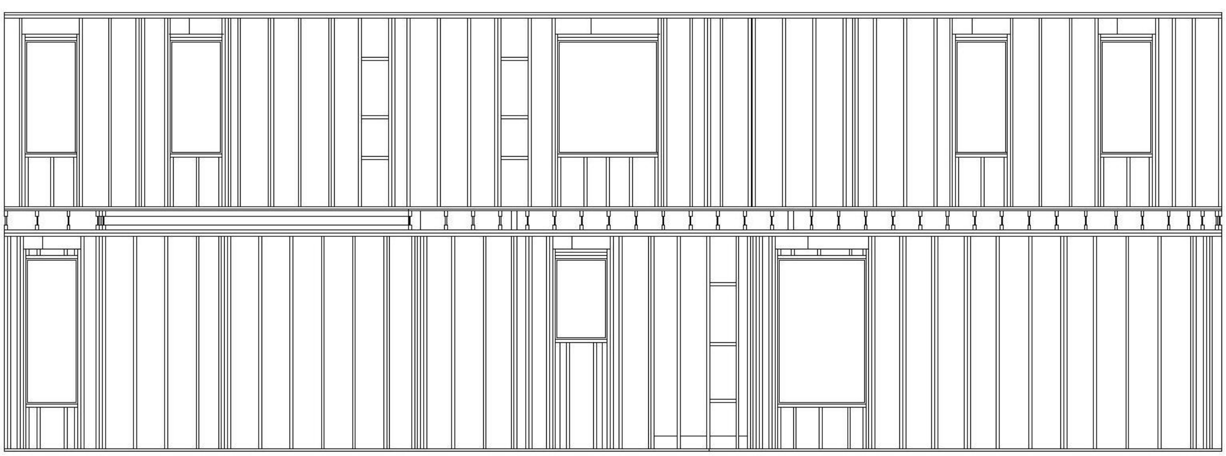


Figure 4.6: Detached house DH4 west-side elevation with the as-built studs installed on the first and second floors including the rim joist area.

Note: in ASHRAE case studies (California energy Commission, 2001) and (ASHRAE 2001), the headers are mentioned as a part of the wall framing area. In this report, the methodology defining the wall framing area is generally the same as ASHRAE except when considering the headers. When two plates with a thickness of 75 mm are used as headers above the windows and door in all the case studies, these 2 plates do not bridging all 140mm of the thickness of the frame as shown in figure 4.7. However in the methodology used in this report generally considers only the elements which completely bridging the wall frame and counts them in the framing area

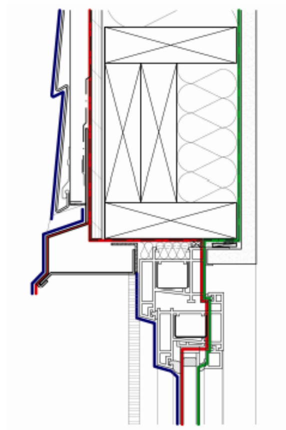


Figure 4.7: Framing at the header of the openings. (HPO, 2011)

In general, if the headers are counted as elements that are completely bridging the framing as ASHRAE researches have used, then the R-values through the wall passing through the headers should be similar to the R-value for the wall when heat flow occurs through the stud.

THERM software was used to simulate the top part of an opening, including 2 header plates and fiber glass batt insulation filling the space behind them, and calculate the U-value for that part, then these 2 plates are replaced by a number of studs (25.4mm x 152.4mm) until the simulation gives the same value for the U-value; it was found that the thermal performance of 2 header plates and the insulation is only equal to 65% of the whole length of each headers filled with studs. So, this percentage has been used to calculate the header areas as a part in the wall framing area.

A Microsoft Excel spread sheet was created to enter all the data based on the as-built timber frame area and the net area for the framed wall for each wall, so the framing percentage for each wall can be computed separately and then calculating the total framing factor for all the walls. Table 4.3 presents the data calculated for the walls of DH 4 including the framing factor for each side and the total framing factor for the walls.

	Net wall area (m^2)	Wall framing area (m^2)	Opening Area (m^2)	Framing factor
Front wall (south elevation)	50.0	19.62	15.4	39.4%
(Eastern elevation)	75.7	15.55	8.7	23.7%
Back wall (northern elevation)	41	15.02	13.8	36.6%
(Western elevation)	84.5	20.46	0	24.2%
				Total-wall Framing factor
Total area(gross)	241.1	70.7	39.9	29.3 %

Table 4.3: Detached house DH4 summary of wall framing factor calculations

Table 4.3 shows separately the net wall area for (northern, eastern, western, and southern walls, these areas are measured in meter square. Furthermore, the last column presents the farming percentage for each wall and then the total wall framing factor. It was computed by dividing the sum of the framing area for all the elevations with the sum of the net wall areas for all the elevations.

Using a similar approach an as-built plan for the ceiling framing was also drawn with 0.05m x 0.1m trusses; the distances between them were measured on site and installed on the drawings. They vary between 0.48m to 0.58 m. The ceiling does not include an attic for all the dwellings of the case studies since the attic is an unheated space. The gross area of the ceiling is counted from the outside of the wall framing. Figure 4.8 presents the framing plans for the ceiling for DH4 with the trusses distributed according to the distance measured on the construction site.

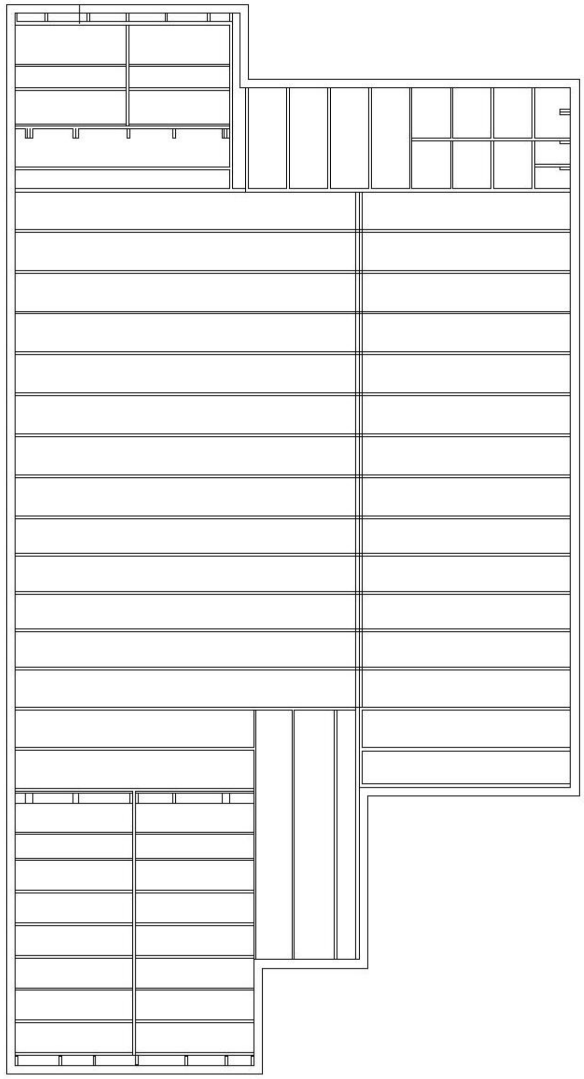


Figure 4.8: Detached house DH4 framing plan for the ceiling

Table 4.4 presents the ceiling area in meter square, total framing area for the ceiling and the ceiling framing percentage.

Ceiling area m^2	Framing area m^2	Ceiling framing factor %
108.81	10.57	9.8 %

Table 4.4: Detached house DH4 framing plan for the ceiling

When calculating the framing factor for floors, only the exposed areas to outside or the areas which are located between heated and unheated zones are counted as heat loss floors. In

Detached house DH4, the only area that can be counted as a heat loss floor is located between the second floor and the garage parking in the first floor. The method of calculating the floor area, floor framing area, and floor framing factor is similar to the method used for the ceiling and the wall calculations, using the definitions from ASHRAE researches (California energy Commission, 2001 and ASHRAE 2001). Figure 4.9 shows the floor area between heated and unheated zones for DH4, while the remaining floor area was not drawn because it was not located between two different conditioned zones. Floor area is considered the area which is located at the top of the parking garage zone. Table 4.5 also presents the calculated data for the floor area and floor wooden frame area. Floor framing factor is also included.

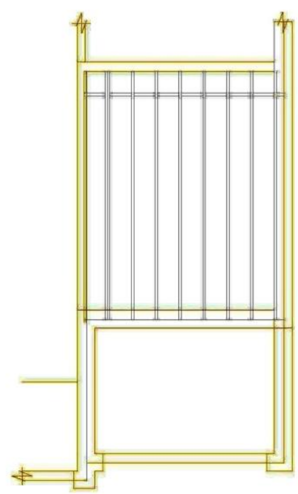


Figure 4.9: Detached house DH1heat loss floor plan –floor above parking garage.

Floor area m^2	Framing area m^2	floor framing factor %
12.7	1.68	13.2

Table 2 Table 4.5: The areas of the floor and the framing and the total framing factor

A similar methodology was used for all 17 house units that are included in this analysis.

Figure 4.10 to figure 4.12 shows some structural details chosen from some DHs, THs and SDHs units

Figure 4.10: Door`s and window`s structural elements in the THs

Figure 4.11 framing elements in some DHs

Figure 4.12: framing elements in some SDHs

5. Results and analysis

5.1. Framing factor results

5.1.1. Framing factor for Detached Houses (DH)

The wall (north, south, east, and west) framing factors for four detached houses are calculated and summarized in Table 5.1. This shows that the front and the back walls achieved higher framing factors than the side walls. Architectural details in these two elevations have the biggest influence on the framing factor results. They achieved framing factors between 36.6% and 46% while the other side elevations achieved framing percentage of 21 % to 29%. The total walls framing factor ranges between 29.3% and 31.3%

	South elevation (Front)	**East elevation**	**North elevation (Rear)**	**West elevation**	**Total wall framing factor**
DH1	46.4%	22.0%	36.9%	27.0%	30.7%
DH2	43.2%	21.8%	38.0%	29.0%	31.1%
DH3	38.2%	27.4%	42.4%	24.2%	31.2%
DH4	39.4%	23.7%	36.6%	24.2%	29.3%

Table 5.1: Walls framing factors for the detached houses

The average wall framing factor for all detached houses reaches 30.3%. Table 5.2 summaries the wall, ceiling and floor framing factors for the detached houses, and also includes the window area and door area.

The overall ceiling framing factor for all the 4 units is 9.6% while the overall floor framing factor is 12.7%. In addition, the overall framing factor achieved by four detached houses is 23.2%. Opening area to wall area ratio varies between 13.6% and 17.0%. Table 5.2 summarizes the framing factor for each component of the units.

	total wall framing factor	ceiling framing factor	floor framing factor	Total framing factor	Opening area to wall area
DH1	30.7%	9.5%	12.1%	20.8%	15.6%
DH2	31.1%	9.7%	12.9%	20.7%	17.0%
DH3	31.2%	8.9%	11.3%	21.2%	16.4%
DH4	29.3%	9.8%	13.2%	20.7%	13.6%
Overall	30.3%	9.6%	12.7%	20.6%	15.6%

Table 5.2: Overall framing factor for walls, ceilings, and floors for detached houses.

5.1.2. Framing factor for Town Houses (TH)

The wall framing factors for 5 town houses were also calculated and are summarized in Table 5.3. All wall framing factors results for town houses show a high framing percentage for all the elevations compared with the result generated for DHs` walls. The lowest reading was 32.5% while the highest was 44.4%.

	south elevation (Front)	east elevation	North elevation (Rear)	West elevation	Total wall framing factor
TH1	44.4%	36.0%	36.6%	N/A	38.3%
TH2	38.2%	N/A	39.0%	N/A	38.5%
TH3	41.8%	39.00%	34.1%	N/A	38.3%
TH4	32.5%	N/A	39.1%	N/A	41.8%
TH5	43.3%	N/A	38.1%	N/A	40.0%

Table 5.3: Walls framing factors for the town houses (TH)

Total walls, ceiling and floor framing factor were also computed for all the 5 town houses; total wall framing factors range between 38.3% and 41.3%. The overall wall framing percentage for town houses also shows higher value than the one achieved by the DHs. Table 5.4 summarizes the wall, ceiling and floor framing factors for the 5 town houses (TH). These range from 8.1% to 10.3% for the ceiling framing factor, and the overall ceiling framing factor for town houses is 9.2% which is similar to the result generated for the DH units while overall floor framing percentage for THs shows higher results than the percentage generated for the DHs, 14% comparing with 12.7%. The opening area to wall area ratio for THs is higher than DHs` opening to wall ratio. So the overall window to wall ratio for THs is 7.5% higher than window to wall ratio for DHs because of having large windows in the elevation which increase that percentage. Opening to wall ratio results divided into 2 results; THs which have 3 elevations have opening to wall ratio around 23.6% while the units which have only 2 elevations got higher results which are around 26.1%. In addition, the overall framing factor for the THs is 22.6%.

	Total wall framing factor	**Ceiling framing factor**	**Floor framing factor**	**Overall framing factor**	**Opening Area to Wall Area**
TH1	38.30%	10.3%	13.7%	28.8%	23.6%
TH2	38.52%	8.9%	13.4%	23.4%	26.1%
TH3	38.30%	9.5%	15.1%	28.3%	23.5%
TH4	41.80%	8.6%	13.7%	24.6%	26.7%
TH5	40%	8.1%	13.7%	24.0%	26.5%
Overall	39.1 %	9.2%	14%	22.6%	24.7%

Table 5.4: Overall framing factor for walls, ceilings, and floors for the town houses.

5.1.3. Framing factor for Semi-detached Houses (SDH)

Eight semi-detached houses were measured for calculating the framing factor. Table 5.5 presents the framing percentage for the 3 elevations for each unit. Front and back elevations in most of the units give higher result than the side elevation because of the architectural details and the big openings used in these 2 elevations. The framing percentage for the front and back walls varies between 30% and 39% while the side walls framing factor starts from 26% to 34% only.

	South Elevation (Front)	Side Elevation	North Elevation (Rear)	West Elevation	Total wall framing factor
SDH1	30.0%	34.2%	35.4%	N/A	33.1%
SDH2	31.5%	26.0%	39.0%	N/A	29.5%
SDH3	32.9%	27.8%	34.7%	N/A	31.1%
SDH4	32.6%	26.3%	34.7%	N/A	30.2%
SDH5	31.8%	26.6%	35.9%	N/A	36.0%
SDH6	32.1%	34.5%	32.6%	N/A	33.3%
SDH7	30.4%	28.0%	36.6%	N/A	30.4%
SDH8	31.1%	28.8%	37.0%	N/A	31.1%

Table 5.5: Walls framing factors for the semi-detached houses

The total framing factor for the semi-detached houses ranges from 29.5% to 36.0%. Table 5.6 summarizes the wall, ceiling and floor framing factors for the 8 semi-detached houses (SDH). Ceiling and floor framing factor varies between 7.10% to 9.6% and 18.60% to 20.40% respectively. On the other hand, these results are lower values than the ones calculated for the THs and DHs. Opening area to wall area ratio for this category varies between 14.7% and 21.0%. but the overall opening area to wall area is lower than the values for DHs and THs ones.

	Total wall framing factor	Ceiling framing factor	Floor framing factor	Over all framing factor	Opening Area to Wall area ratio
SDH1	**33.1%**	9.5%	13.4%	23.8%	19.6%
SDH2	**29.5%**	8.0%	11.9%	20.8%	14.9%
SDH3	**31.1%**	7.1%	10.7%	21.7%	18.0%

SDH4	30.2%	7.4%	9.5%	21.2%	17.4%
SDH5	36.0%	7.7%	12.2%	22.5%	14.4%
SDH6	33.3%	7.8%	11.5%	22.5%	21.0%
SDH7	30.4%	8.7%	9.2%	22.1%	14.8%
SDH8	31.1%	8.4%	12.4%	23.0%	14.7%
Overall	31.1%	8.0%	11.4%	22.3%	16.8%

Table 5.6: Overall framing factor for walls, ceilings, and floors for the semi-detached houses

5.2. Analysis and Discussion;

In general, framing factor is affected by the number of stories. Figure 5.1 illustrates the relationship between the number of stories and the framing factors. Units with three stories have higher framing factor than the units with two stories only. This relation is noticeable in THs, SDH6, and SDH8. These units tend to have more studs with a short distance between them in the first story in order to hold the load of the second and third floors above it. These units also have more architectural details and big openings in their elevations which require additional construction supports, additional framing elements, headers and cripple studs around windows.

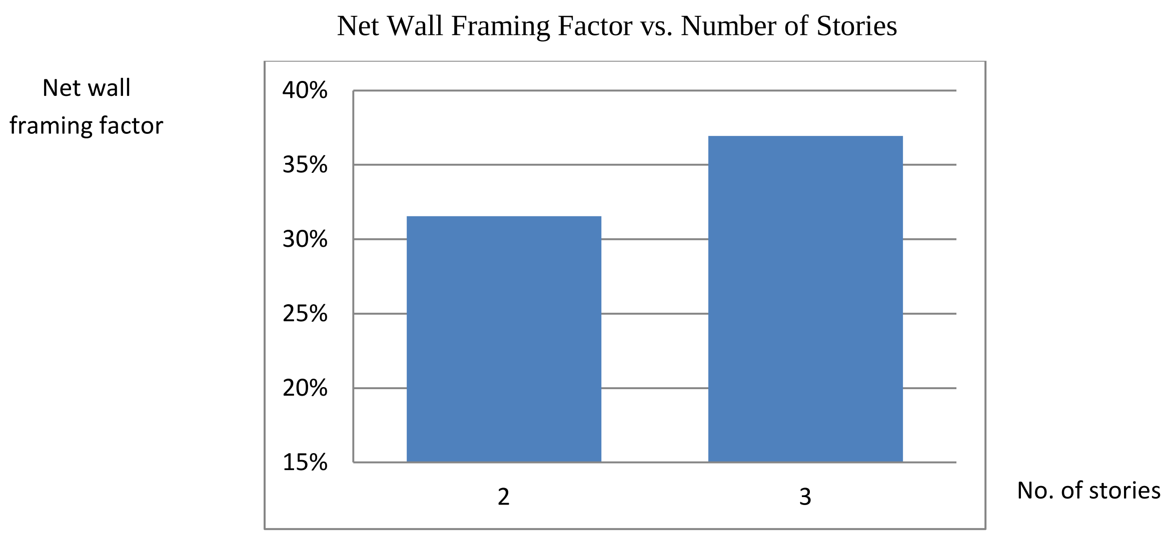


Figure 5.1: Effect of number of stories to wall framing factor

Windows and doors require additional structural elements to hold the load of the wall above the openings such as 2 headers boards, king, jack, and cripple studs and sill plates. These elements participate in increasing the percentage of framing factor for walls. Figure 5.2 shows the relation between the framing factor and the ratio of gross wall area to opening (sum of window and door) area.

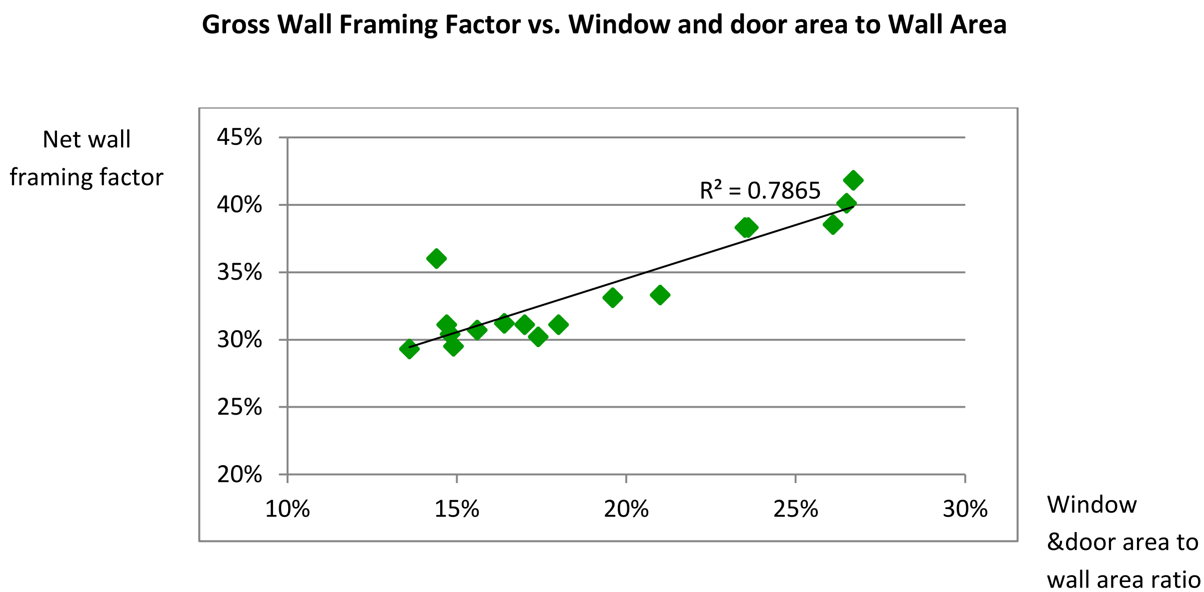


Figure 5.2: Net wall area vs. window +door area to wall area ratio for all the 17 units.

Figure 5.3 to 5.4 and Table 5.7 present examples of individual walls chosen from the case studies to show the relation between the opening area (window and door area) to wall area and its correlation with the framing factor. TH2 had the highest window area to wall area ratio. SDH6 had also 2nd highest ratio because of having many windows and a door in the wall. These opening increase the opening to wall ratio and increase the framing factor as extra framing elements are required around openings. Opening area to wall area ratio for these 2 examples exceeded the recommended by ASHRAE, (window 12% plus door 5%) , while SDH5 and DH2 had lower opening area to wall ratios of 7% and 2% which are well below ASHRAE recommendations, and also lead to lower framing factors.

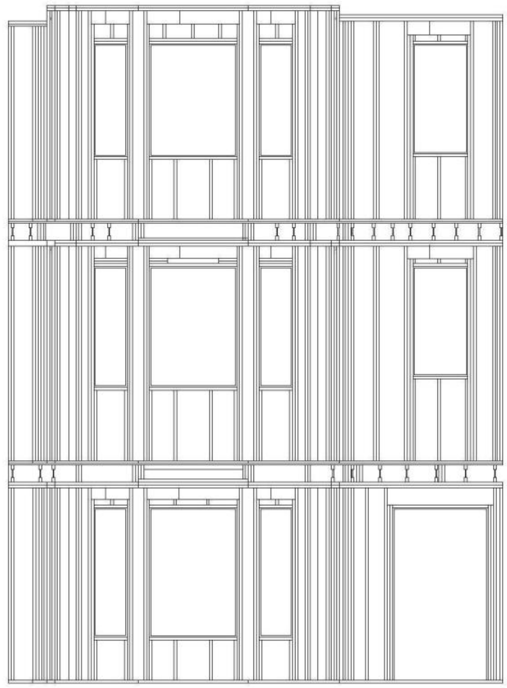


Figure 5.3: Front elevation for TH2

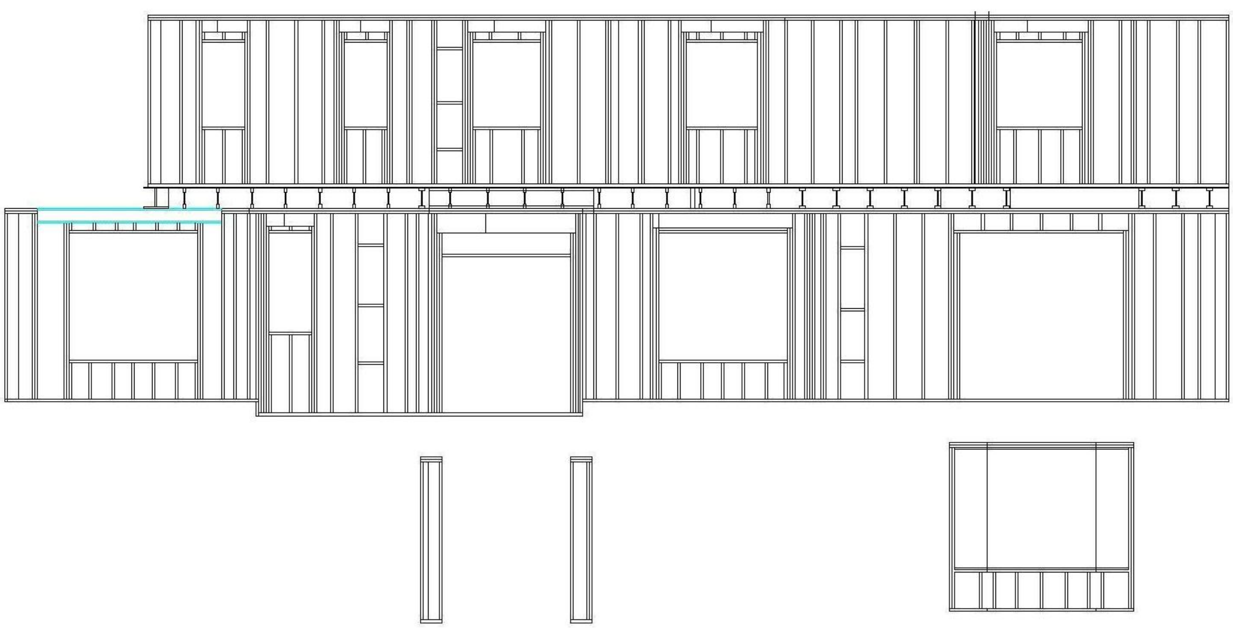


Figure 5.4: East elevation for unit SDH6

Figure 5.5: West elevation for unit SDH5

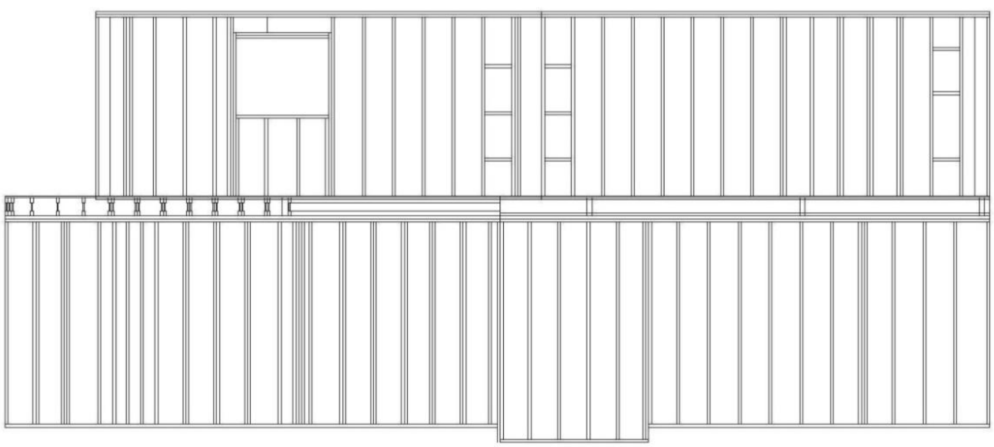


Figure 5.6: East (side) elevation for unit DH2

Unit	Elevation	Framing factor	Opening area to wall area
TH2	Front	38.2%	30.8%
SDH6	Side/east	34.5%	30.1%
SDH5	Side /west	26.6%	7.6%
DH2	Side	21.8%	2.0%

Table 5.7: Individual elevations chosen for some case studies and their framing factor and opening area to wall area

Figure 5.7 presents the correlation between net wall framing factor and the floor area. The chart shows a trend of increasing framing factor when the floor area increases because of having more studs, columns, and structural elements in the walls in order to carry the load above them.

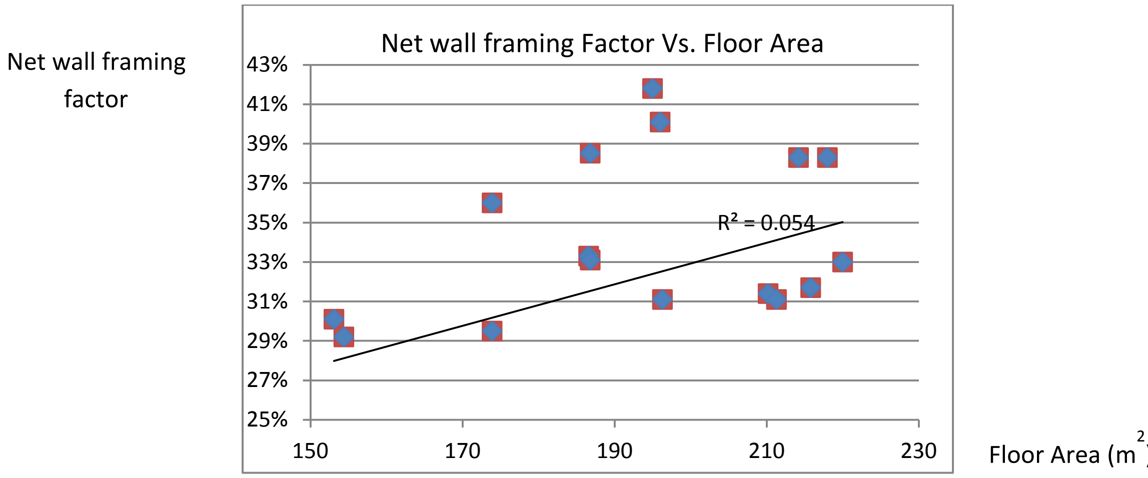


Figure 5.7: Net wall framing factor vs. Floor Area (m^2)

According to the previous analysis, it is concluded that the number of stories, floor area, and opening area have a direct effect on the net wall framing factor. Other characteristics that may also have an effect on the wall framing factor include architectural details, building type, type of framing, builder practices, shape of the dwelling and complexity, and the size of the openings. It is common that two typical buildings built with the same builder could have variation in the framing factor. ASHRAE revealed in one of their case studies that five out of eight pairs of units constructed with the same builder have a difference in framing factor within 1%. Although it is a small percentage, it shows variation of framing for different builders, even within the same builder which leads to the absence of any standard method to be followed (California 2001).

5.3. Comparison to ASHRAE and NBC Results:

ASHRAE Handbook and National building Code (NBC) have recommended framing factors for walls, ceiling and floor for wood framed building. The following table presents the commended values by ASHRAE and NBC

Components	***Frame Spacing***	***ASHRAE***	***New draft Canadian NBC 2012***
		Framing Factor	**Framing Factor**
Window area to wall area	-	12.0%	N/A
Door area to wall area	-	5.0%	N/A
Framing factor based on Gross Area			
Wall	16" c/c	25.0%	23.0%
Ceiling (raised heel truss)	24" c/c	7.0%	7.0%
Floor (I joists and truss)	16" c/c 19.2" c/c	12.0% -	9.0% 7.5%
Overall	**-**	**16.0%**	**N/A**

Table 5.8: The recommended Framing Factor for a typical Wood-framed Assembly (ASHRAE 2006, and Canadian Commission on building and fire code 2012)

Table 5.9 presents the framing factor results for DHs, THs, and SDHs and compares them with the results recommended by ASHRAE and NBC. The results show that all total wall framing factors for DHs, THs, and SDHs achieved higher values than the recommended ones by the codes. Thus the heat loss calculations for these houses are likely to underestimate the heat loss through the envelope since the real proportion of timber in the walls is higher than assumed by the codes.

The highest values for wall framing factor and floor framing factor are presented by THs. Larger opening (windows and doors) and more architectural details have a big influence on the results generated for that the type of houses. DHs and SDHs also achieved floor framing factors higher than the values recommended by ASHRAE and NBC but they are still lower than the framing factor generated by THs. Ceiling framing factor for that type of buildings is also higher than the recommended results by ASHRAE and NBC.

Window area to wall area for DHs and SDHs are within the recommended percentage by ASHRAE, which is 12% window area to wall area ratio, while the percentage resulted for THs are much higher than the recommended values. In addition, door area to wall area ratio for THs and SDHs are also around 5% which is the recommended values by ASHRAE but the values for DHs showed lower percentage than the recommended one. To sum up, the overall framing factor for ceiling floor and walls for all the 3 types illustrate higher framing percentage than the recommended by ASHRAE and NBC Codes as presented in figure 5.4

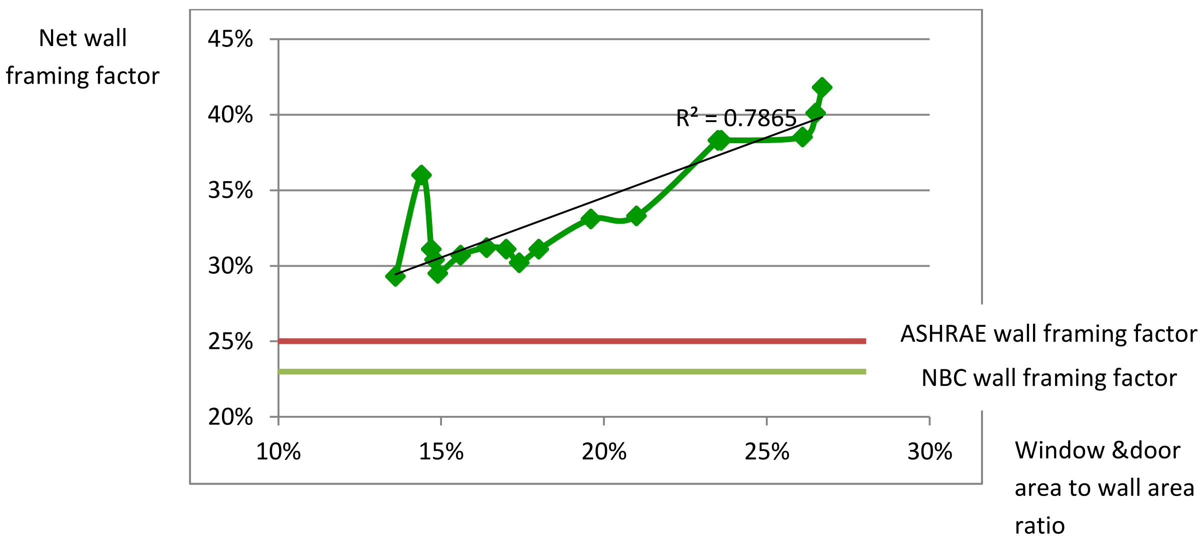


Figure 5.8: Net Wall Framing Factor vs. Window and door area to Wall Area Ratio for the 17 units compared with ASHRAE and NBC wall framing factor

Framing factor based on Net Area (%)						
Components	**DHs**	**THs**	**SDHs**	**Average framing factor for all the units**	**ASHRAE**	**NBC 2012**
Wall	30.3	39.1	31.1	33.0	25.0	23.0
Ceiling	9.6	9.2	8.0	8.7	7.0	7.0
Floor	12.7	14.0	11.4	12.6	12.0	7.5
Overall	23.0	22.6	22.3	23.5	16.0	N/A

Table 5.9: Framing factor results for DHs, THs, and SDHs compared with ASHRAE and NBC

5.4. Application for the Framing Factor

5.4.1. Calculating the Effective R-value for the as-built walls;

The effective R-value for the existing walls and roofs are calculated for the 17 case studies using the ASHRAE methodology and NBC as set out in section 3.1.1.4. All the units in this report have the same wall assembly components as shown in Figure 5.9. Table 5.10 presents the wall components for the units and the thermal resistance for each component. The first column presents the R-value through the framing (Ri) while the second column presents the R-value through fiberglass batt insulation l

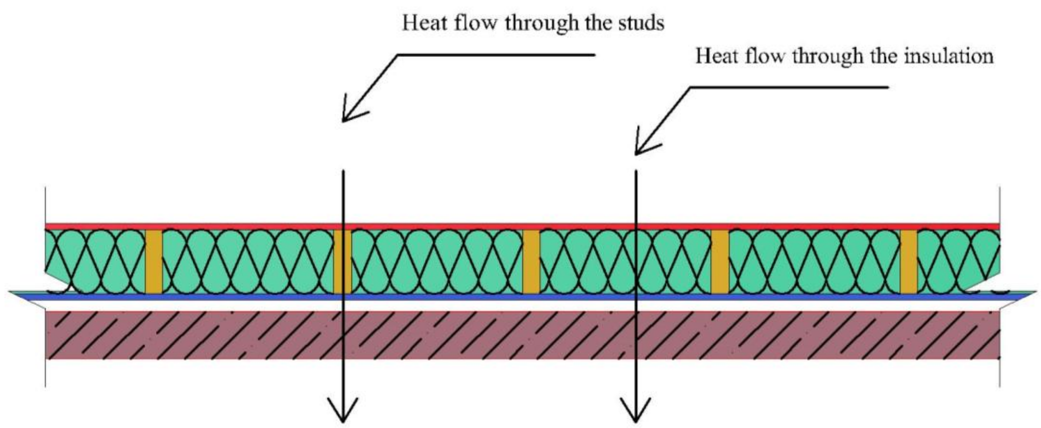


Figure 5.9: Heat path through the stud and through the insulation

materials	R-value at framing- Rf (m2.k/w)	R-value between framing- Ri (m2.k/w)
Inside air film	0.12	0.12
1/2 " dry wall (gypsum)	0.08	0.08
5 1/2 " fiberglass batt	0	3.9
2x6 wood studs	1.16	0
3/8" exterior sheathing (8mm)	0.1	0.1
1 " air space	0.21	0.21
4 " brick	0.08	0.08
exterior air film	0.03	0.03
Total R RSI (m2.K)/ W	**1.78**	**4.52**
Total R-value (Btu/h.ft2.F)	**10.1**	**25.7**

Table 5.10: R-value calculation for wall assembly for all the 17 units

The values calculated for the total R-value or RSI can be used in the equations mentioned before (section 3.1.1.4) to compute the effective R-value. First, the framing factor through the framing is assumed to be 25% and 75% through the insulation as recommended framing factor by ASHRAE Handbook fundamentals.

$$\mathbf{U_{AVGE} = F.F_{i} \times U_{I} + F.F_{f} \times U_{f}}$$

$$U_{AVGE} = 0.25 \times 1/1.78 + 0.75 \times 1/4.52$$

$$U_{AVGE} = 0.31 \text{ W/(m2.K)}$$

$$R_{effective} = 3.26 \text{ (m2.K)/ W}$$

Or the following equation:

$$\boldsymbol{RSI_T = \frac{100}{\frac{25}{10} + \frac{75}{22.3}}}$$

$$RSI_{total} = 18.46 \textbf{ (Btu/h.ft2.F)}$$

$$R_{effective} = 3.26 \text{ (m2.K)/ W}$$

The same values of R_i and R_f-values generated from Table 5.9 are used with the as-built overall wall framing factor for each type of houses, 30% FF for DHs, 36.1%FF for THs, and

31.1% FF for SDHs, to calculate the effective R-values for each house type. This generated the following results:

	Framing factor (Net)	Wall Thermal Resistance	Difference percentage from ASHREA
ASHRAE	25.0%	3.26 (m^2.K)/ W	0.0%
DHs	30.0%	3.09 (m^2.K)/ W	5.2%
THs	39.1%	2.91(m2.K)/ W	10.7%
SDHs	31.1%	3.06(m2.K)/ W	6.1%

Table 5.11: The thermal resistance for the wall of DHs, THS, and SDHs and the percentage difference in the thermal resistance for each

Appendix (D) presents all the calculations in details.

The effective R-vales calculated for each building type shows the effect of framing percentage on the value of the effective R-value. Town houses (THs) which have the highest framing percentage between the 3 types of houses have the lowest thermal performance, so the heat loss through this type of houses will be the highest. The effective R-value in this case is approximately 10.7% lower than the figure calculated using ASHRAE assumptions. The detached houses have the lowest framing factor between the 3 types shows better thermal performance, which varies little from the assumptions in ASHRAE.

The new draft -Ontario Building Code, 2012 for Canada recommends the minimum R-value (RSI) for space heat requirement for Ontario region. GTA locates in Zone 1 with AFUE ≥90% as a worst case scenario. The Minimum R-values recommended for the insulation material for Walls above Grade is 4.75 (m^2.K)/ W (R27), but the total R-value calculated through the insulation and all the Effective R-values calculated for the 3 buildings types with different framing factors are less than the recommended values for the insulation part only. This occurs partly because of the increase in the wood percentage which reduces the thermal performance and produces more thermal bridging areas within the envelope.

5.4.2. Calculating the Effective R-value for the as-built ceiling;

Table 5.12 shows the ceiling components with the thermal resistance for each material and Figure 5.6 shows the typical ceiling construction.

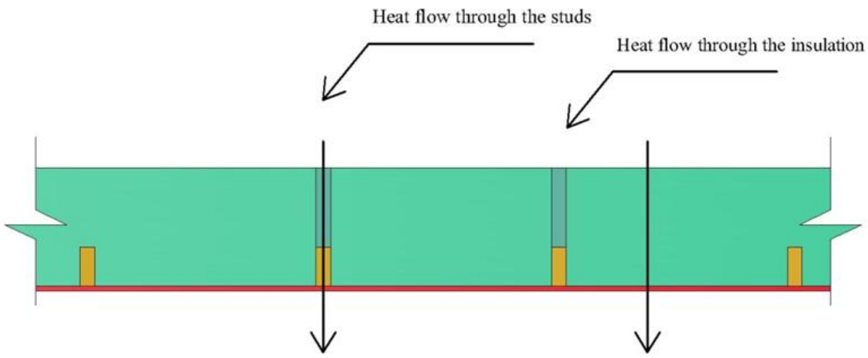


Figure 5.10: Heat path through the ceiling trusses and through the insulation

Ceiling assembly

materials	(RSI) R-value at framing	(RSI) R-value between framing
Bottom air film	0.107	0.107
1/2 " dry wall (gypsum	0.08	0.08
2"x4" wood studs	0.85	0
fiberglass batt	4.9	7
Inside air film	0.03	0.03
Total RSI (m^2.k/W)	**5.967**	**7.217**
Total R-value (Btu/h.ft2.F)	**34**	**41**

Table 5.12: R-value calculation for ceiling assemblies for all the 17 units with their thermal resistances

The effective R-value calculated for the ceiling follows the same equations, each time, different values of framing factor is applied depending on the percentage resulted for each house type. First, the Effective R-value for the ceiling is computed by using the data from Table 14 with 7% framing factor as a standard framing recommended by AHRAE, as follow

$$RSI_T = \frac{\mathbf{100}}{\frac{\mathbf{7}}{\mathbf{34}} + \frac{\mathbf{93}}{\mathbf{41}}}$$

RSI $_{total}$ = 40.4 **(Btu/h.ft2.F)**

R $_{effective}$ = 7.12 (m2.K)/ W

The effective R-value resulted from the calculation is 7.12 (m2.K)/ W, then, the effective R-value is calculated for the 3 units types by using the same data from Table 14 with 9.6% framing factor for DHs, 9.2% framing factor for THs, and 8% framing factor for SDHs. The values computed for the effective R-value for the ceiling f each type is 7.08 (m^2.K)/ W, 7.09 (m^2.K)/ W, and 7.10 (m^2.K)/ W, respectively. These three results are very close to each other due to the insulation above the timber that reduces the effect of the thermal bridge and close to the assumption of using the ceiling framing factor which is recommended by ASHRAE. Appendix D shows the calculation for the effective thermal resistance for the ceiling.

OBC has recommended the minimum RSI (R) - values for ceiling insulation to be 5.46(m^2.K)/ W (R31) for ceiling without Attic Space. When this value is compared with the values of the R-value calculated for the insulation part only and the effective R-value calculated for the three types of houses, it shows the thermal performance of the ceilings exceed the recommended values by OBC because the insulation layer extends above of the trusses. Then trusses do not connect between two different zones. This helps decrease the heat loss through the ceiling.

5.5. Upgrading the thermal performance of the existing wall

5.5.1 Add a continuous layer of insulation to the existing wall

In order to improve the thermal performances of the existing walls for the 3 dwellings types and reduce the effect of the thermal bridging within the envelope, a 50.8mm layer of rigid insulation can be added to the exterior side of the wall before the air gap as presented in Figure 5.11

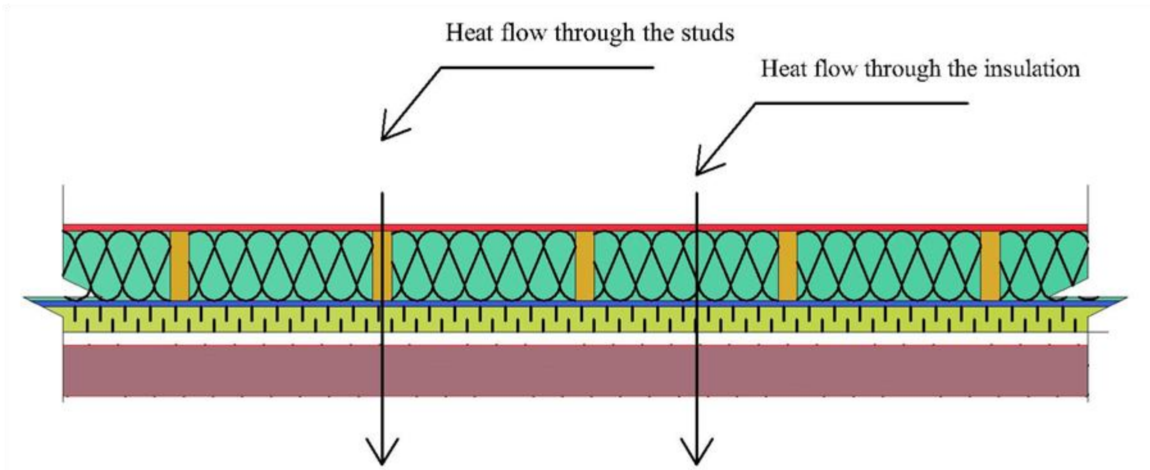


Figure 5.11: Wall assembly with a continuous layer of rigid insulation

Table 5.13 contains the same wall assembly with a continuous layer of Polystyrene rigid insulation to improve the thermal performance of the wall; it also contains the thermal resistance for each material composing the wall.

Materials	**R-value at framing (m^2.k/W)**	**R-value between framing(m^2.k/W)**
Inside air film	0.12	0.12
12.5 mm dry wall (gypsum	0.08	0.08
140mm fiberglass batt (5' 5")	0	3.90
140mm 2x5.5" wood studs	1.16	0
8mm exterior sheathing (3/8")	0.1	0.1
2" rigid insulation (Polystyrene)	1.85	1.79
1 " air space	0.21	0.21
100mm brick (4")	0.08	0.08
exterior air film	0.03	0.03
Total RSI (m2.k/W)	**3.63**	**6.30**
Total R-value (Btu/h.ft2.F)	**20.6**	**35.77**

Table 5.13: R-value calculation for the conventional wall assembly with a continuous layer of rigid insulation added

The total R- values calculated through the framing and through the insulation are used in the same equations to calculate the effective thermal performance for the upgraded wall. Appendix c presents the calculation process in details.

When 25% framing factor, as recommended by ASHRAE, is used with the values of the total R-values from table 14, the effective R-value improved to 5.32(m2.K)/ W even the effective R-values for DHs, THs, and SDHs walls improved too; 5.16(m2.K)/ W, 4.98(m2.K)/ W, and 5.13 (m2.K)/ W, respectively. In addition, all of these values for the effective R-values exceed the minimum R-values for walls insulation - 4.75(R27) - which is recommended by NBC. As a result thermal bridging through the wall is minimized, the impact of framing factor is reduced and the thermal performance of the wall increases.

	Framing factor (Net)	**Wall Thermal Resistance**	**Difference percentage from ASHREA**
ASHRAE	25.0%	5.32 (m^2.K)/ W	0.0%
DHs	30.00%	5.16 (m^2.K)/ W	3.0%
THs	39.1%	4.98 (m2.K)/ W	6.6%
SDHs	31.10%	5.13 (m2.K)/ W	3.6%

Table 5.14: the thermal resistance for the upgraded wall of DHs, THS, and SDHs and the percentage difference in the thermal resistance for each

The effective R-vales calculated for each upgraded wall system for each building type shows the effect of framing percentage on the value of the effective R-value. Town houses (THs) which still have the highest framing percentage between the 3 types of houses still have the lowest thermal performance even after upgrading the wall system for each type, but the thermal resistance for the new wall is better than the r-values for the conventional one. The effective R-value for the upgraded THs wall is approximately 6.6%, which is lower than the figure calculated using the same conventional wall system which was 10.7%. This shows the reduction in the effect of increasing the framing factor in the wall. The detached houses have the lowest framing factor between the 3 types shows better thermal performance, which varies least from the assumptions in ASHRAE.

5.5.2 THERM simulation comparison

The TH wall is chosen to be simulated by THERM software because of achieving the highest framing factor between the 3 types of houses. THERM software is used to analyse a two-dimensional heat transfer through building assemblies. A 2.4m x 2.4m wood framed wall is used as a sample with the total framing factor resulted for THs, which is 39.1% in order to calculate the U-Value for that type of walls that carries that percentage of framing. Figure 6.12 presents the framed wall which is used in the simulation.

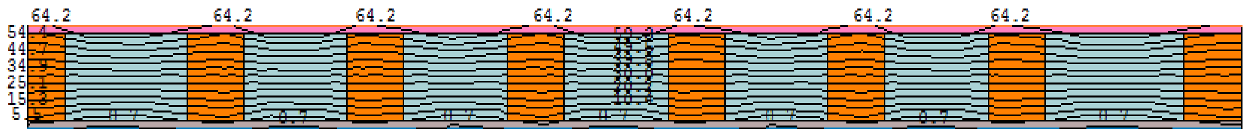


Figure 6.12: The conventional wall assembly simulated using THERM with 39.1% framing factor

The U-value resulted from the simulation is 0.44 W/ (m^2.K) and the effective R-value is 2.3 (m^2.K)/ W, R-13.1, then the same wall is used to be simulated with 25% framing percentage as recommended by ASHRAE code as presented in Figure 5.13;

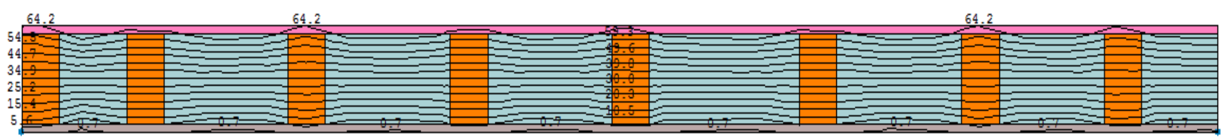


Figure 5.13: the conventional wall assembly simulated using THERM with 25% framing factor (as recommended by ASHRAE)

The U-value for this wall is (0.36W/ (m^2.K) and the R effective is 2.8(m^2.K)/ W, R-15.9.

The previous simulations confirmed that the thermal performance for the wall with less framing factor (25%) is higher than the thermal performance of the wall that has more framing factor (39.1%). THERM simulations resulted in less thermal resistance for both walls compared with the effective R- values calculated by using the parallel path method in section 5.4.1 for the same walls because it is more accurate in calculation. But the effective R-values calculated for both walls by using the THERM program also did not meet the minimum R-values recommended by the codes. So the same walls are re-simulated with additional layer of rigid insulation for each wall. Figure 5.10 shows the same wall sample used to present 36.1% of framing factor with adding 50.8 mm of rigid insulation layer.

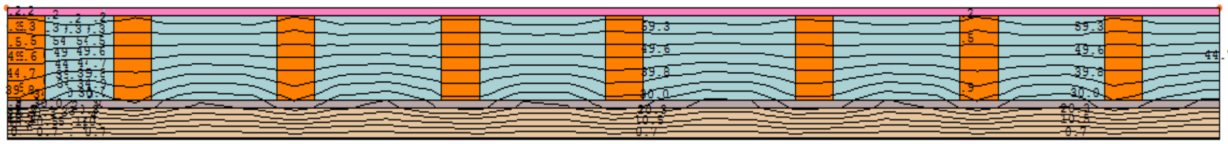


Figure 5.14: the conventional wall assembly simulated through THERM with 39.1% framing factor and adding 2 inches of rigid insulation layer

U-factor for this wall is (0.23 W/ (m^2.K) and the effective R-value is 4.3 (m^2.K)/ W, R 24.4, then the same wall is simulated with 25% framing factor and additional layer of rigid insulation as follow

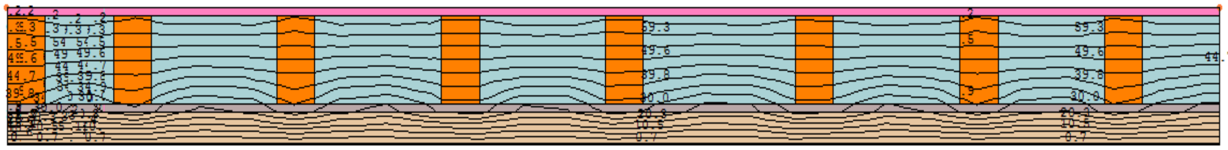


Figure 5.15: the conventional wall assembly simulated using THERM with 25% framing factor with adding 2 inches of rigid insulation layer

U-factor for this wall is (0.2 W/ (m^2.K)) and the effective R –value is 4.8 (m^2.K)/ W, R26.7.

When the 50.8 mm of a rigid insulation layer is added to the conventional wall, THERM simulations showed better thermal performance for the wall with25% framing factor than the thermal performance for the wall with 39.1%. On the other hand, the effective R-values for both walls resulted by using THERM simulations did not meet the minimum requirement for R-values by the codes.

Although THERM simulation is more accurate than the values calculated by using the parallel path method which is recommended by ASHRAE and NBC as mentioned before in section 5.5.1. ASHRAE recommends the parallel path method because it is relatively simple to use compared to the THERM simulation.

5.6. Advanced framing

Conventional wall framing contains a 50.8 mm x 101.6 mm or 50.8 mm x 152.4 mm frames at 0.41 mm centers, 3 studs corner, double headers, jack studs, cripples and extra framing around openings which have a big impact on increasing the framing factor for the wall in a way that exceeds the minimum recommendation for framing percentage by the codes- ASHRAE and the new draft for NBC. This system can be improved by replacing it with "advanced framing system" which composes of a 50.8 mm x 152.4 mm frame at 0.61mm centers with single top plates, two stud corners, no jack studs, no cripples and single headers (and in many cases no headers at all) (Lstiburek, 2010).

"In line framing" is the system adopted in the advanced framing. the upper level studs are located at the top of the lower level studs to form a vertical lines of structural elements in order to give the ability for each stud to carry the load above it, so the double top plate is no longer required in the new system. Single headers are only used in load-bearing walls. This system contains 5-10% less wood (Lstiburek, 2010). The framing elements are further apart to provide better insulation space. The number of insulation spaces is also less than the number available in the standard framing system

The west wall for DH3 is chosen to be reframed by the advanced framing system in order to study the effect of the new framing system on the framing percentage. Figure 6.16 shows the west wall with the existing framing using dimensions between studs taken on site, and Figure 5.17 presents the same wall with a proposed advanced framing system.

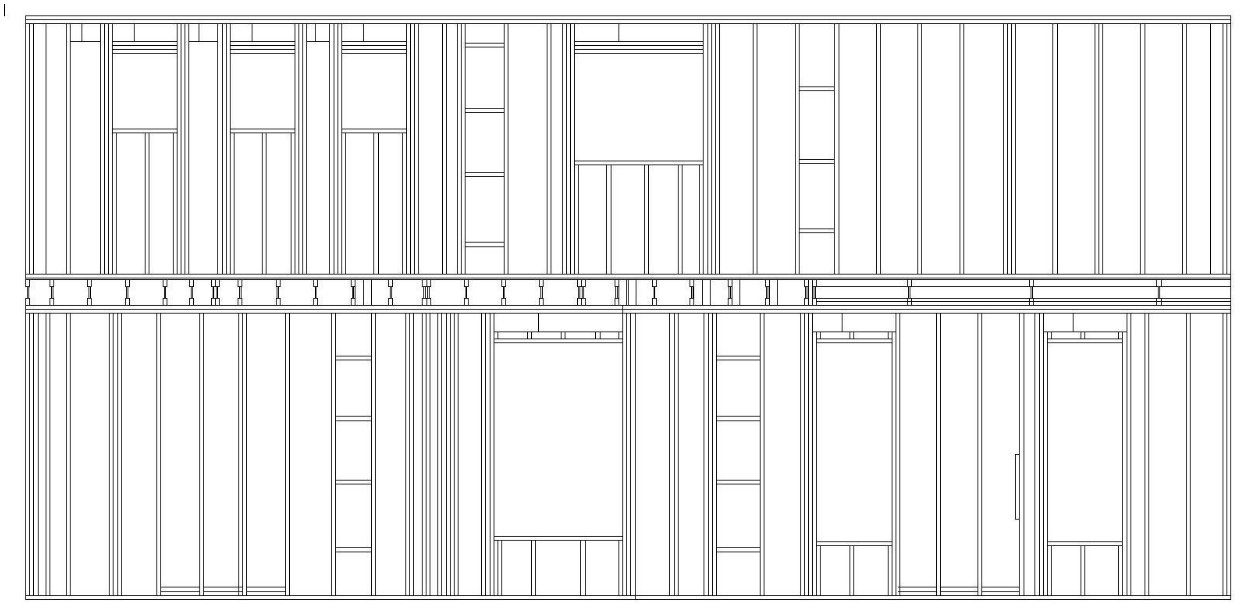


Figure 5.16: The DH-west wall with the existing framing on the site

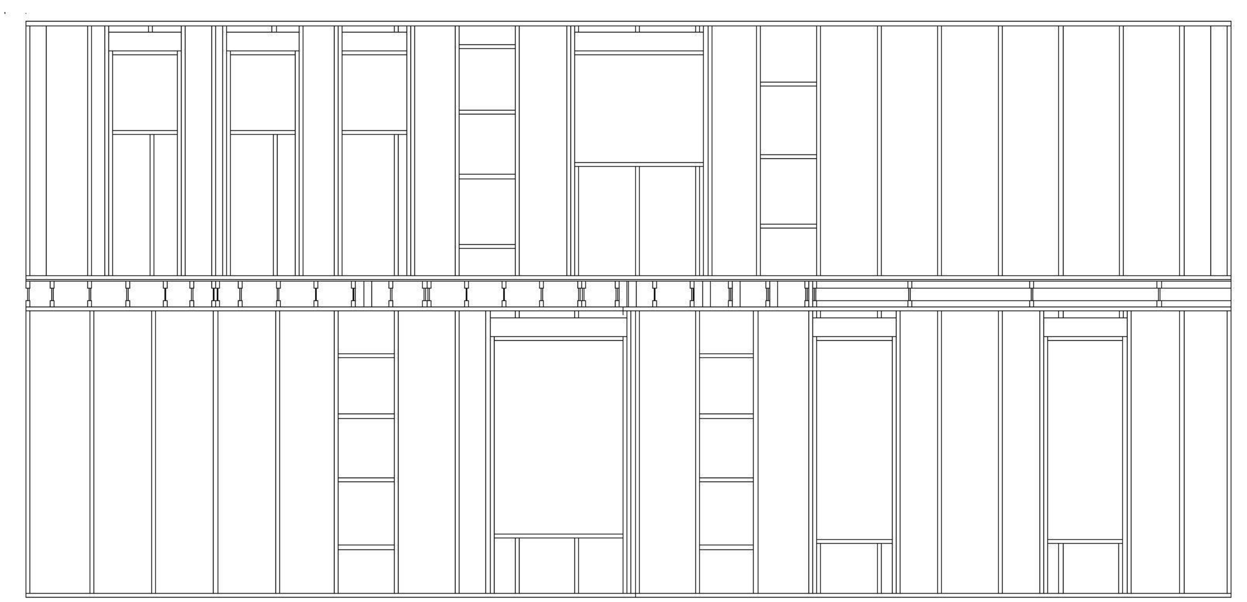


Figure 5.17: The DH- west wall with a proposed advanced framing system.

	Wood Area (m^2)	Gross wall area(m^2)	Net wall area(m^2)	Framing Factor (Gross)	Framing Factor (Net)
Conventional Framing	16	62.8	55	25.5%	28.4%
Advanced Framing	10	62	54.7	16.1 %	18.2%

Table 5.15: Comparison between the framing factor for the conventional wall framing system and the framing factor for advanced wall framing system

When the same wall reframed with advanced framing, the framing factor is reduced from 25.5% to 16.1 %(Gross wall area used in calculation the framing factor) and from 28.4% to 18.2% (net wall area used) , which means that the amount of framing elements that provide thermal bridging area are reduced, then the thermal performance of the wall will improve by adding more areas for the insulation materials which have higher R-value tan the wood studs. Consequently, the heat loss through the wall will reduce.

6. Conclusion

Seventeen dwellings were studied in three different locations in the Great Area of Toronto to calculate the framing factor depending on the amount of timber used during the construction. The seventeen units were divided into three categories; Detached Houses DHs, Town Houses THs, and Semi-detached house SDHs. Wall framing factors computed for each type of houses exceed the recommended framing factors by ASHRAE and NBC, 25% and 23% respectively. The highest wall framing factor was achieved by THs, 39.1% while DHs and SDHs obtained 30.3% and 31.1% respectively. The wall framing factor calculated for the three house types exceed the framing factor recommended by codes. In addition, floor and ceiling framing factors for THs also exceed the recommended factor by the codes.

All of these new framing factors are higher than the recommended factors by ASHRAE and Canadian proposals for an energy code.

Framing factor correlates with the number of factors such as number of stories, floor area, and window and door area to wall area ratio. This study shows that framing factor increases with the increase in any one of the previous factors. Having more stories increases the percentage of timber used in the lower level with narrower distance between studs to be able to carry the load above it such as all the five town houses, SDH7 and SDH8 which all have three stories. Increasing the floor area also tends to the increase in the framing factor. Furthermore, having higher percentage of window and door (opening) area to wall area ratio indicates having high framing factor presented by THs. That happens according to the fact that having more openings needs more framing elements around them, additional headers and additional cripple studs.

Understanding the thermal performance of the as-built walls and ceiling is crucial. When the effective R-value calculated for the walls by using the parallel path method and THERM software, it was found the thermal performance of the existing walls is underestimated, and the thermal resistance for walls in the example house does not meet the minimum requirement by Ontario building Code for Ontario region, 2012 when both ways of calculating the effective R-value are used. Adding 50.8 mm of a continuous layer of a rigid insulation improves the thermal performance of the walls, a continuous layer of rigid insulation works on reducing the thermal bridging through the wall, reducing the effect of framing factor, and control the heat flow through the envelope. On the other hand the effective R-value for the ceiling in the test houses met the minimum requirement for the insulation layer by OBC because of having thicker layer of the insulation which covers the ceiling trusses and prevents any direct connection between the trusses and the external environment.

Thee advanced framing system is an upgraded method of framing; it is introduced to reduce the percentage of timber framing in the wall, and thus improve the thermal performance of the walls. Advanced framing is recommended by the Building codes but it is not widely used because it limits having architectural details in the building but it can reduce the thermal bridging with the wall because of having less number of framing elements.

7. Future work

This work was done in a short period of time on a small number of houses. More comprehensive survey is required to extend the work. More case studies are required to be chosen in other different location in the GTA in order to give more accurate framing factor for all the region. It is also recommended to study the thermal resistance of the envelope of the new building before the construction stage to make sure that it meets the Code recommendation

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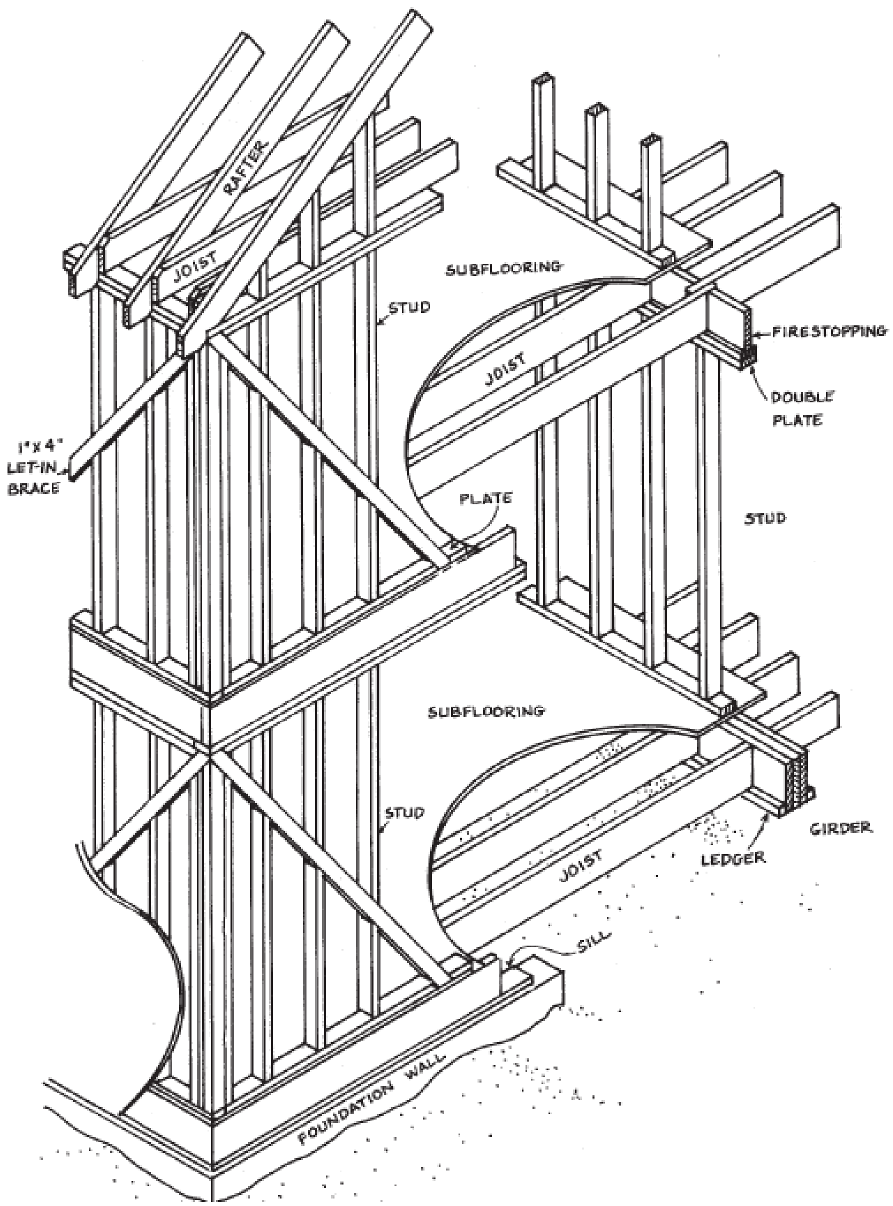
APPENDICES

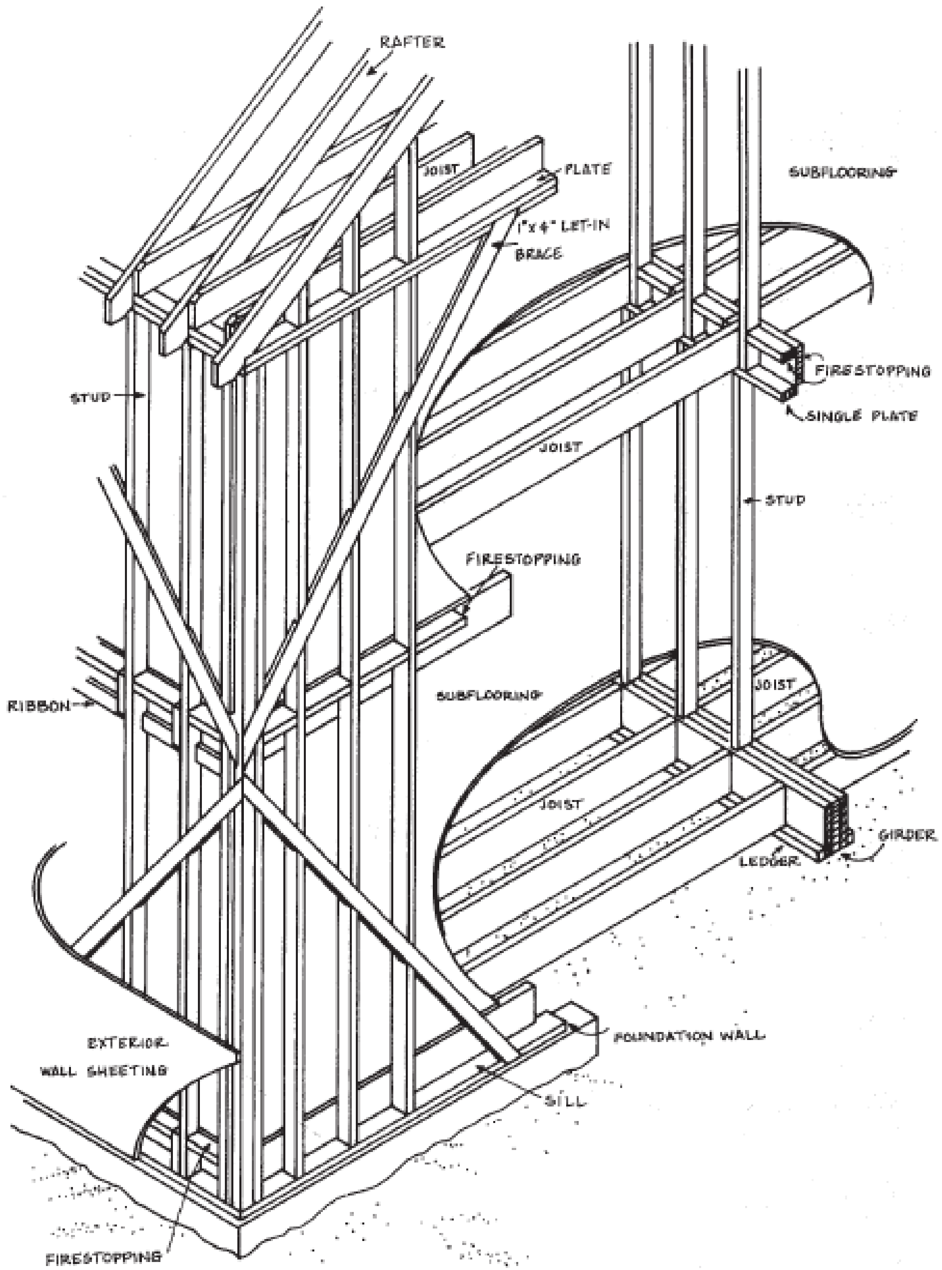
Appendix A:
Platform wood frame

Figure 1. Platform Frame Construction



Balloon framing

Figure 2. Balloon Frame Construction



Appendix B

Three "wood stud" walls and three "steel stud" walls which were used in the hot box test done by Kosny.

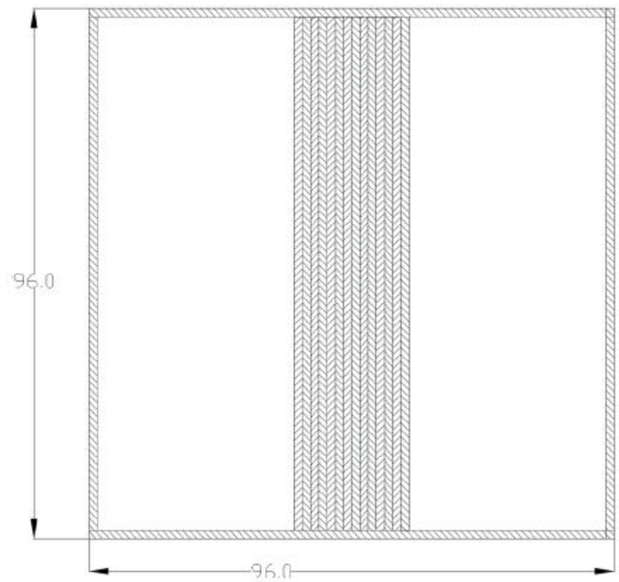


Figure 4 *Centrally located studs for a 27% framing factor at 8 × 8 ft (2.44 × 2.44 m) wall.*

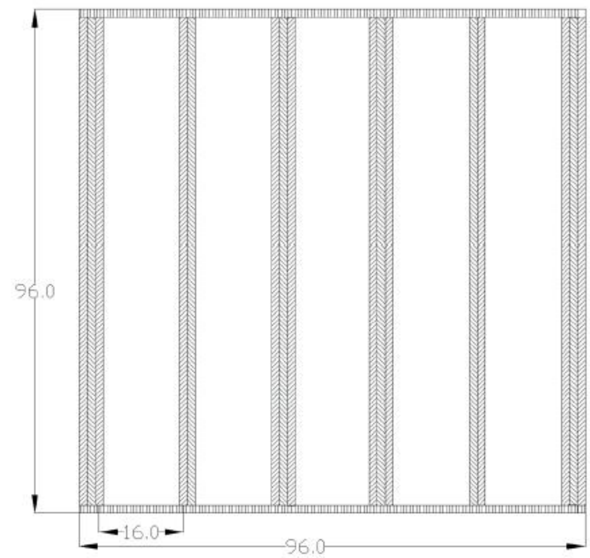


Figure 5 *Equally distributed studs with 16 in. (40 cm) o.c. for a 27% framing factor.*

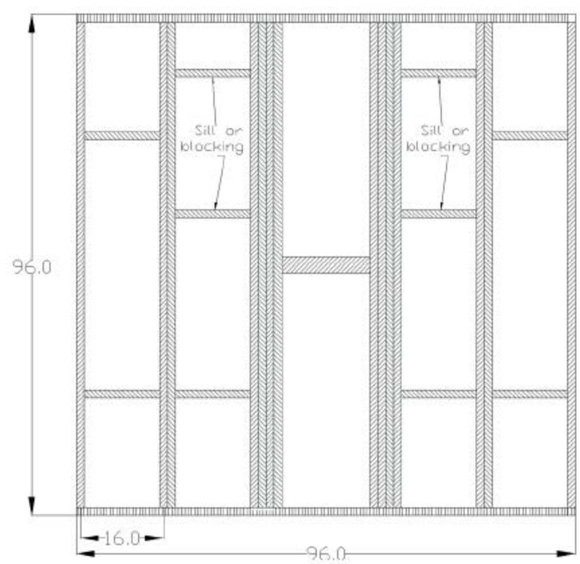


Figure 6 *Stud distribution with a 27% framing factor at th 8 × 8 ft (2.44 × 2.44 m) wall.*

Appendix C

R-value calculation for the walls:

1.1 conventional wall system with 25% Framing Factor (ASHRAE standard)

$$\mathbf{U_{AVGE} = F.F_i \times U_I + F.F_f \times U_f}$$

$$U_{AVGE} = 0.25 \text{ x } 1/1.78 + 0.75 \text{ x } 1/4.52$$

$$U_{AVGE} = 0.306 \text{ W/(m2.K)}$$

$$RSI_{total} = 3.26 \text{ (m2.K)/ W}$$

1.2 Upgraded wall system with 25% Framing Factor (ASHRAE standard)

$$U_{AVGE} = 0.25 \text{ x } 1/3.63 + 0.75 \text{ x } 1/6.3$$

$$U_{AVGE} = 0.188$$

$$RSI_{total} = 5.32 \text{(m2.K)/ W}$$

2.1 Detach houses-conventional wall with Framing Factor= 30.0%

$$U_{AVGE} = 0.30 \text{x } 1/1.78 + 0.70 \text{ x } 1/4.52$$

$$U_{AVGE} = 0.323 \text{W/(m2.K)}$$

$$Rsi_{total} = 3.09 \text{(m2.K)/ W}$$

2.2 Upgraded wall with 30.00% framing factor :

$$U_{AVGE} = 0.30 \text{x } 1/3.63 + 0.70 \text{ x } 1/6.3$$

$$U_{AVGE} = 0.194 \text{W/(m2.K)}$$

$$Rsi_{total} = 5.16 \text{(m2.K)/ W}$$

3.1 Row houses -conventional wall with 36.1% framing factor

$$\mathbf{U_{AVGE} = F.F_i \times U_I + F.F_f \times U_f}$$

$$U_{AVGE} = 0.361 \text{x } 1/1.78 + 0.639 \text{ x } 1/4.52$$

$$U_{AVGE} = 0.344$$

$$Rsi \text{ effe} = 2.91$$

3.2 Upgraded wall with 36.1% framing factor :

$$U_{AVGE} = 0.361 \text{x } 1/3.63 + 0.639 \text{ x } 1/6.3$$

$U_{AVGE} = 0.201 W/(m2.K)$

Rsi total = 4.98(m2.K)/ W

4.1 Semi detached houses-conventional wall with 31.1% framing factor

$$\mathbf{U_{AVGE} = F.F_i \times R_I + F.F_f \times R_f}$$

$$U_{AVGE} = 0.311 \times 1/1.78 + 0.689 \times 1/4.52$$

$$U_{AVGE} = 0.327$$

R total = 3.06

4.2 Upgraded wall with 31.1 % framing factor :

$$\mathbf{U_{AVGE} = F.F_i \times R_I + F.F_f \times R_f}$$

$$U_{AVGE} = 0.311 \times 1/3.63 + 0.689 \times 1/6.3$$

$$U_{AVGE} = 0.195$$

Rsi= 5.13

Appendix D

R-value calculation for ceiling

1- conventional ceiling with framing factor 7% (ASHREA recommendation)

$$\boldsymbol{RSI_T} = \frac{\mathbf{100}}{\frac{\mathbf{7}}{\mathbf{34}} + \frac{\mathbf{93}}{\mathbf{41}}}$$

$RSI_{total} = 40.4$ (Btu/h.ft2.F)

$R_{effective}$ 7.12 **(m2.K)/ W**

2- Detach houses-conventional wall with Framing Factor= 9.6%

$$\boldsymbol{RSI_T} = \frac{\mathbf{100}}{\frac{\mathbf{9.6}}{\mathbf{34}} + \frac{\mathbf{90.4}}{\mathbf{41}}}$$

$RSI_{total} = 40.21$ **(Btu/h.ft2.F)**

$R_{effective} = 7.08$ (m2.K)/ W

3- Town houses -conventional wall with 9.2% framing factor

$$RSI_T = \frac{100}{\frac{9.2}{34} + \frac{90.8}{41}}$$

$RSI_{total} = 40.24$ **(Btu/h.ft2.F)**

$R_{effective} = 7.09$ (m2.K)/ W

4- Semi detached houses-conventional wall with 8% framing factor

$$RSI_T = \frac{100}{\frac{8}{34} + \frac{92}{41}}$$

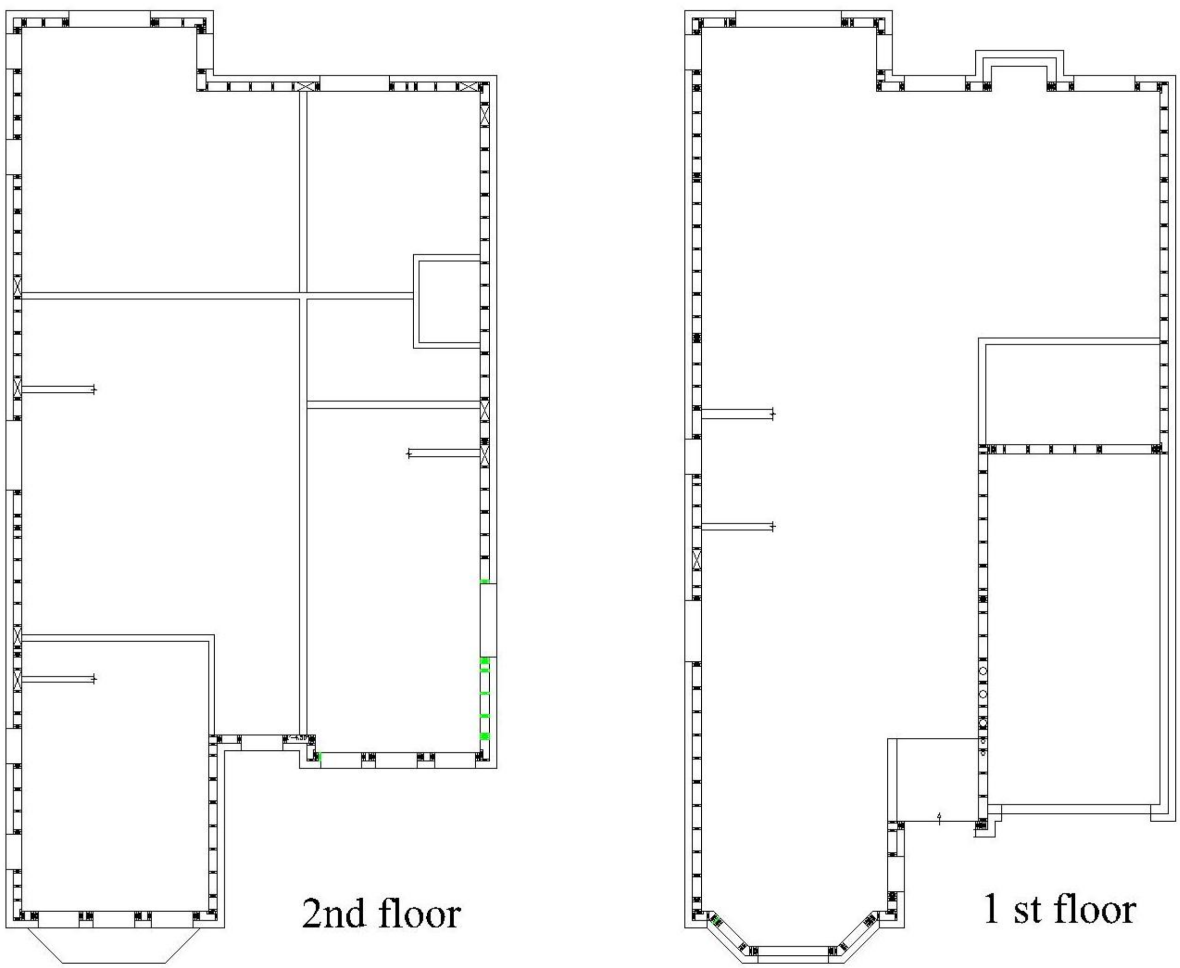
$RSI_{total} = 40.34$ **(Btu/h.ft2.F)**

$R_{effective} = 7.10$ (m2.K)/ W

Appendix E

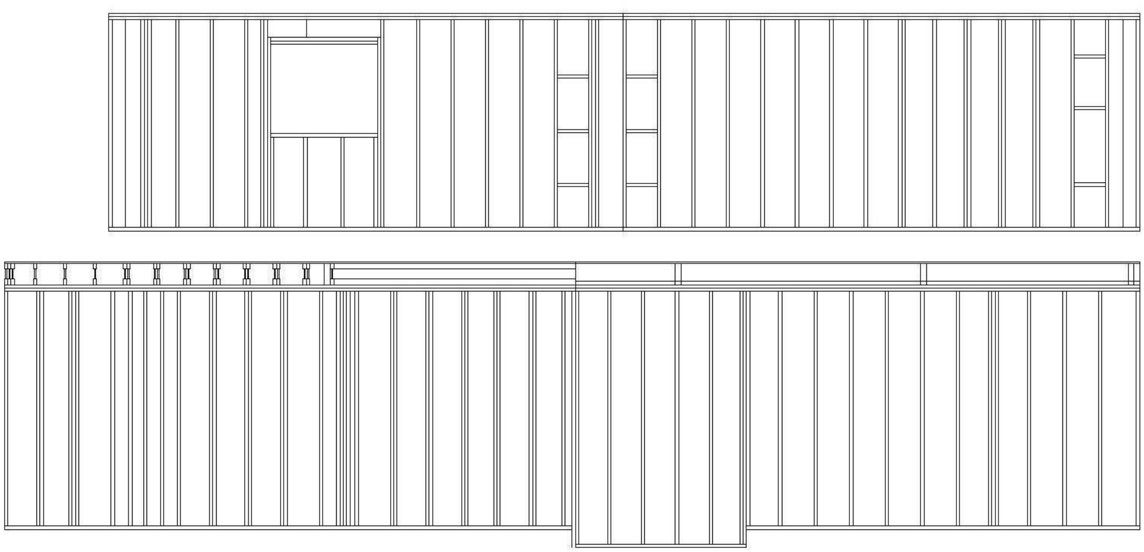
Case studies:

Detached house 1/ DH1

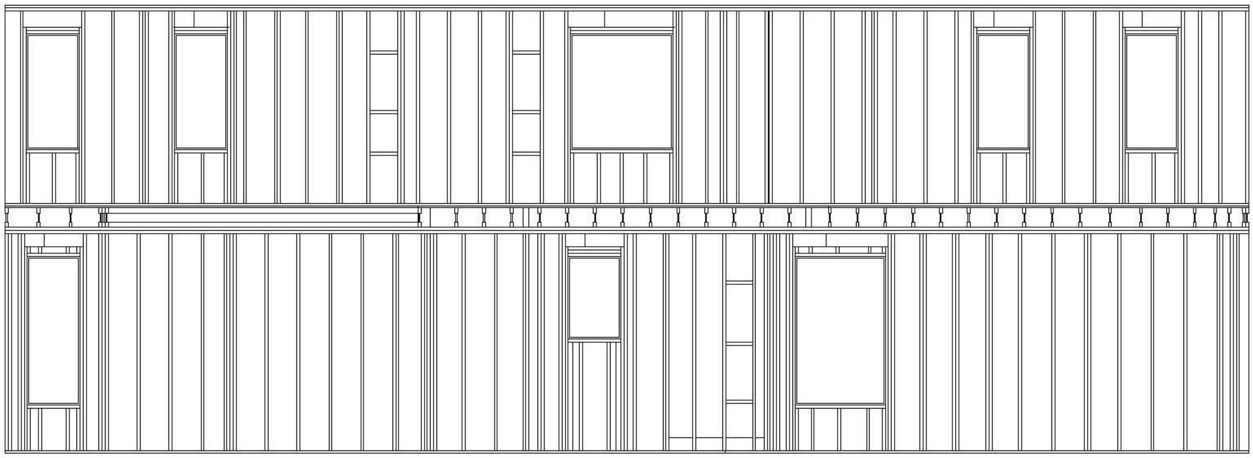


The first and the second floors for detached house (DH1) with the a built studs

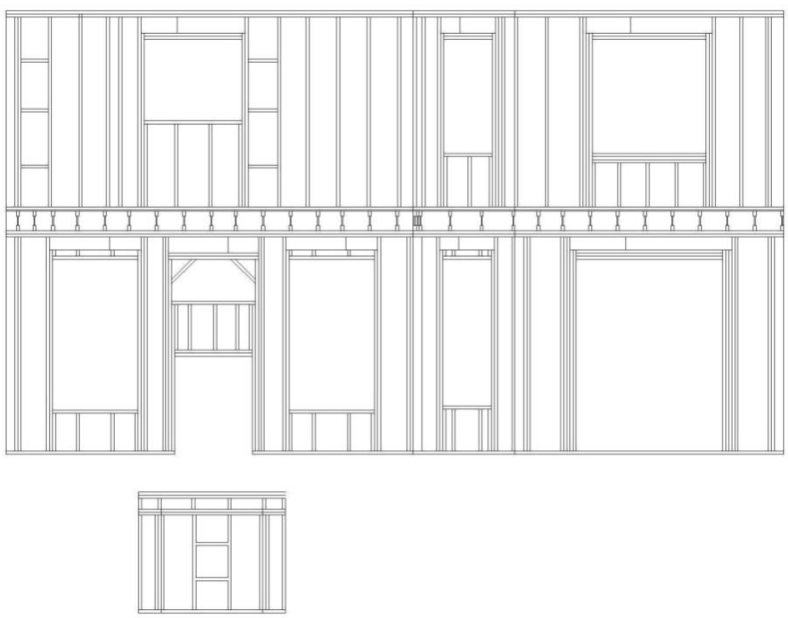
Detached house DH1 front (extended) elevation with the as-built studs



Detached house DH1 east-side elevation with the as-built studs



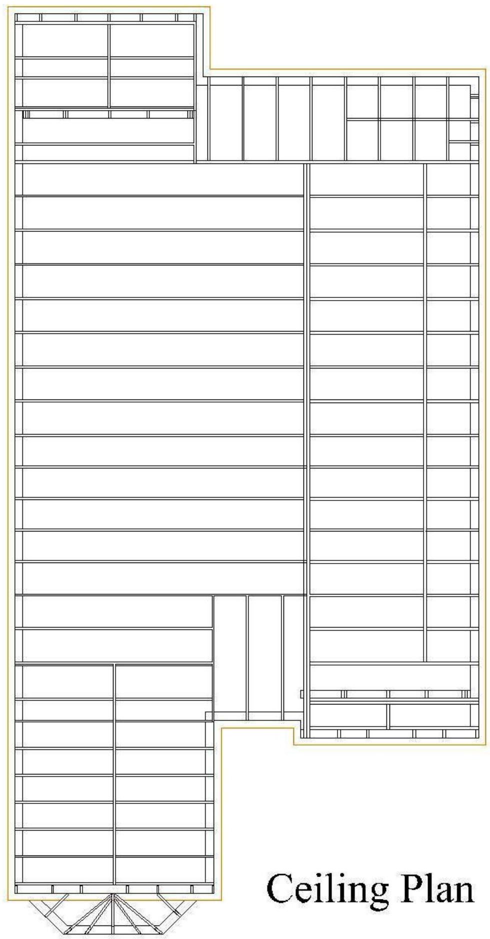
Detached house DH1 west-side elevation with the as-built studs



Detached house DH1 back-side (north) elevation with the as- built studs

TH1			
	Wood area m^2	**Wall area m^2**	**Framing factor**
Front	18.9	203	32.30%
Side/east	67.1	14.7	22.0%
Back	40.7	15.0	36.9%
Side/ west	929	20.9	24.20%
TOTAL	228	69.5	30.6%

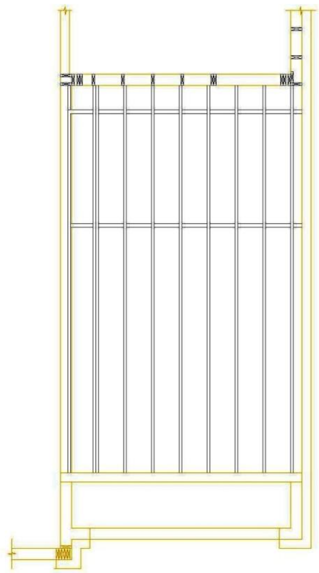
Detached house DH1 summary of wall framing factor calculations



Detached house DH4 framing plan for the ceiling

Ceiling area m^2	Framing area m^2	Ceiling framing factor %
112.15	10.7	9.5%

The areas of the ceiling and the framing and the ceiling framing factor

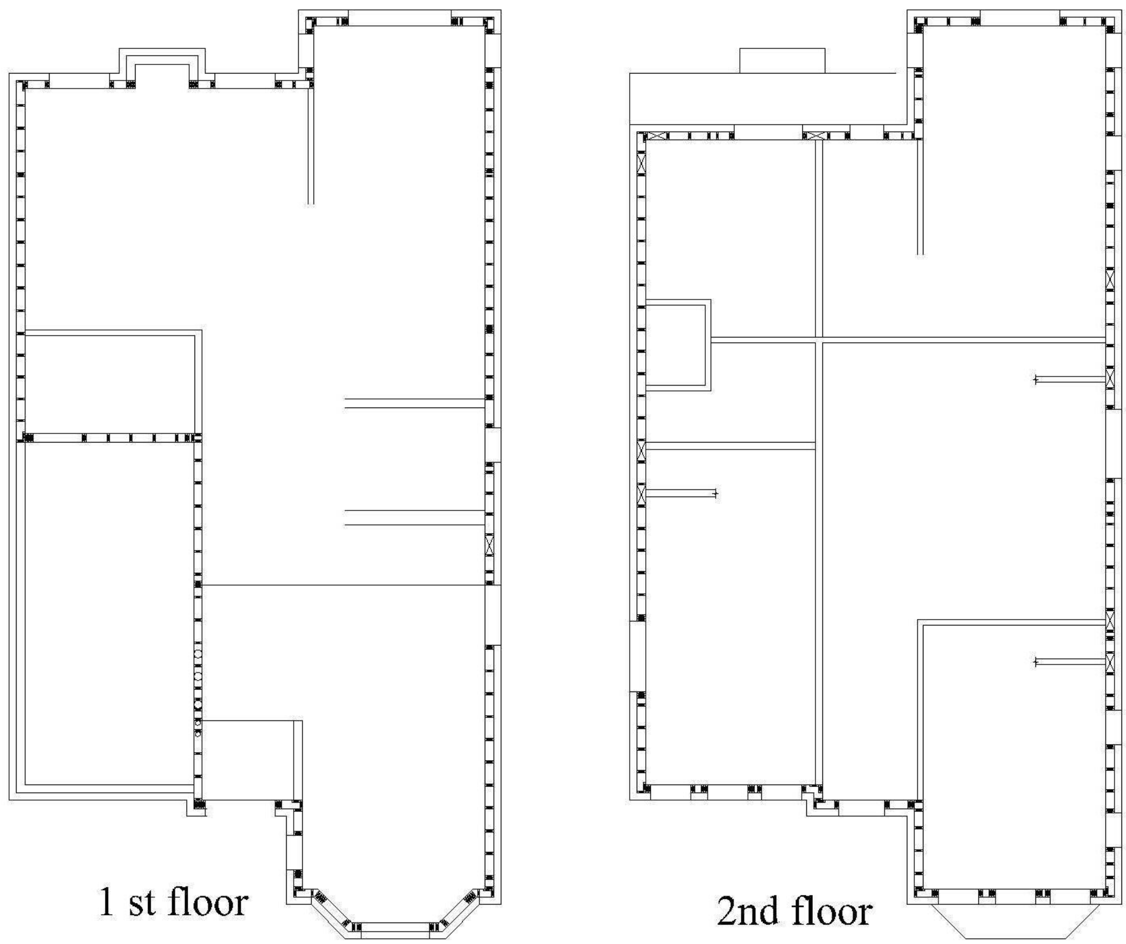


Detached house DH1heat loss floor plan –floor above parking garage.

Floor area m^2	Framing area m^2	floor framing factor %
12.5	1.51	12.1

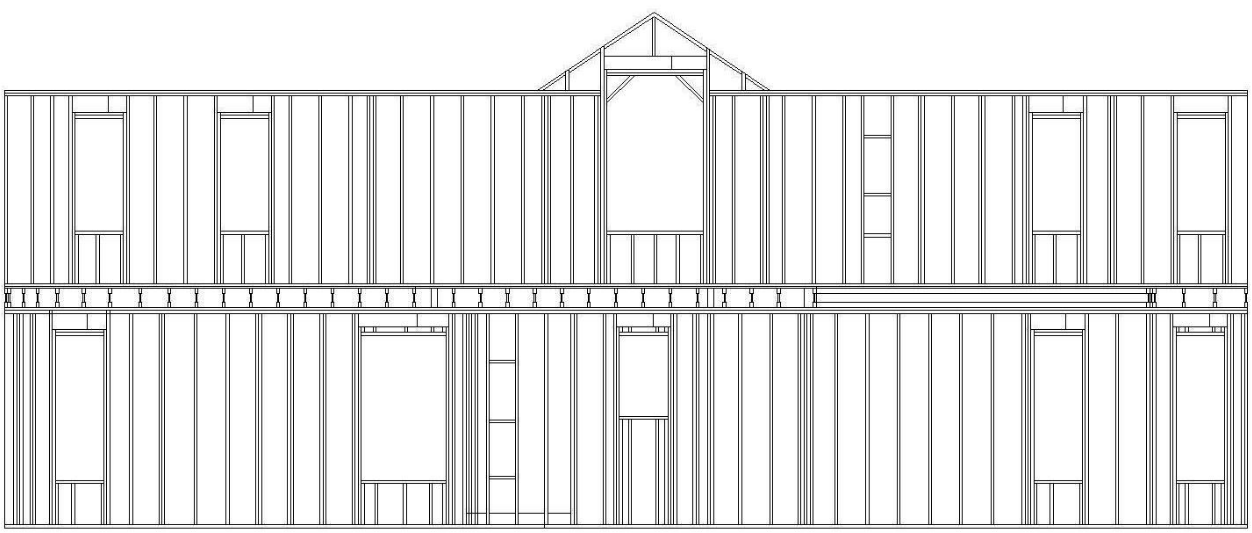
The areas of the floor and the framing and the total framing factor

Detached house 2/ DH2



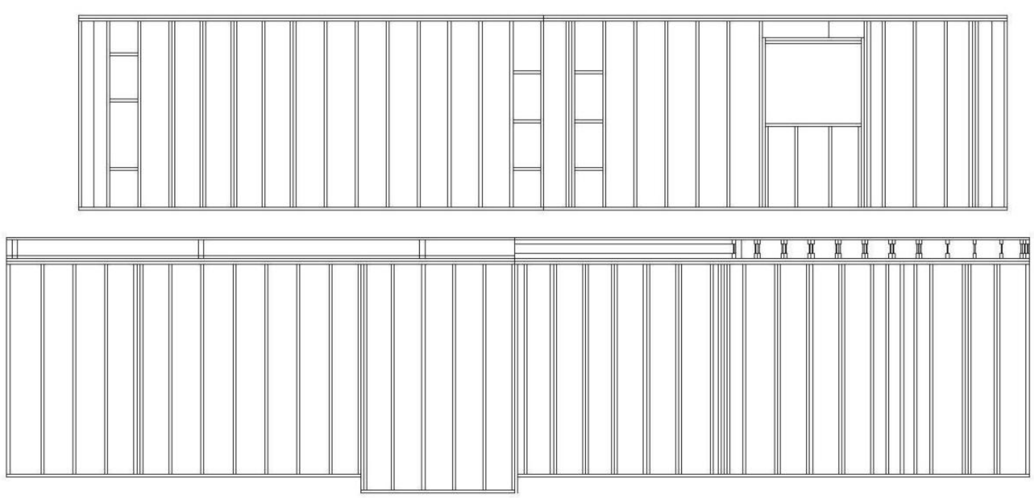
The first and the second floors for detached house (DH2) with the a built studs

Detached house DH2front (extended) elevation with the as-built studs



Detached house DH1 east- side elevation with the as-buit studs

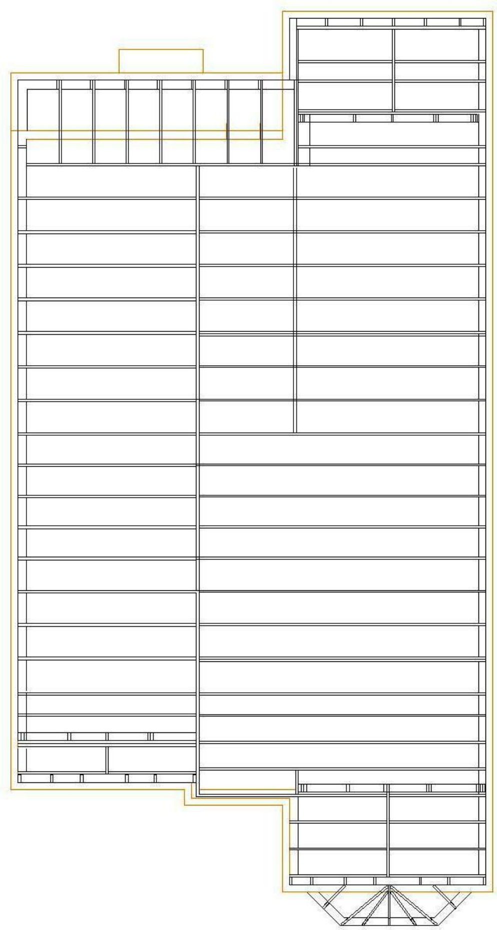
Detached house DH2 back-side (north) elevation with the as- built studs



Detached house DH2 east-side elevation with the as-built studs

DH 2			
	Wall area m^2	Wood area m^2	Framing factor
Front	40.7	19	46.6%
Side/east	67.1	14.7	21.8%
Back	40.1	15.2	38.0%
Side/ west	76.3	22.0	29.0%
Total	231.3	72	31.1%

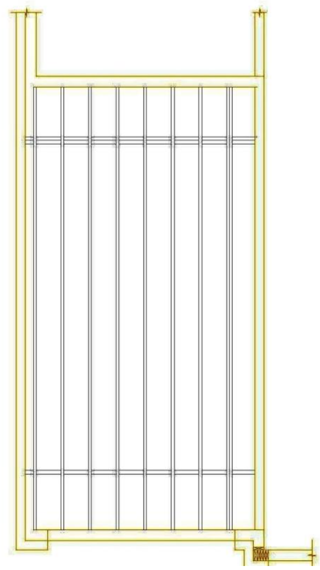
Detached house DH2 summary of wall framing factor calculations



Detached house DH2 framing plan for the ceiling

Ceiling area m^2	Framing area m^2	Ceiling framing factor %
120	11.6	9.7 %

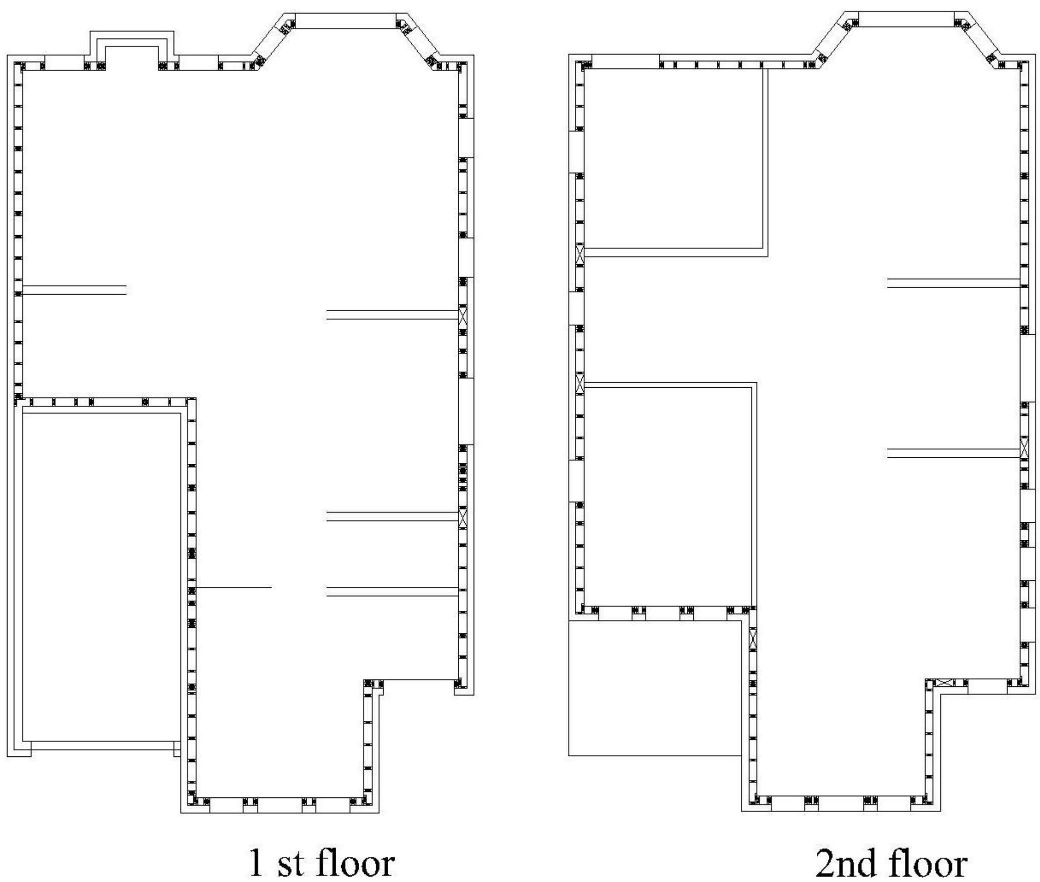
The areas of the ceiling and the framing and the ceiling framing factor



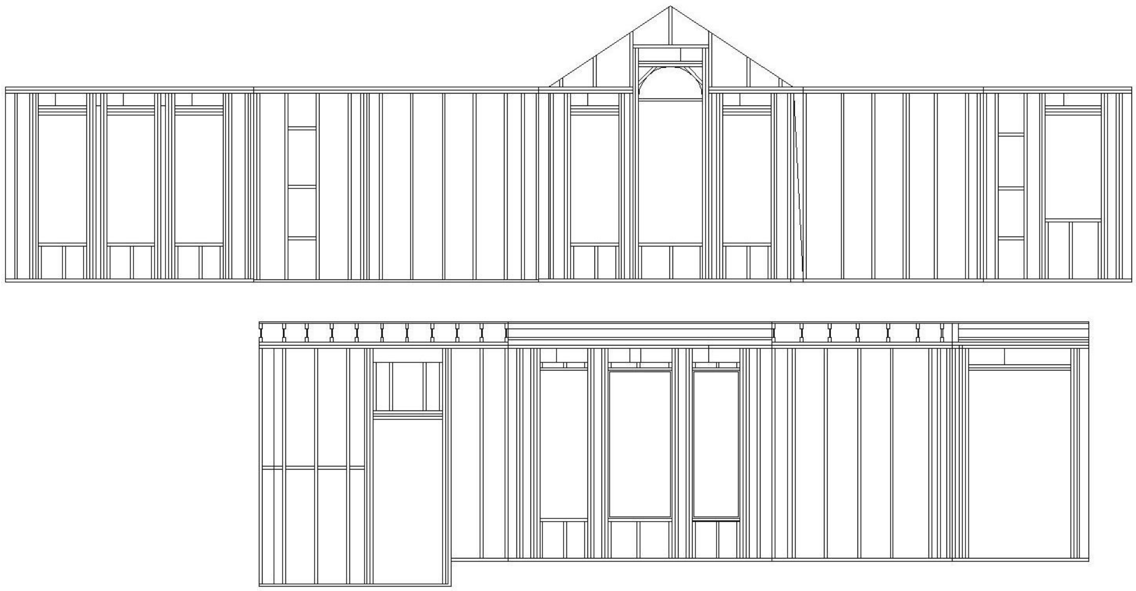
Detached house/ DH2 floor plan above parking garage.

Floor area m^2	**Framing area m^2**	**floor framing factor %**
19.4	**2.51**	**12.9%**

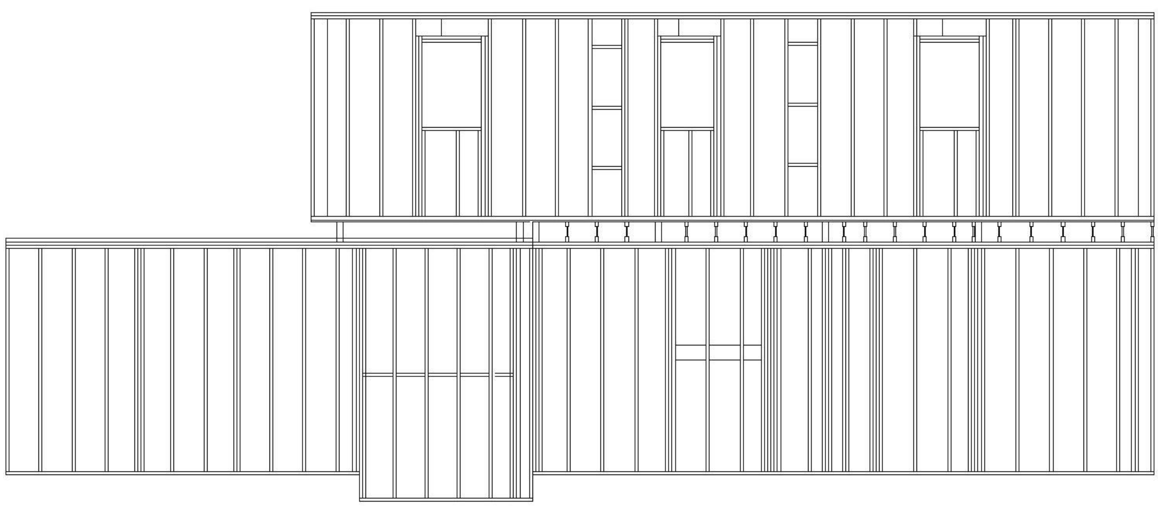
The areas of the floor and the framing and the total framing factor



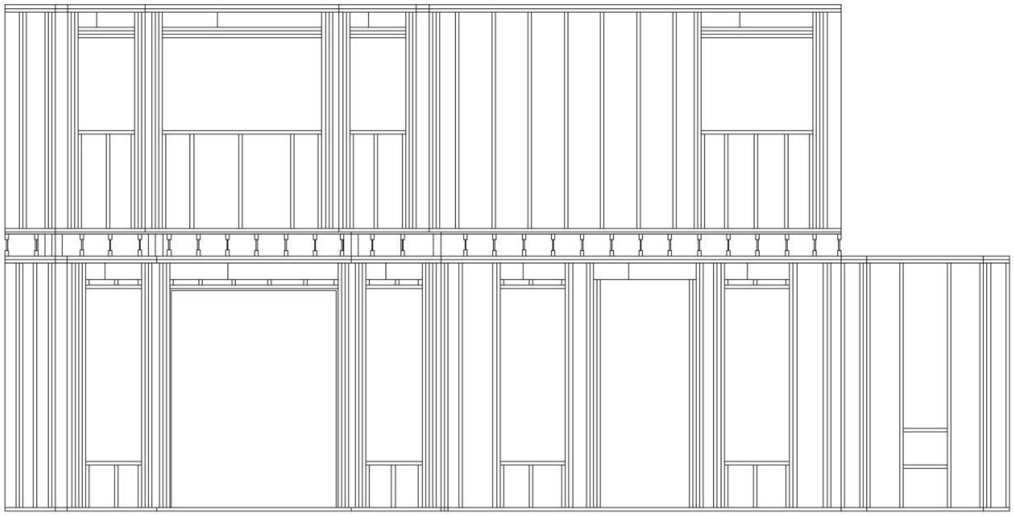
The first and the second floors for detached house (DH3) with the a built studs



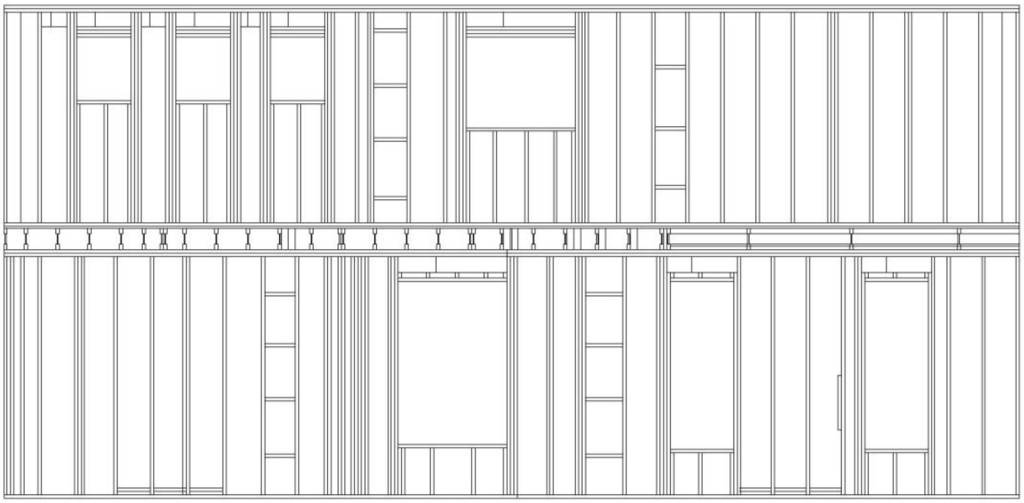
detached house DH3front (extended) elevation with the as-built studs



Detached house DH3 east-side elevation with the as-built studs



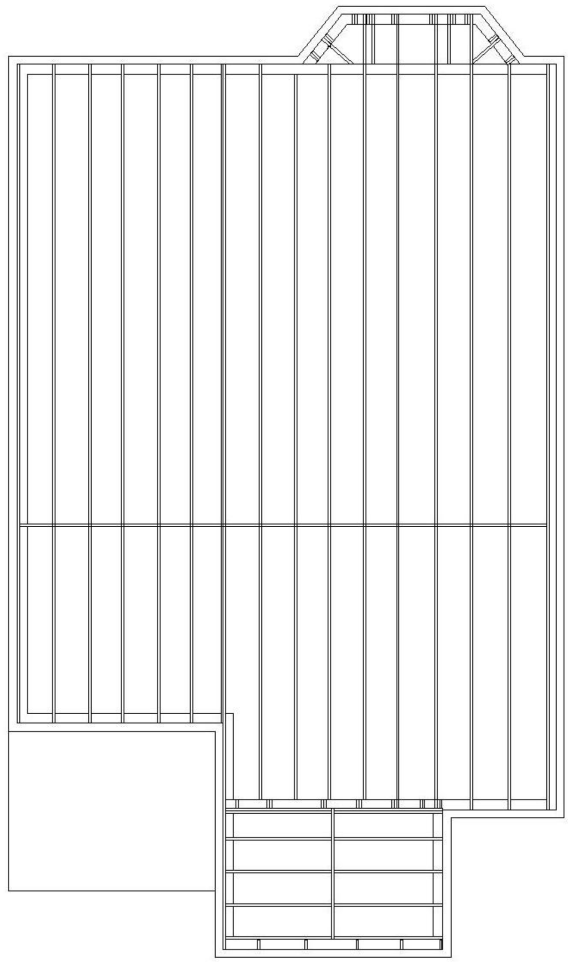
Detached house DH3 back-side (north) elevation with the as- built studs



Detached house DH3 west-side elevation with the as-built studs

TH3			
	Wall area m^2	Framing area m^2	Framing factor
Front	43.2	16.5	38.2%
Side/east	55	15.1	27.4%
Back	39.1	16.6	42.4%
Side/ west	75	18.1	24.2%
total	212.2	66.3	31.2%

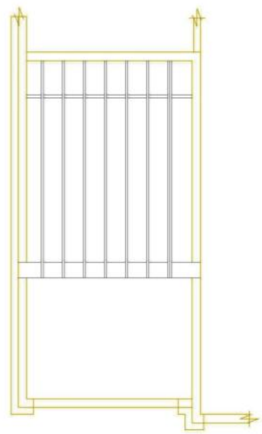
Detached house DH3 summary of wall framing factor calculations



Detached house DH3 heat loss floor plan –floor above parking garage

Ceiling area m^2	Framing area m^2	Ceiling framing factor %
98.8	8.76	8.9 %

The areas of the floor and the framing and the total framing factor

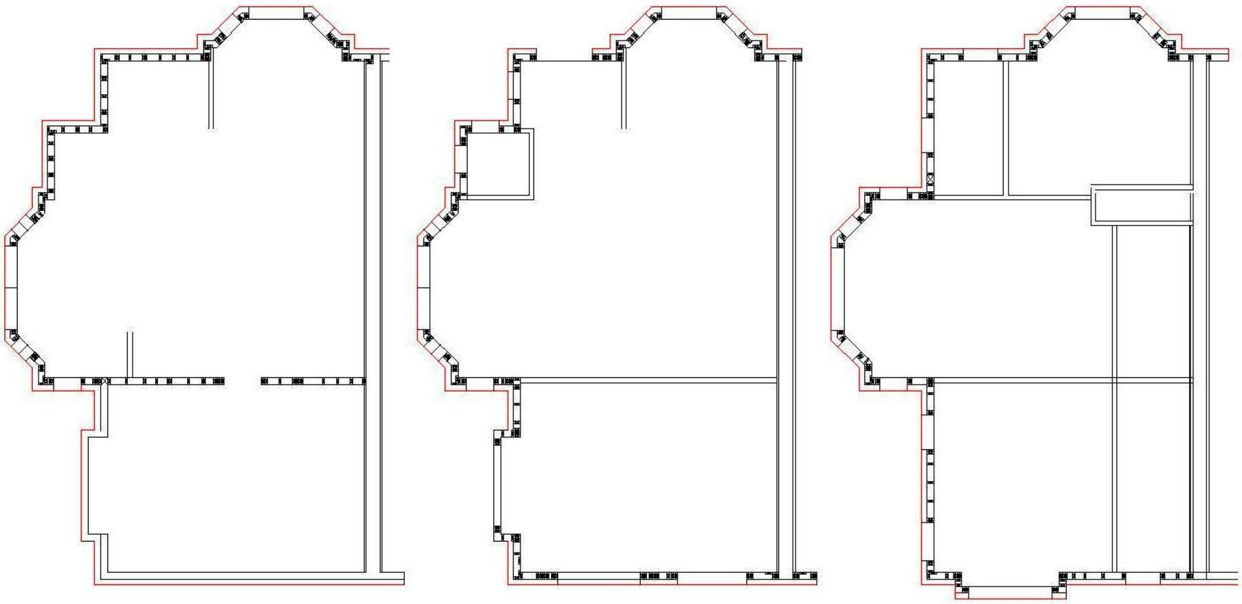


Detached house DH3 heat loss floor plan –floor above parking garage.

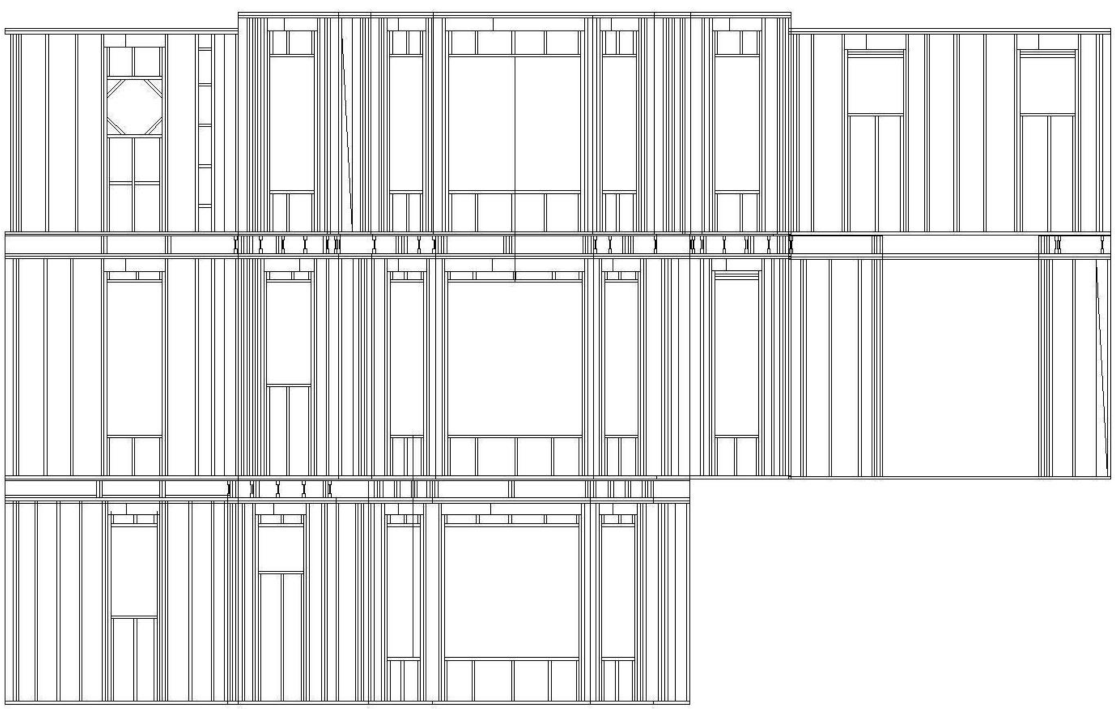
Floor area m^2	**Framing area m^2**	**floor framing factor %**
11.74	**1.33**	**11.33%**

The areas of the floor and the framing and the total framing factor

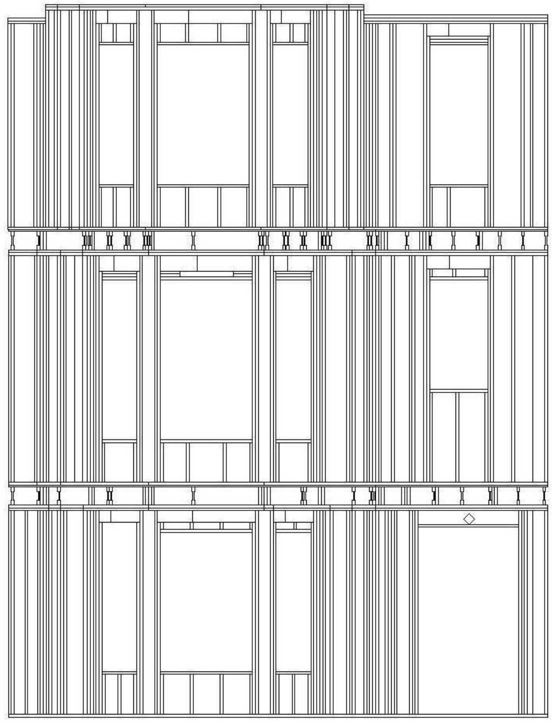
Town house 1 /TH 1/TH3



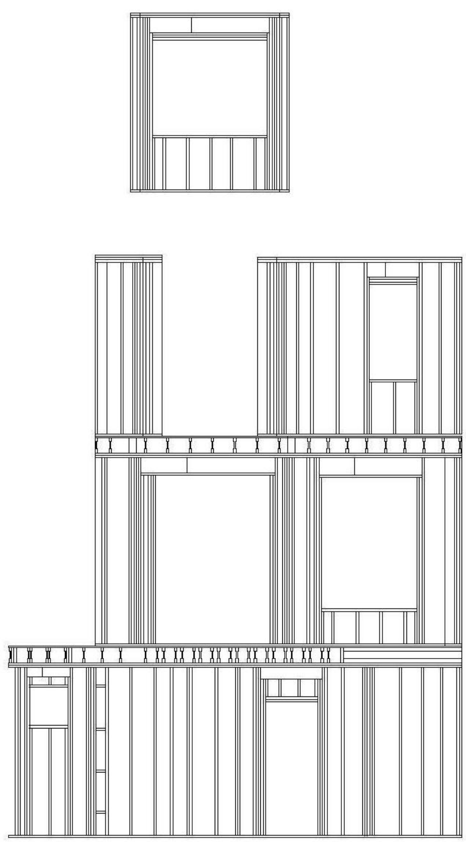
The first, the second, and the third floors for semi-detached house (TH1/TH3) with the as- built studs



Town house TH1 side elevation with the as-built studs



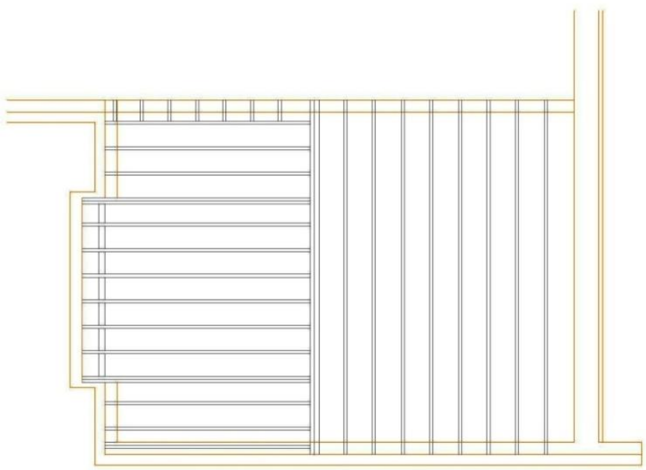
Town houseTH1 front (extended) elevation with the as-built studs



Town house TH1 back-side (north) elevation with the as- built studs

TH 1			
	Wood area m^2	Wall area m^2	Framing factor
Front	47.9	21.5	44.4%
Side/east	99.8	36.0	36.0%
Back	47.1	17.3	36.6%
Side/ west	N/A	N/A	N/A
total	194.8	74.5	38.3%

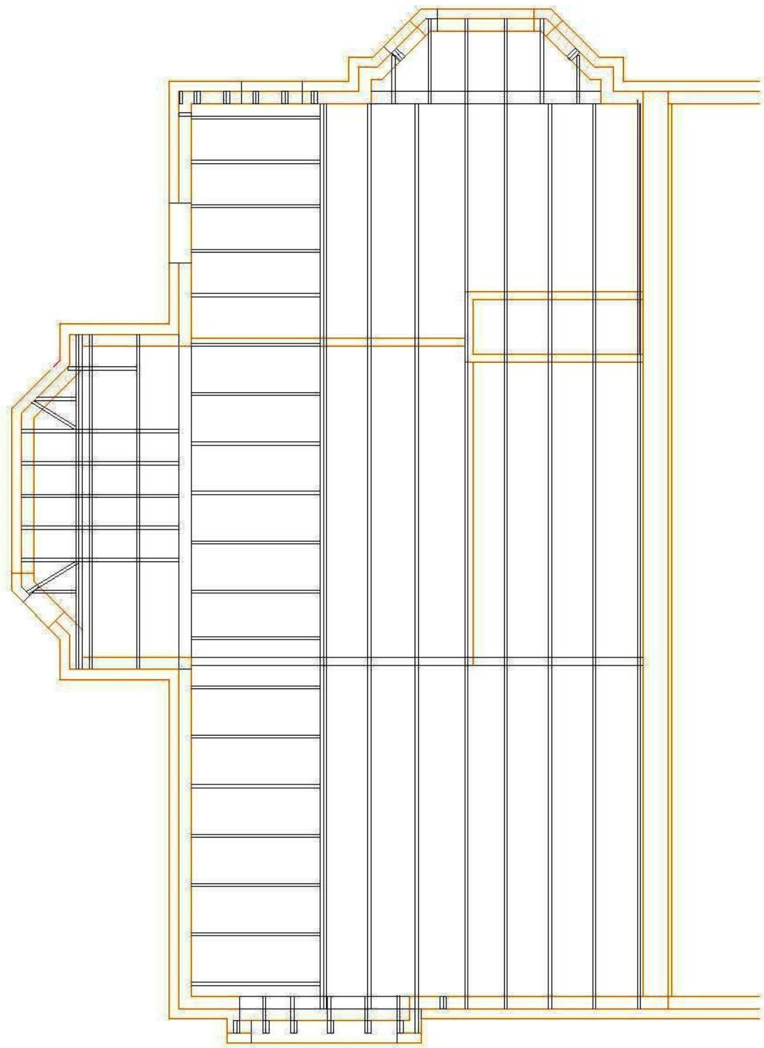
Town house TH1 summary of wall framing factor calculations



Town house TH1heat loss floor plan –floor above parking garage.

Floor area m^2	Framing area m^2	floor framing factor %
25.7	3.5	13.7 %

The areas of the floor and the framing and the total framing factor

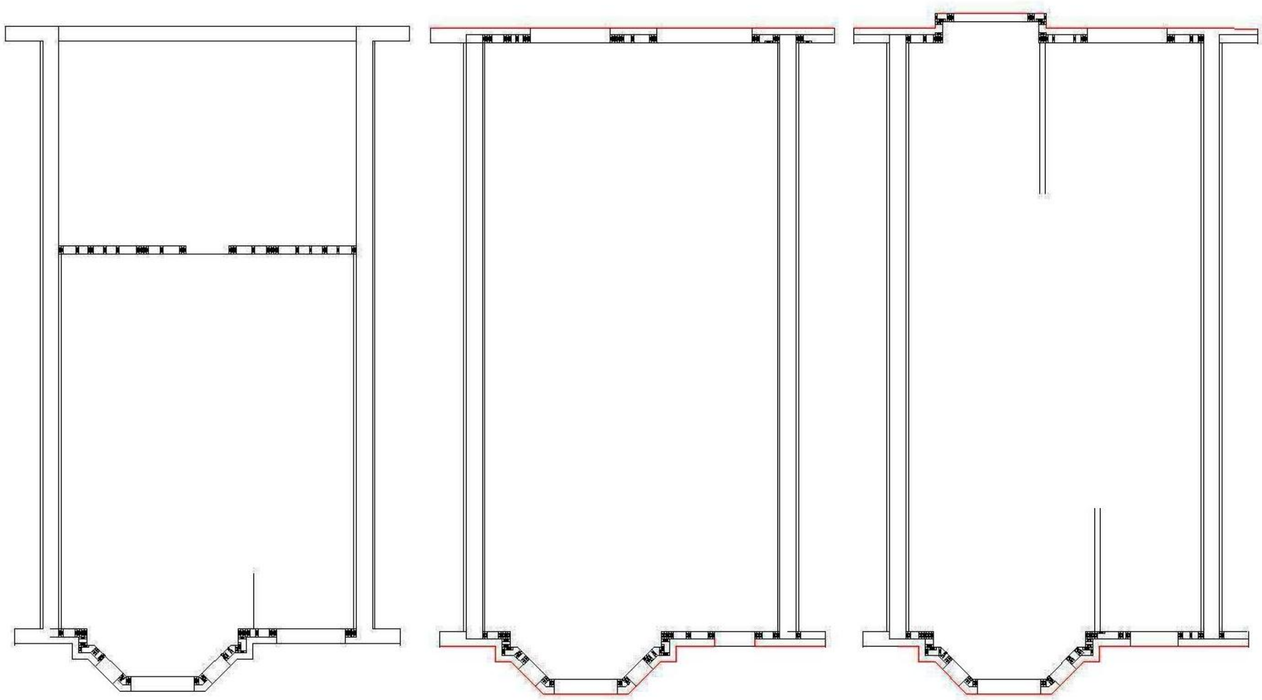


Town house TH1 framing plan for the ceiling

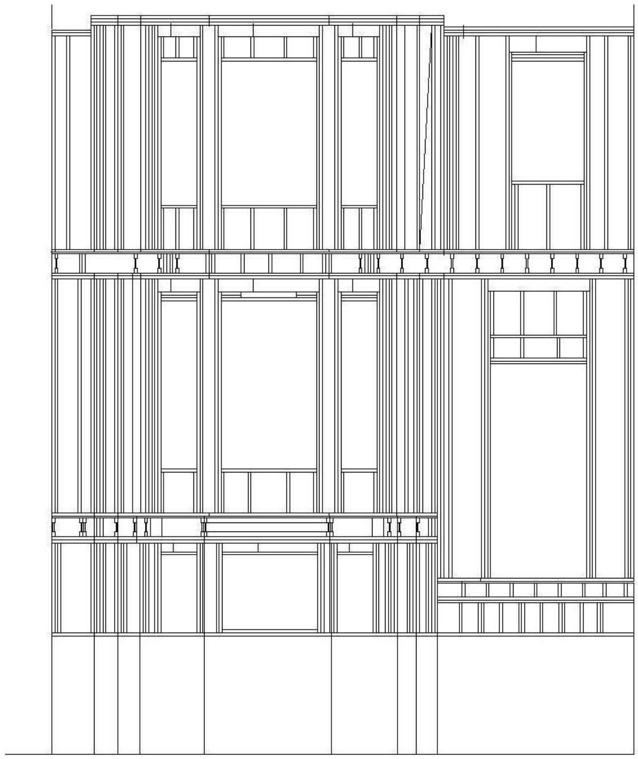
Ceiling area m^2	Framing area m^2	Ceiling framing factor %
77.7	8.0	10.3%

The areas of the ceiling and the framing and the ceiling framing factor

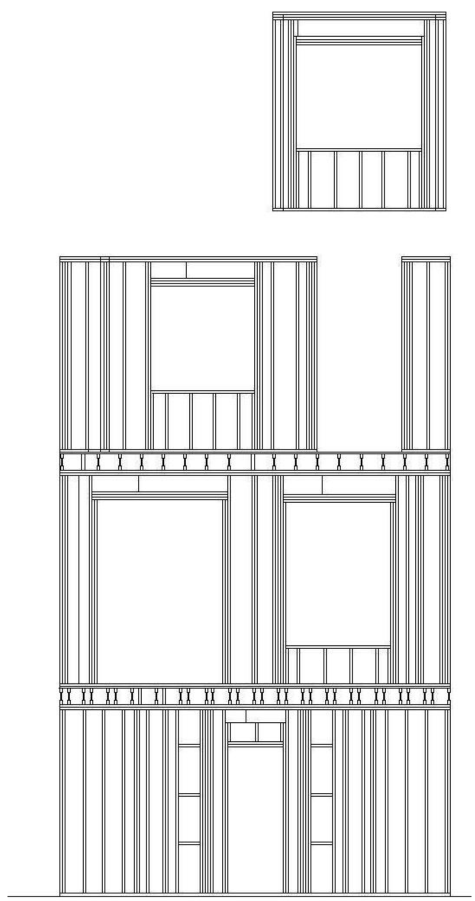
Town house /TH 2/TH4/TH5



The first, the second, and the third floors for semi-detached house (TH2/TH4/TH5) with the as-built studs



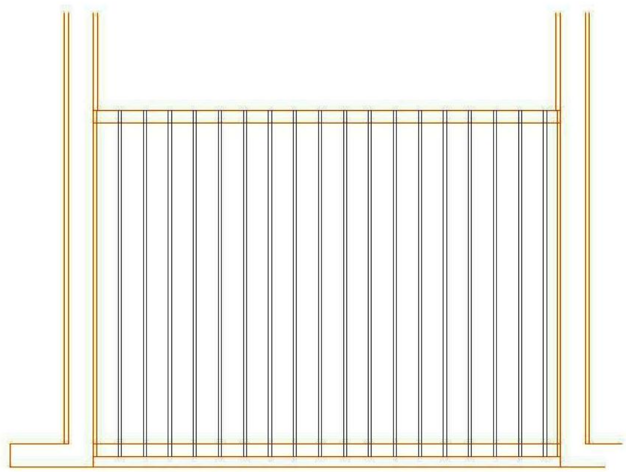
Town houseTH2 front (extended) elevation with the as-built studs



Town house TH2 back-side extended elevation with the as- built studs

TH 2			
	Wood area m^2	Wall area m^2	Framing factor
Front	48.8	18.6	38.2%
Side/east	N/A	N/A	N/A
Back	39.6	15.5	39.0%
Side/ west	N/A	N/A	N/A
total	88.4	34.1	38.5 %

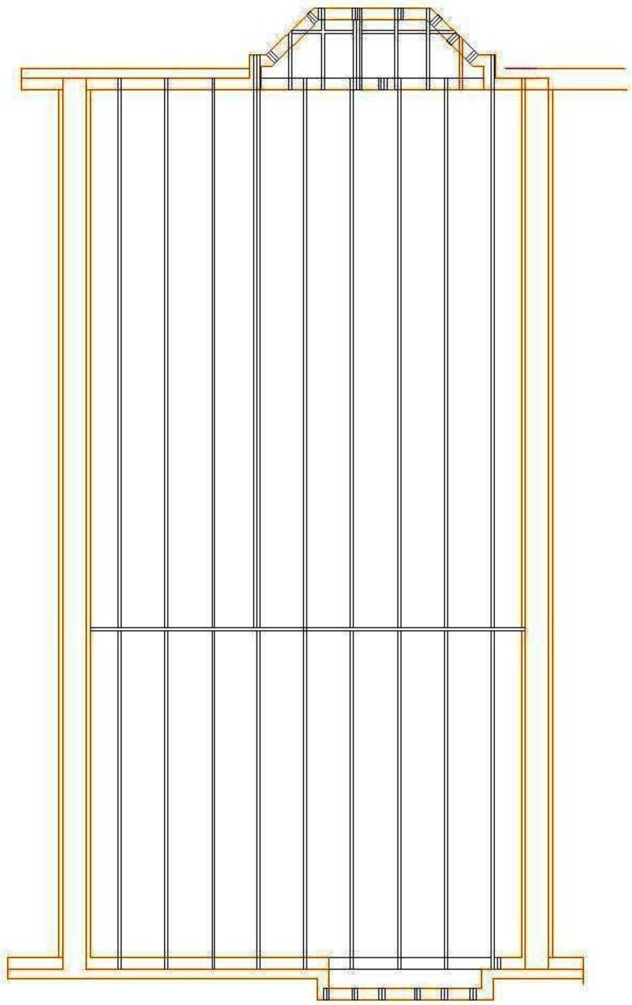
Town house TH2 summary of wall framing factor calculations



Town house TH2 heat loss floor plan –floor above parking garage.

Floor area m^2	Framing area m^2	floor framing factor %
24.0	3.2	13.4%

The areas of the floor and the framing and the total framing factor

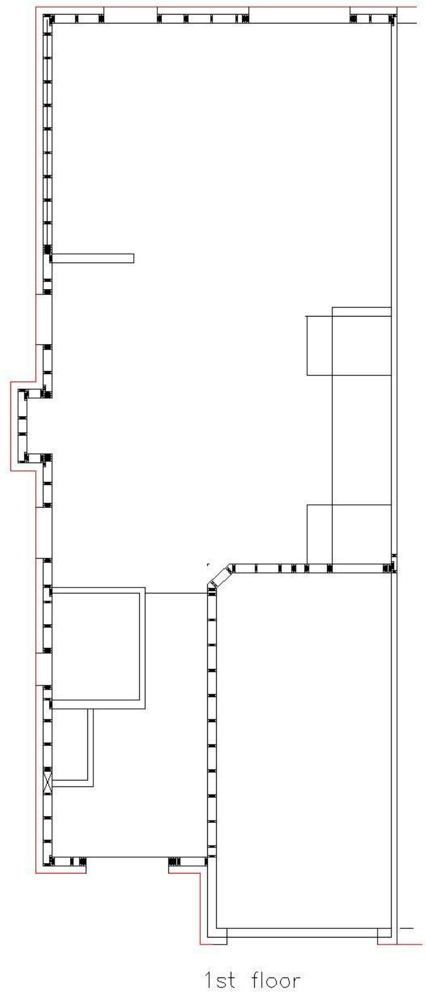


Town house TH2 framing plan for the ceiling

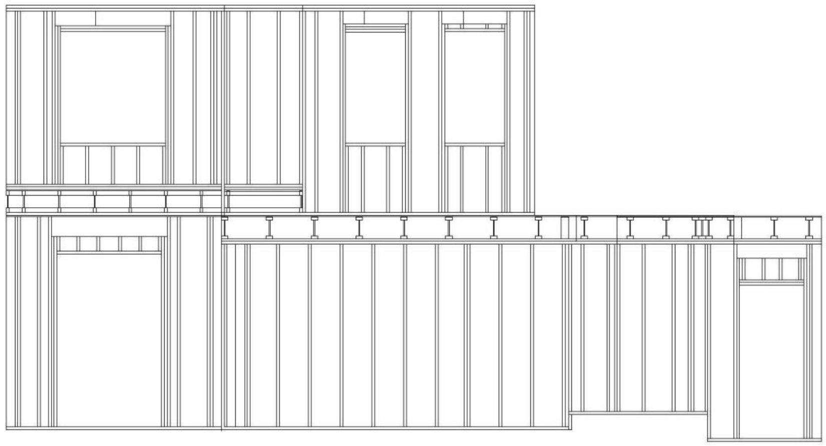
Ceiling area m^2	Framing area m^2	Ceiling framing factor %
72.5	6.4	9%

The areas of the ceiling and the framing and the ceiling framing factor

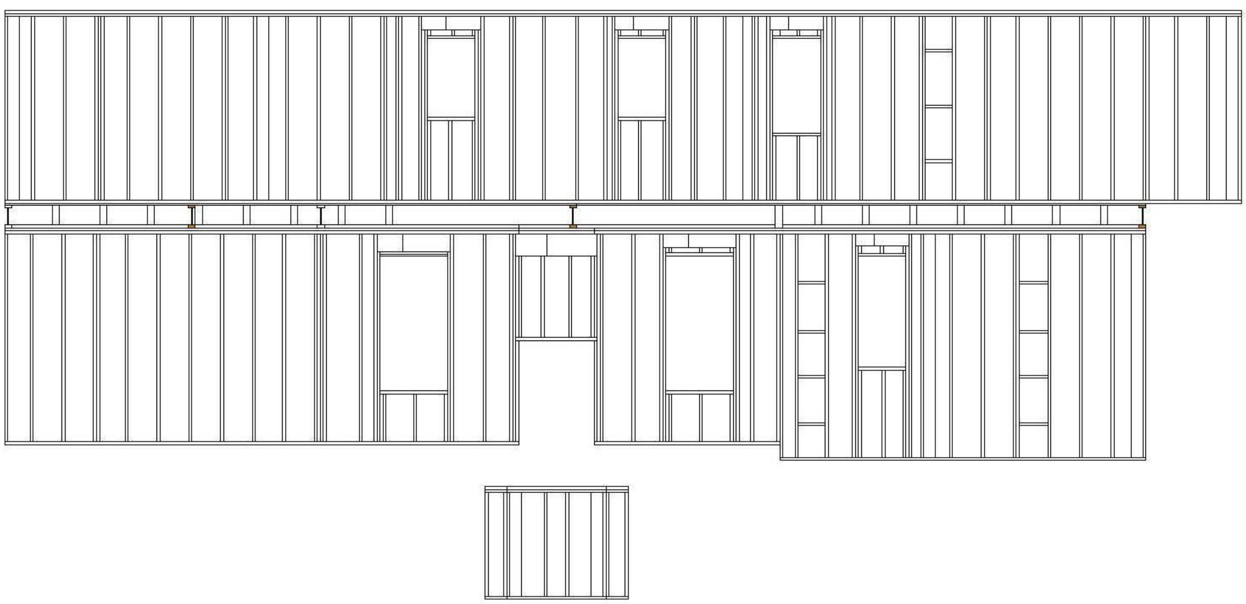
Semi- detached house 1 /SDH 1



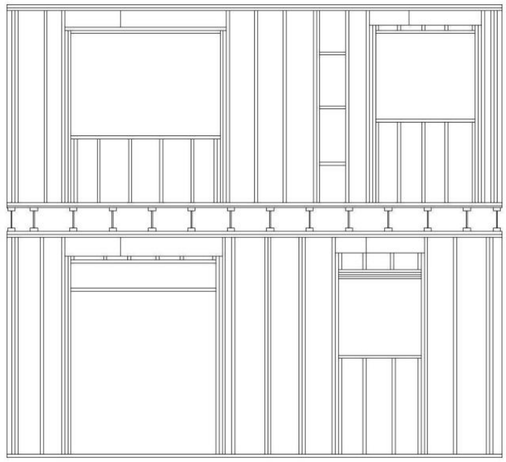
The first and the second floors for semi-detached house (SDH1) with the as- built studs



Semi-detached house SDH1 front (extended) elevation with the as-built studs



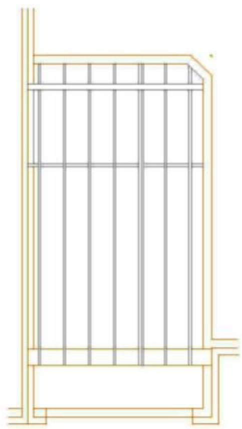
Semi-detached house SDH1 east-side elevation with the as-built studs



Semi- house SDH1 back-side (north) elevation with the as- built studs

SDH 1			
	Wood area m^2	Wall area m^2	Framing factor
Front	56	16.7	30.0%
Side/east	N/A	N/A	N/A
Back	37.4	13.3	35.4%
Side/ west	79.1	27.1	34.2%
total	172.5	57.1	33.1%

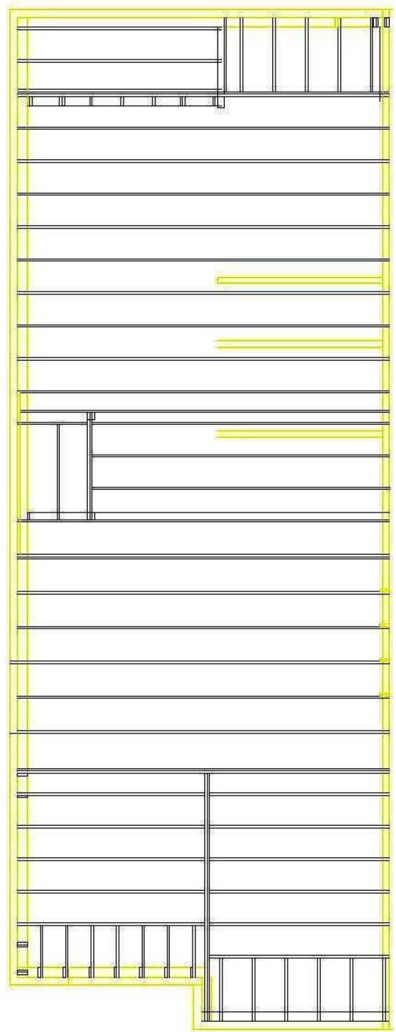
Semi- house SDH1 summary of wall framing factor calculations



Semi-detached house SDH1heat loss floor plan –floor above parking garage.

Floor area m^2	**Framing area m^2**	**floor framing factor %**
15.9	**2.14**	**13.4%**

The areas of the floor and the framing and the total framing factor

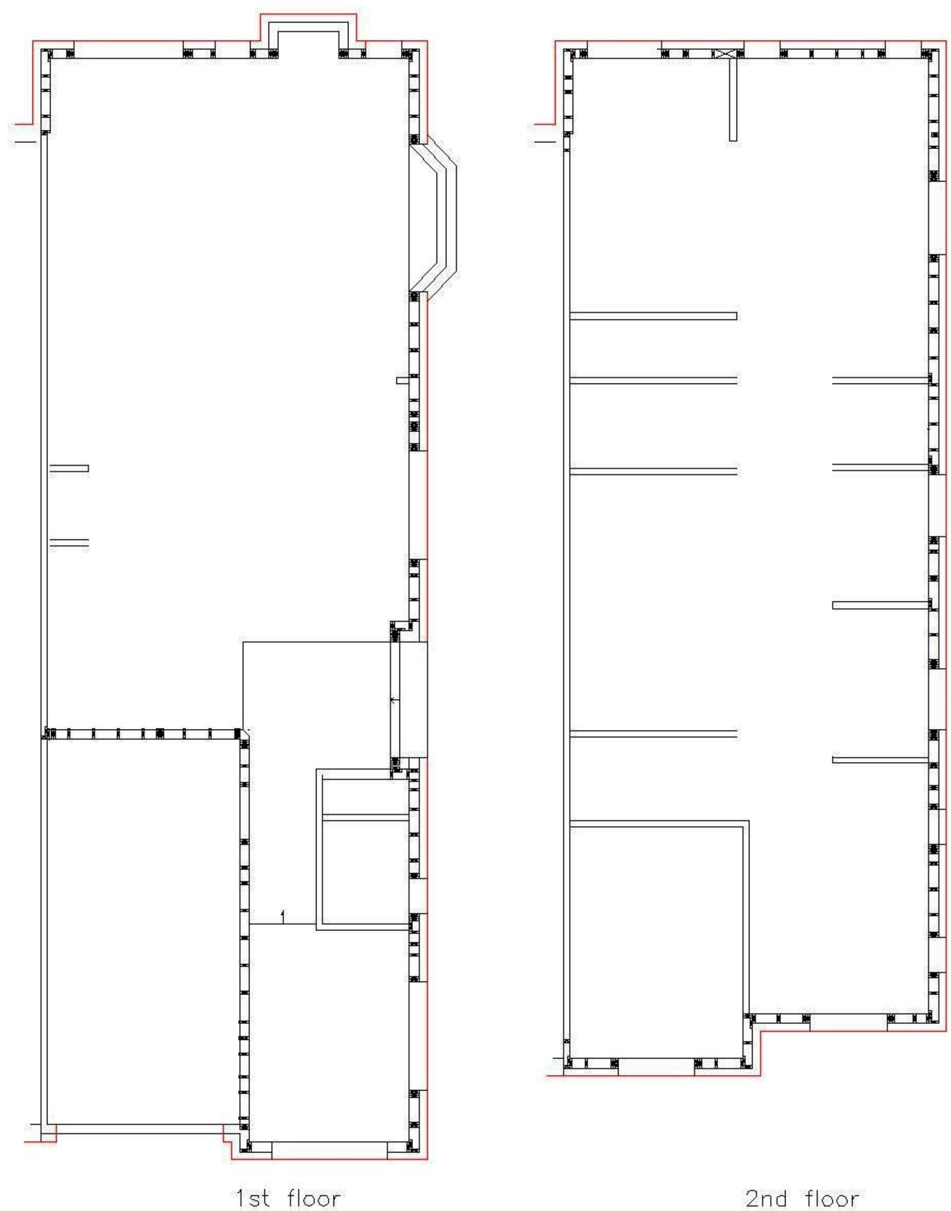


Detached house SDH1 framing plan for the ceiling

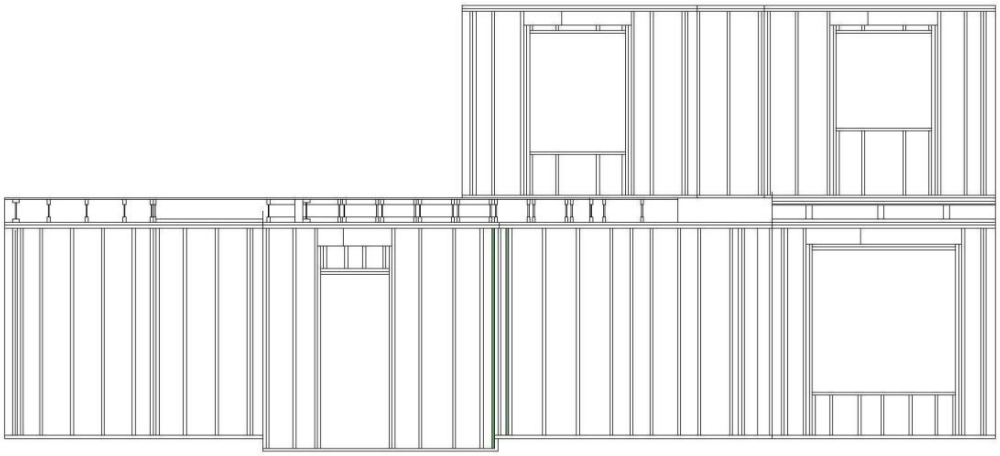
Ceiling area m^2	Framing area m^2	Ceiling framing factor %
99.3	9.4	9.5%

The areas of the ceiling and the framing and the ceiling framing factor

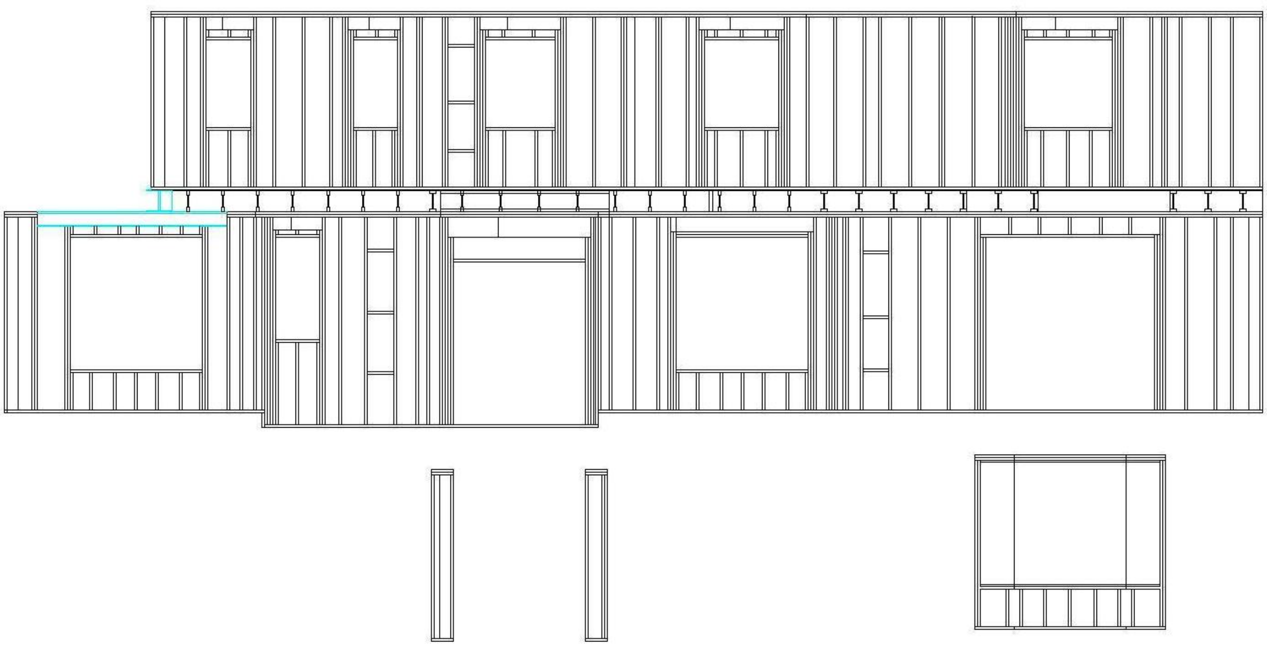
__Semi-detached house 2/ SDH 2__



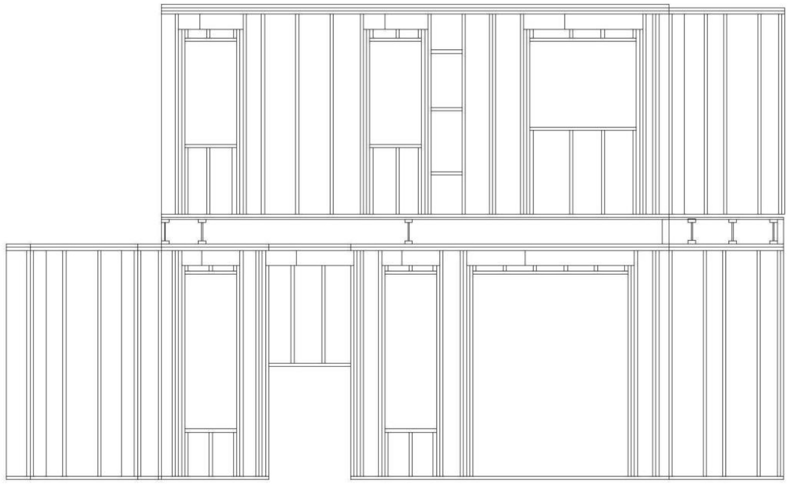
The first and the second floors for semi-detached house (SDH2) with the as- built studs



Semi-detached house SDH2 front (extended) elevation with the as-built studs



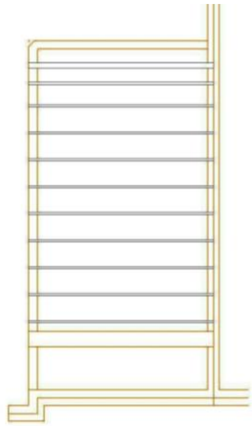
Semi-detached house SDH2 east-side elevation with the as-built studs



Semi- house SDH2 back-side (north) elevation with the as- built studs

SDH 2			
	Wood area m^2	**Wall area m^2**	**Framing factor**
Front	45.2	14.2	31.4%
Side/east	88.6	23.0	26.0%
Back	23.5	9.2	39.0%
Side/ west	N/A	N/A	N/A
total	157.4	46.4	29.5%

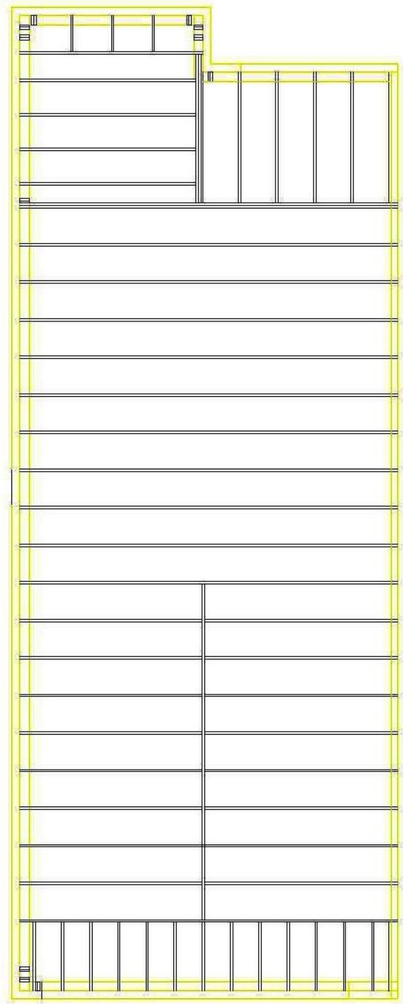
Semi- house DH2 summary of wall framing factor calculations



Detached house DH2 heat loss floor plan –floor above parking garage.

Floor area m^2	**Framing area m^2**	**floor framing factor %**
16.46	**1.95**	**11.9**

The areas of the floor and the framing and the total framing factor

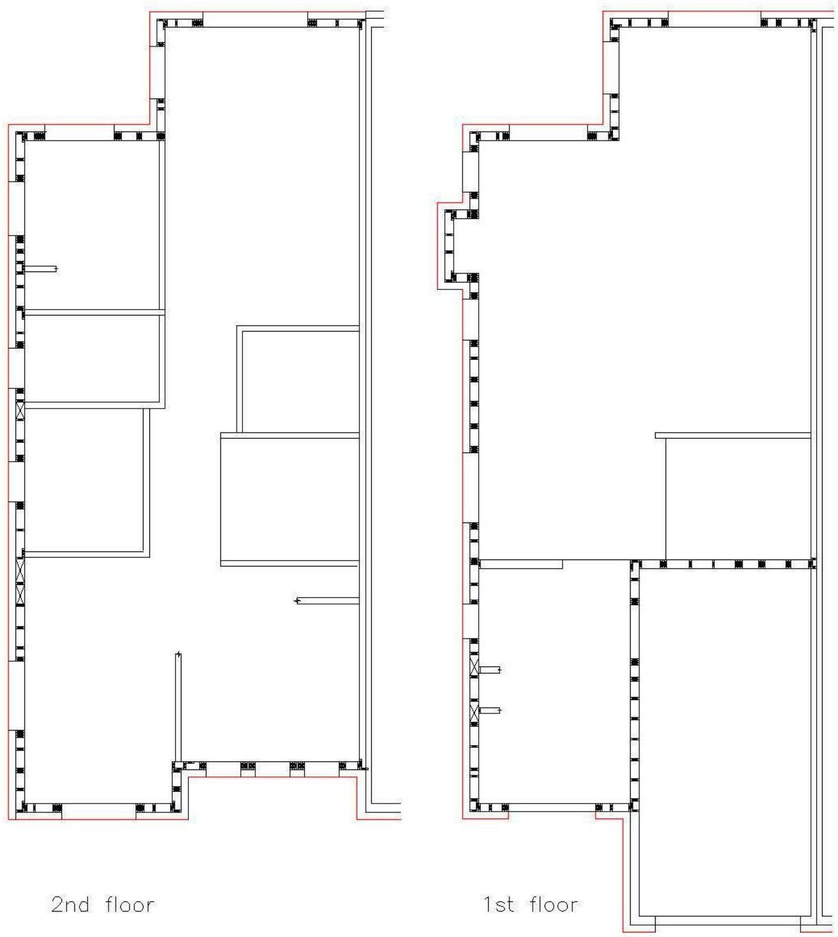


Detached house SDH2 framing plan for the ceiling

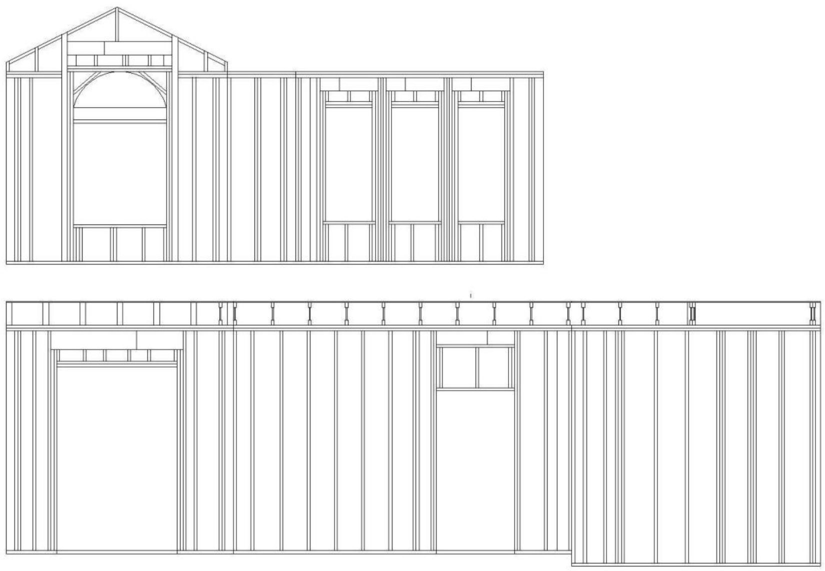
Ceiling area m^2	Framing area m^2	Ceiling framing factor %
94.02	7.44	8%

The areas of the ceiling and the framing and the ceiling framing factor

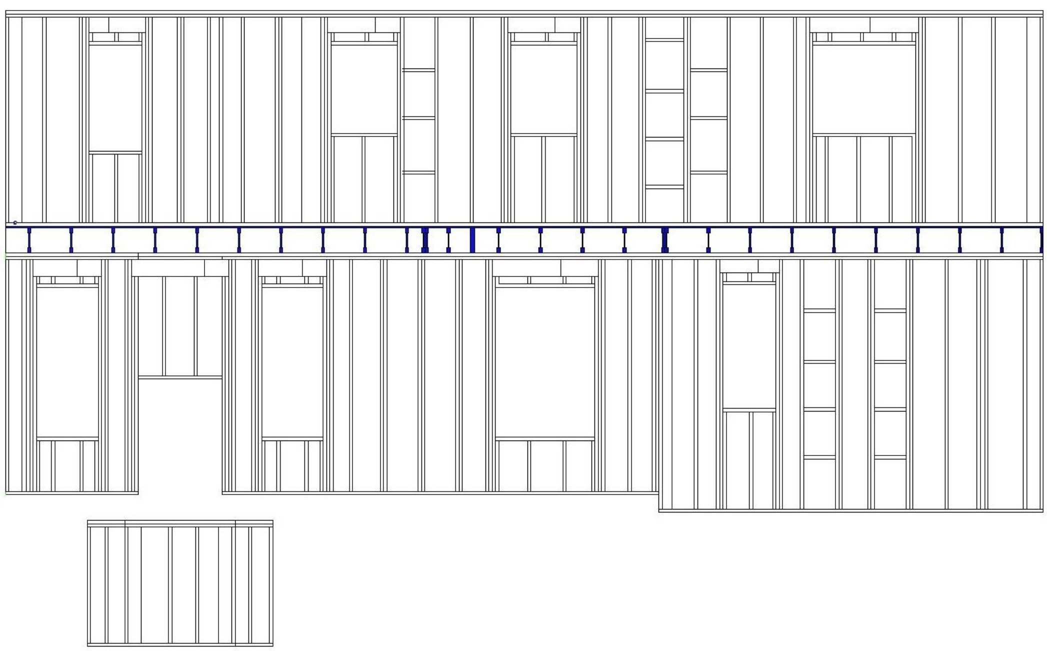
Semi-detached house 3/ SDH 3



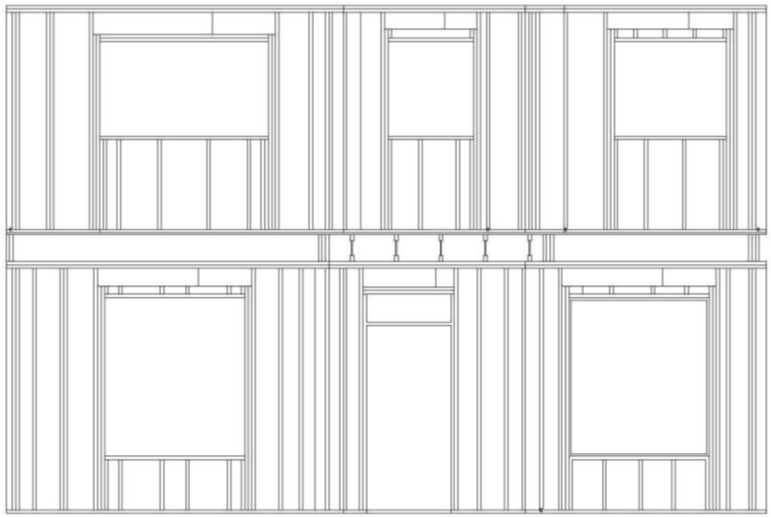
The first and the second floors for semi-detached house (SDH3) with the as- built studs



Semi-detached house SDH3 front (extended) elevation with the as-built studs



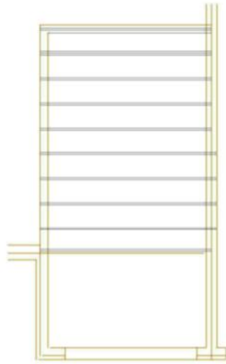
Semi-detached house SDH3 east-side elevation with the as-built studs



Semi- house SDH3 back-side (north) elevation with the as- built studs

SDH 3			
	Wood area m^2	**Wall area m^2**	**Framing factor**
Front	34.0	14.1	32.9%
Side/east	36.2	17.6	27.8%
Back	34.5	12.0	34.7%
Side/ west	N/A	N/A	N/A
total	140.7	43.8	31.1%

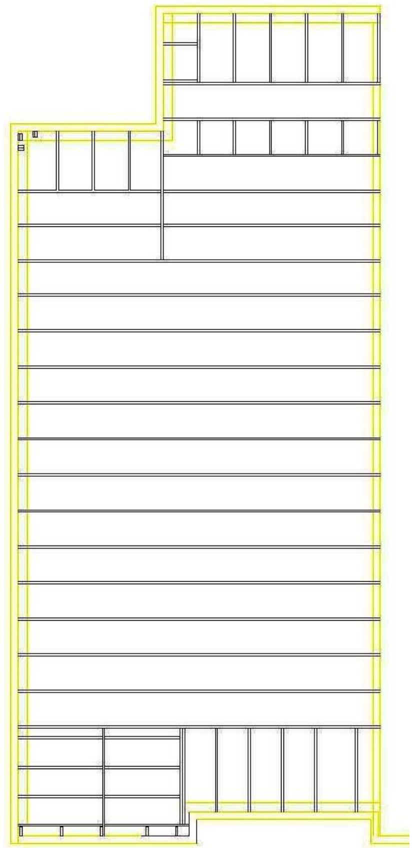
Semi- house SDH3 summary of wall framing factor calculations



Detached house SDH3 heat loss floor plan –floor above parking garage.

Floor area m^2	**Framing area m^2**	**floor framing factor %**
13.02	1.4	10.7%

The areas of the floor and the framing and the total framing factor

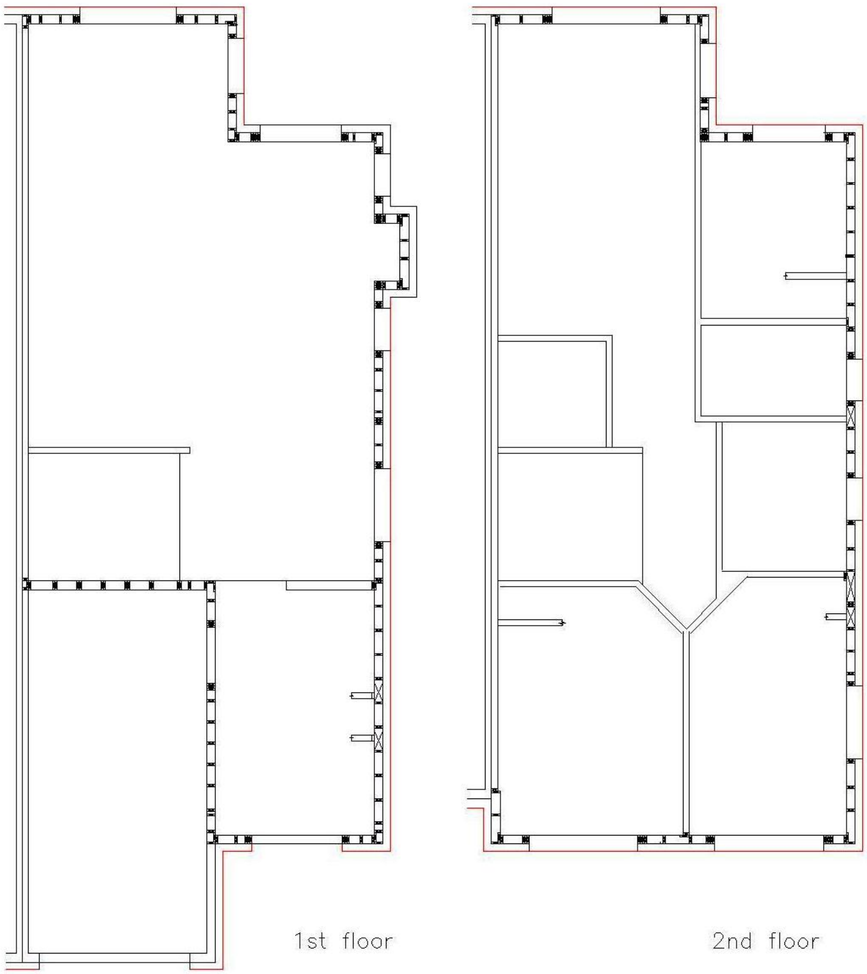


Detached house SDH3 framing plan for the ceiling

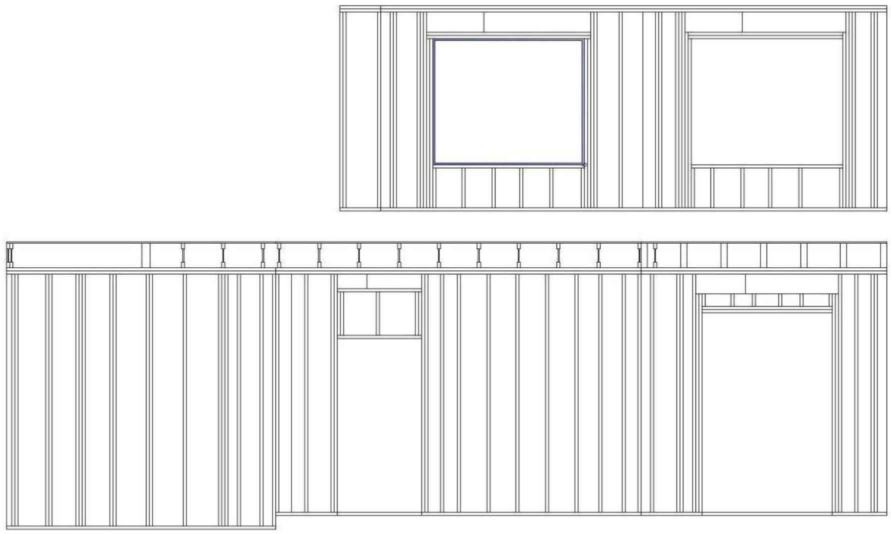
Ceiling area m^2	**Framing area m^2**	**Ceiling framing factor %**
80.4	**5.7**	**7.1%**

The areas of the ceiling and the framing and the ceiling framing factor

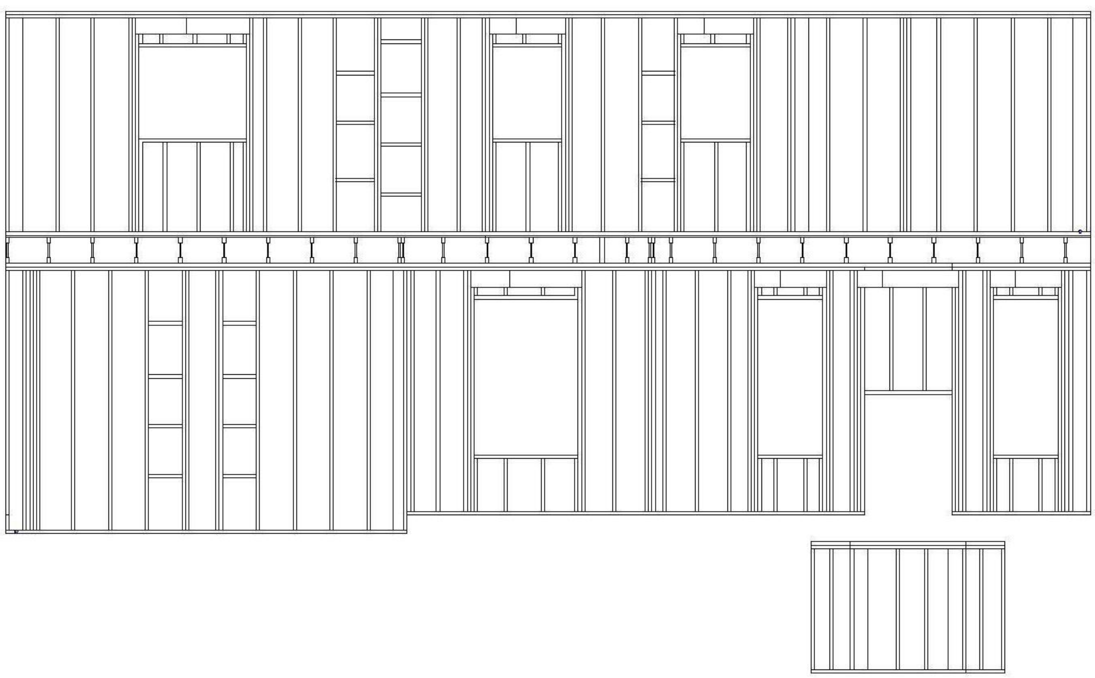
Semi- detached house 4/ SDH 4



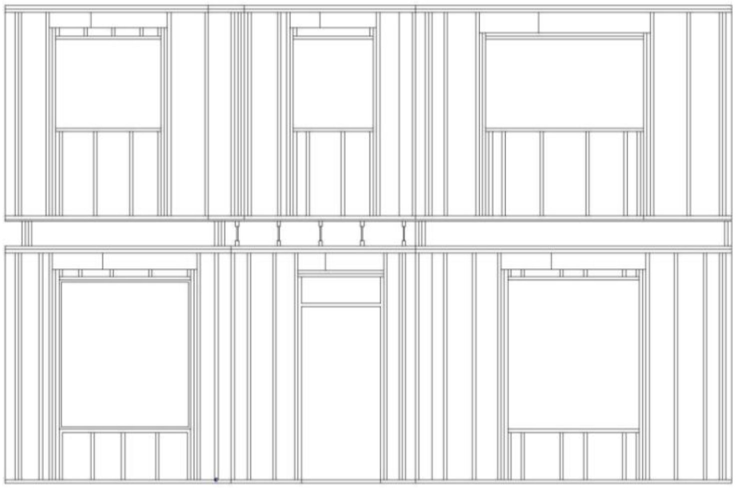
The first and the second floors for semi-detached house (SDH6) with the as- built studs



Semi-detached house SDH4front (extended) elevation with the as-built studs



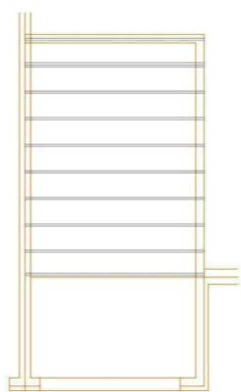
Semi-detached house DH6 east-side elevation with the as-built studs



Semi- house DH4 back-side (north) elevation with the as- built studs

SDH 4			
	Wood area m²	**Wall area m²**	**Framing factor**
Front	40.8	13.3	32.6%
Side/east	64.8	17.0	26.3%
Back	35.1	21.2	34.7%
Side/ west	N/A	N/A	N/A
total	140.6	42.5	30.2%

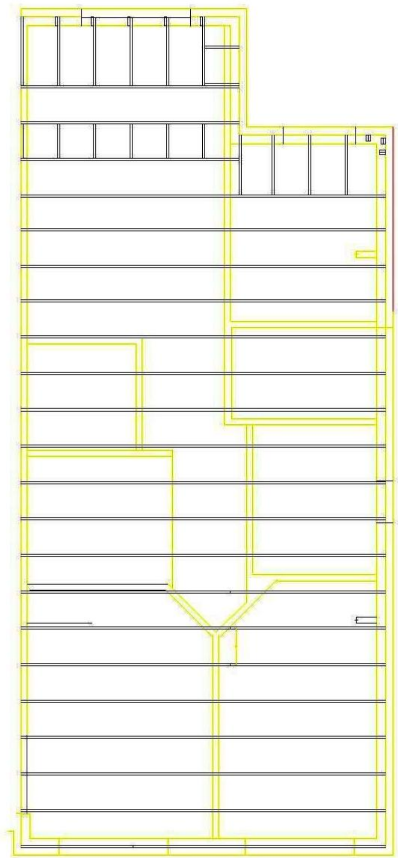
Semi- house DH4 summary of wall framing factor calculations



Detached house SDH4 heat loss floor plan –floor above parking garage.

Floor area m²	**Framing area m²**	**floor framing factor %**
13.95	1.33	9.5%

The areas of the floor and the framing and the total framing factor

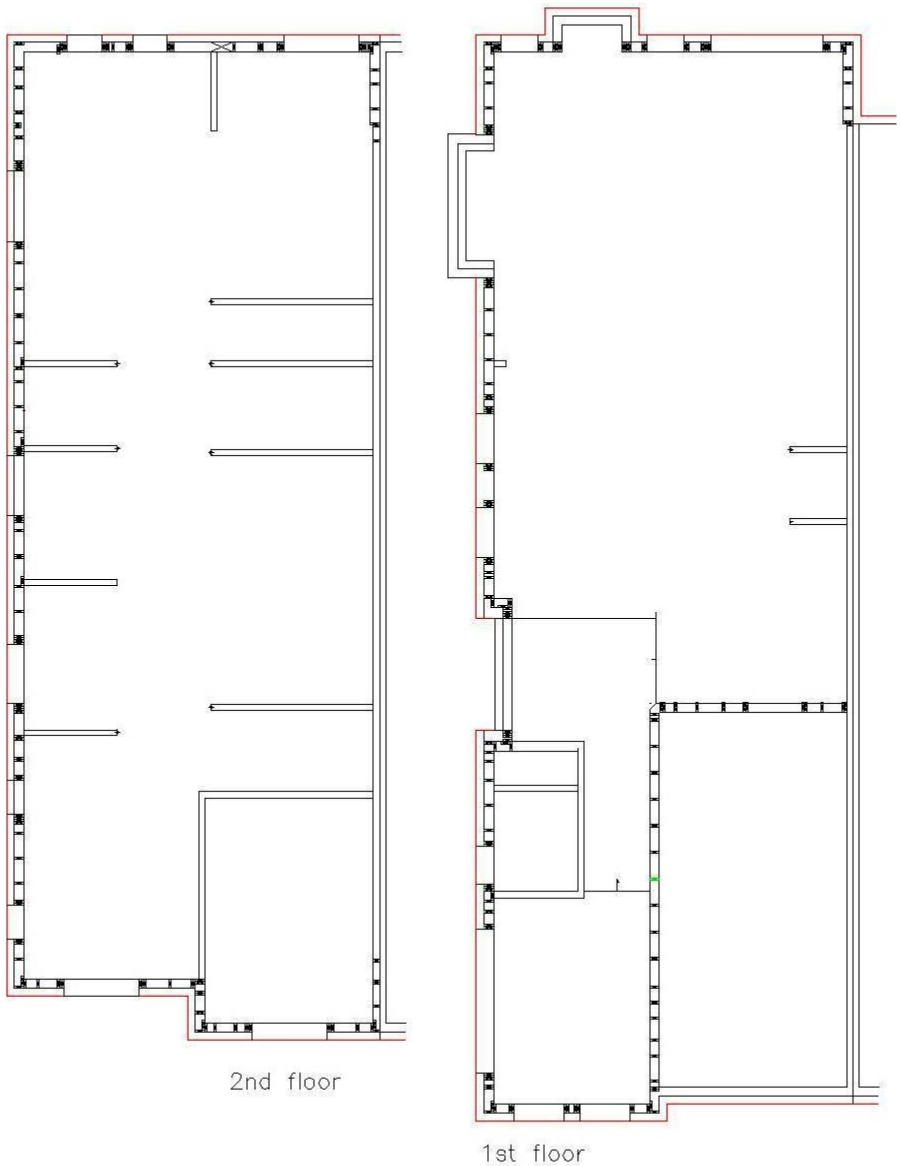


Detached house SDH4framing plan for the ceiling

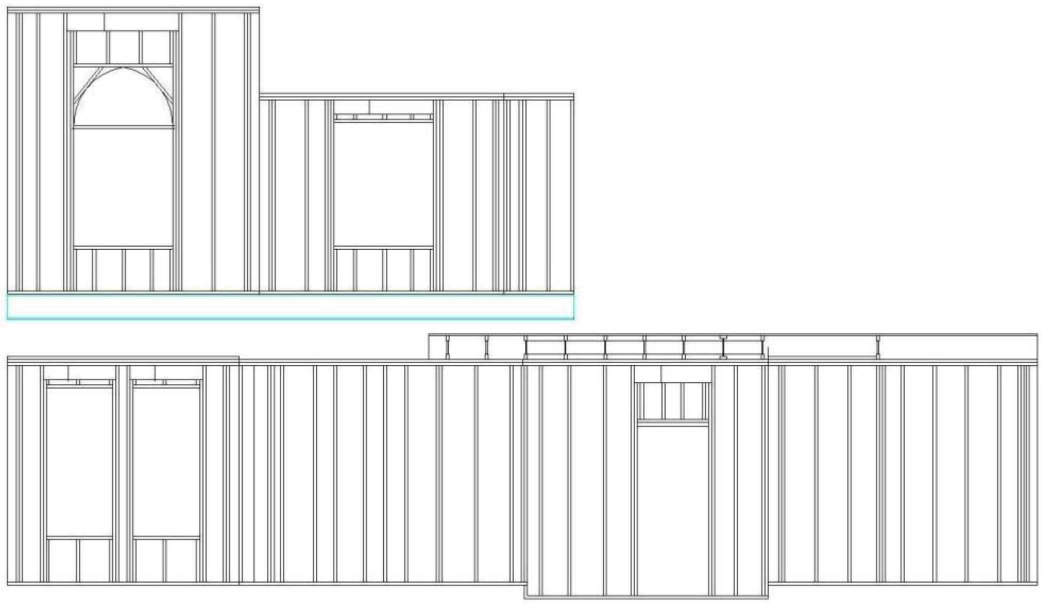
Ceiling area m^2	Framing area m^2	Ceiling framing factor %
79.05	**5.86**	**7.4%**

The areas of the ceiling and the framing and the ceiling framing factor

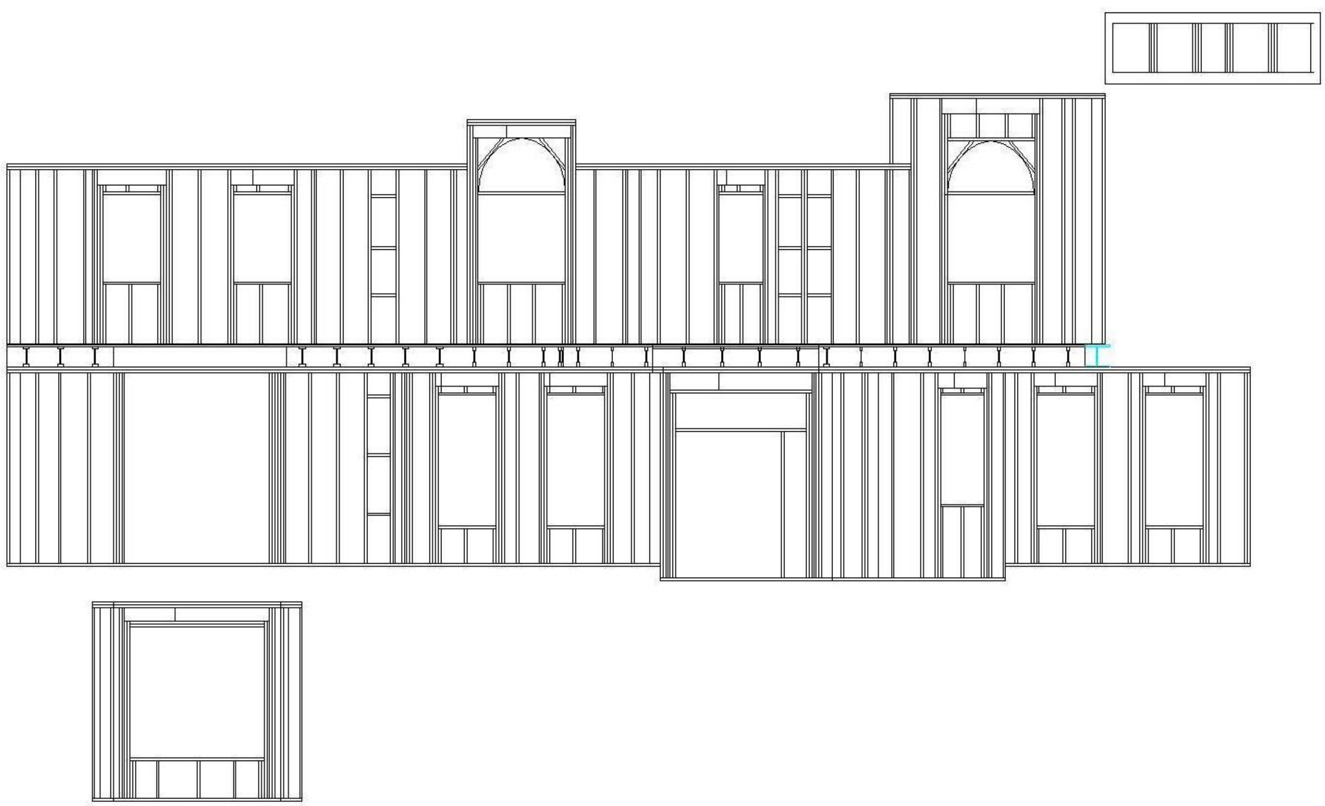
Semi-detached house /SDH 5



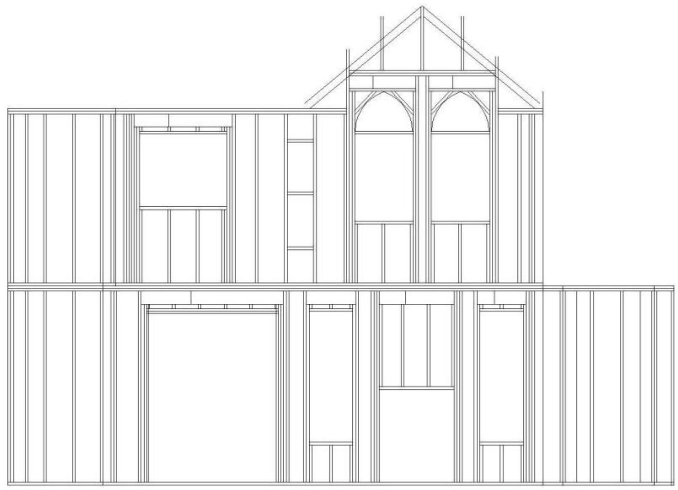
The first and the second floors for semi-detached house (SDH5) with the as- built studs



Semi-detached house SDH5 front (extended) elevation with the as-built studs

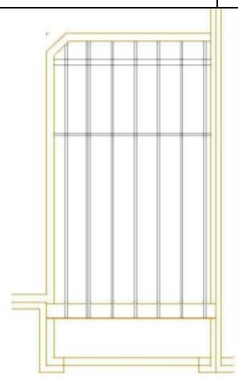


Semi-detached house SDH5 west-side elevation with the as-built studs



Semi- house SDH5 back-side (north) elevation with the as- built studs

TH5			
	Wood area m^2	**Wall area m^2**	**Framing factor**
Front	42.6	13.5	31.8%
Side/east	N/A	N/A	N/A
Back	77.3	20.6	26.6%
Side/ west	25.1	9.0	35.9%
TOTAL	120.1	43.1	36.0%

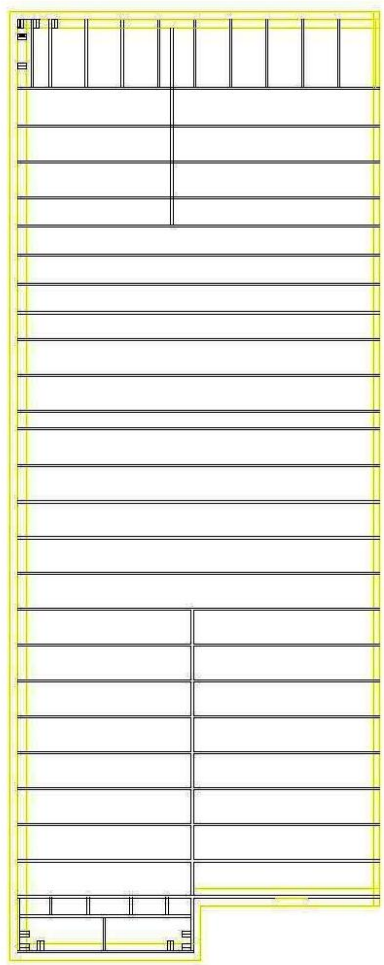


Semi- house/ SDH5 summary of wall framing factor calculations

Detached house SDH5 heat loss floor plan –floor above parking garage.

Floor area m^2	**Framing area m^2**	**floor framing factor %**
19.84	2.4	12.1%

The areas of the floor and the framing and the total framing factor

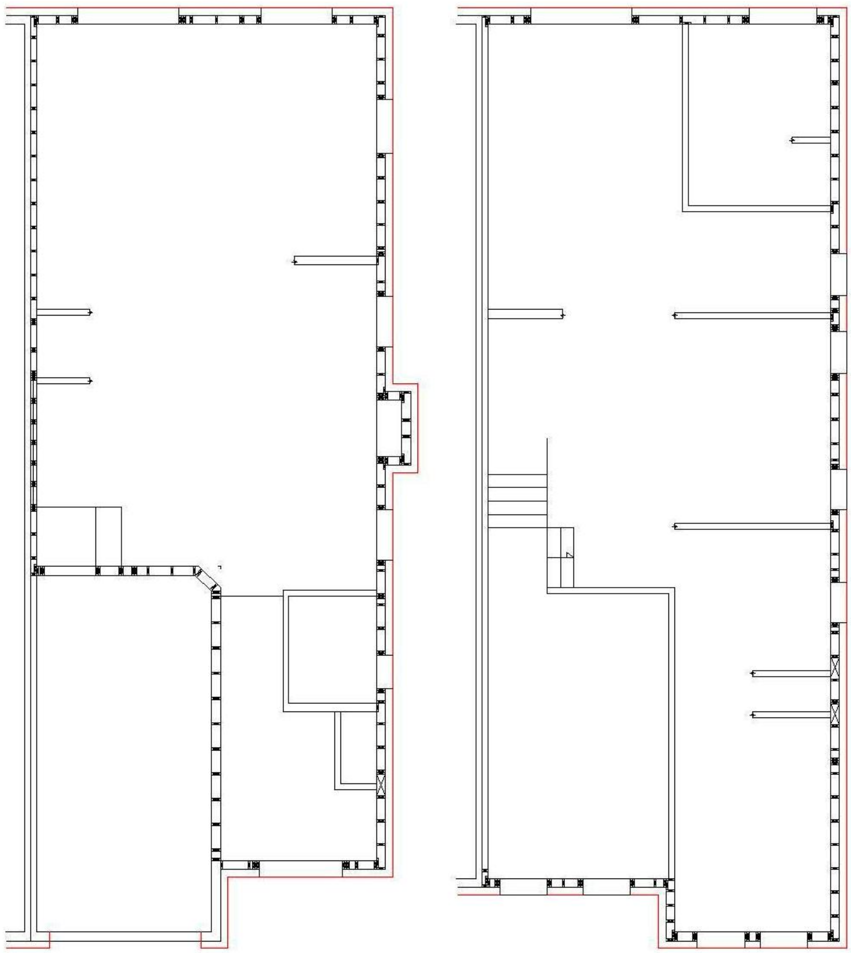


Detached house SDH5 framing plan for the ceiling

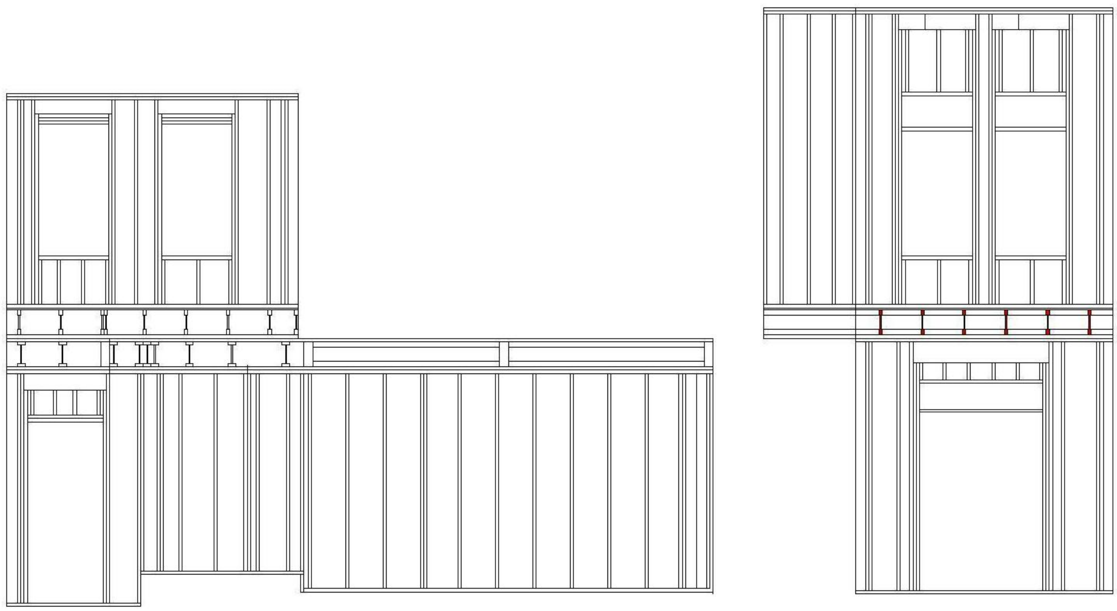
Ceiling area m^2	Framing area m^2	Ceiling framing factor %
94	**7.1**	**7.6%**

The areas of the ceiling and the framing and the ceiling framing factor

Semi-detached house/ SDH 6

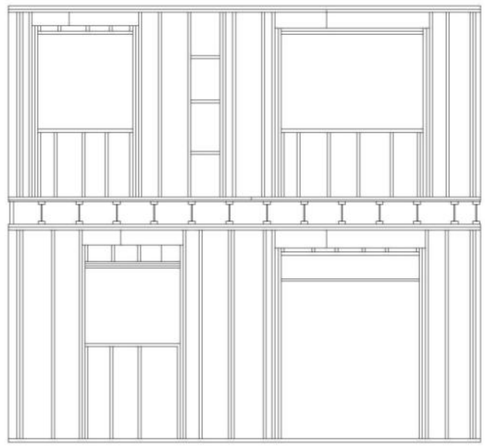


The first and the second floors for semi-detached house (SDH6) with the as- built studs



Semi-detached house SDH6 front (extended) elevation with the as-built studs

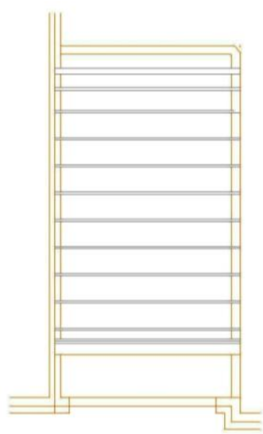
Semi-detached house DH6 east-side elevation with the as-built studs



Semi- house DH6 back-side (north) elevation with the as- built studs

TH6			
	Wood area m^2	**Wall area m^2**	**Framing factor**
Front	43.4	14	32.1%
Side/east	71.5	24.6	34.5%
Back	35.6	11.6	32.6%
Side/ west	N/A	N/A	N/A
Total	150.7	50.2	33.3%

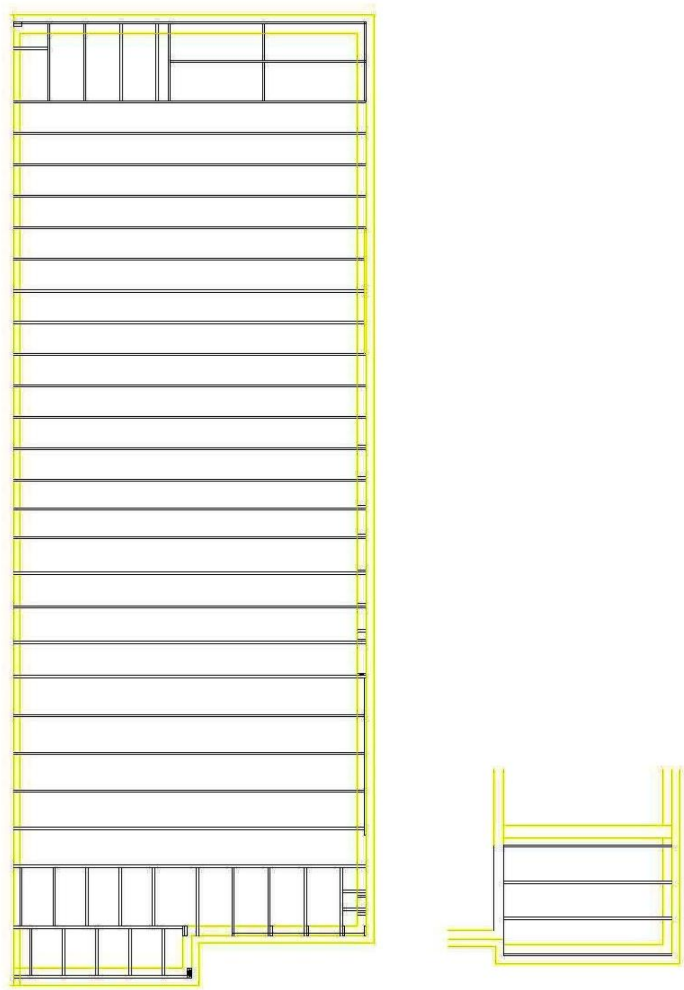
Semi- house DH6 summary of wall framing factor calculations



Detached house SDH5 heat loss floor plan –floor above parking garage.

Floor area m^2	**Framing area m^2**	**floor framing factor %**
15.8	1.82	11.5%

The areas of the floor and the framing and the total framing factor

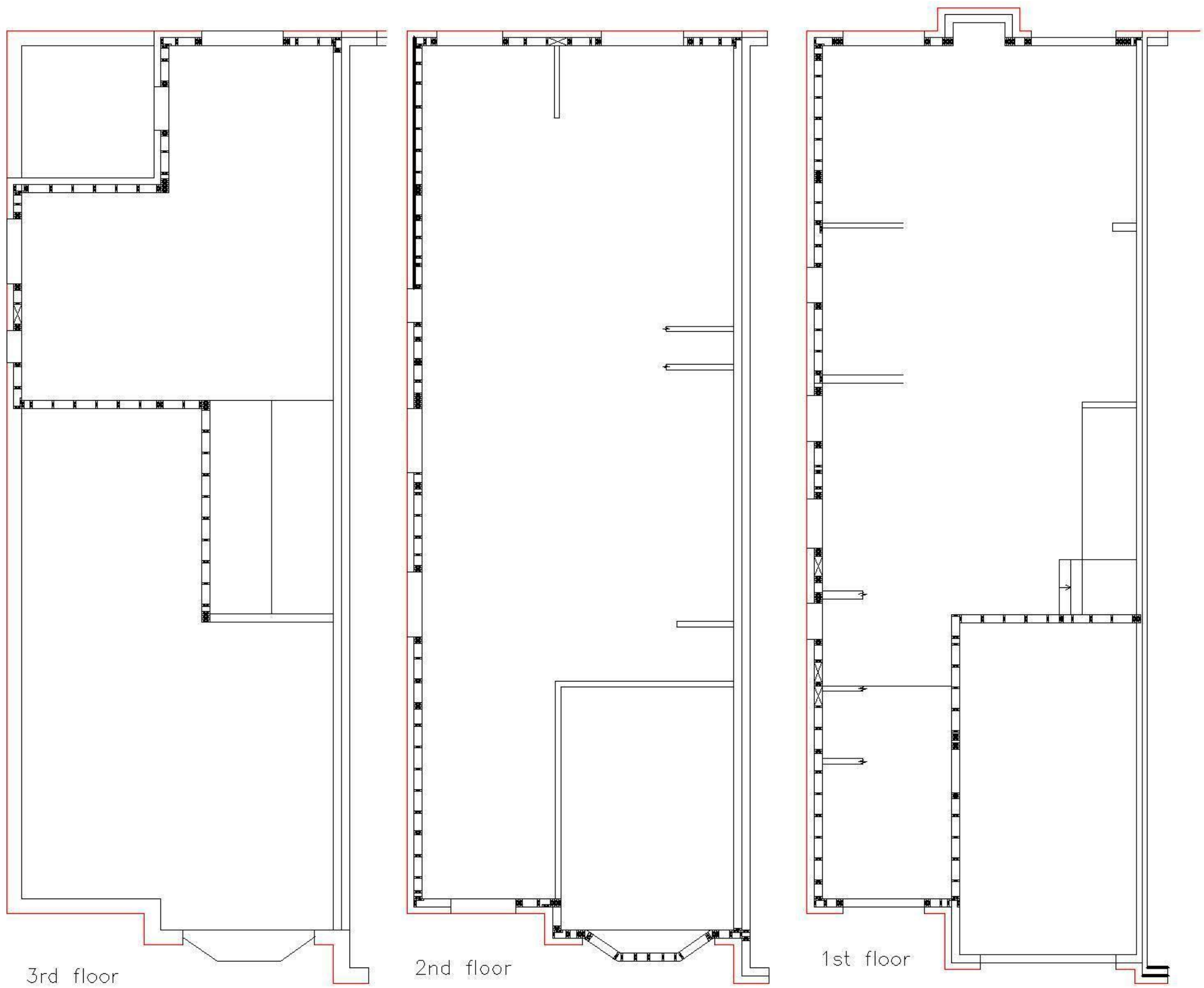


Detached house SDH6 framing plan for the ceiling

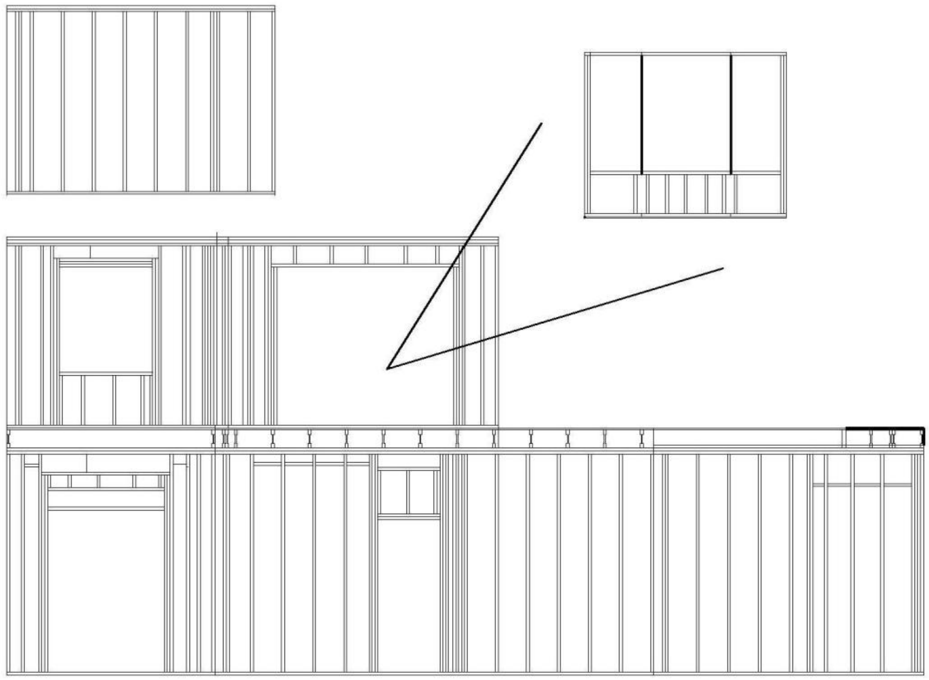
Ceiling area m^2	Framing area m^2	Ceiling framing factor %
99.02	**7.85**	**8%**

The areas of the ceiling and the framing and the ceiling framing factor

Semi-detached house /SDH 7

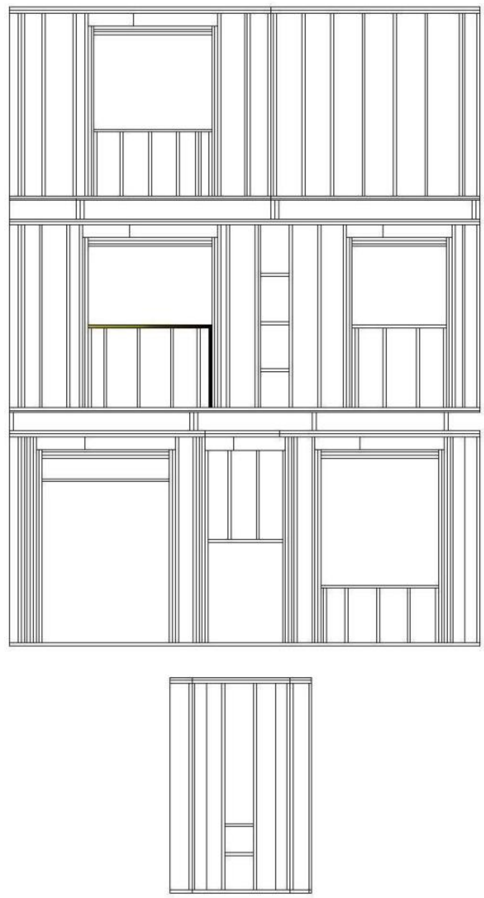


The first, the second, and third floors for semi-detached house (SDH7) with the as- built studs



Semi-detached house SDH7 front (extended) elevation with the as-built studs

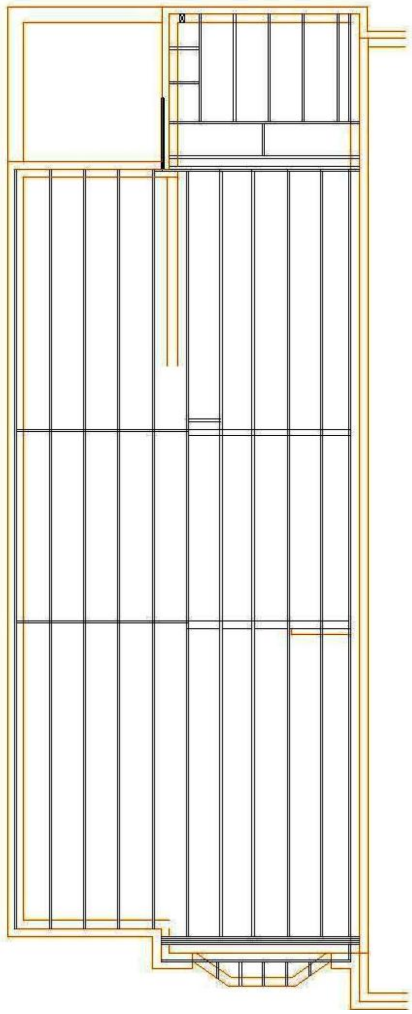
Semi-detached house DH7 east-side elevation with the as-built studs



Semi- detached house SDH7 back-side (north) elevation with the as- built studs

SDH 7			
	Wood area m^2	**Wall area m^2**	**Framing factor**
Front	54.1	16.5	30.4%
Side/east	N/A	N/A	N/A
Back	39.1	14.3	36.6%
Side/ west	102.2	28.6	28.0%
total	195.5	59.4	30.4%

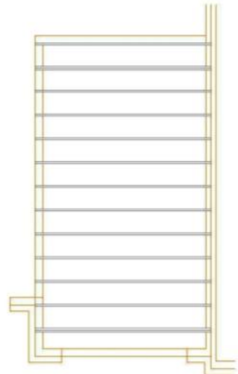
Semi- detached house SDH7 summary of wall framing factor calculations



Semi-detached house SDH7 framing plan for the ceiling

Ceiling area m^2	**Framing area m^2**	**Ceiling framing factor %**
94.8	7.53	8%

The areas of the ceiling and the framing and the ceiling framing factor

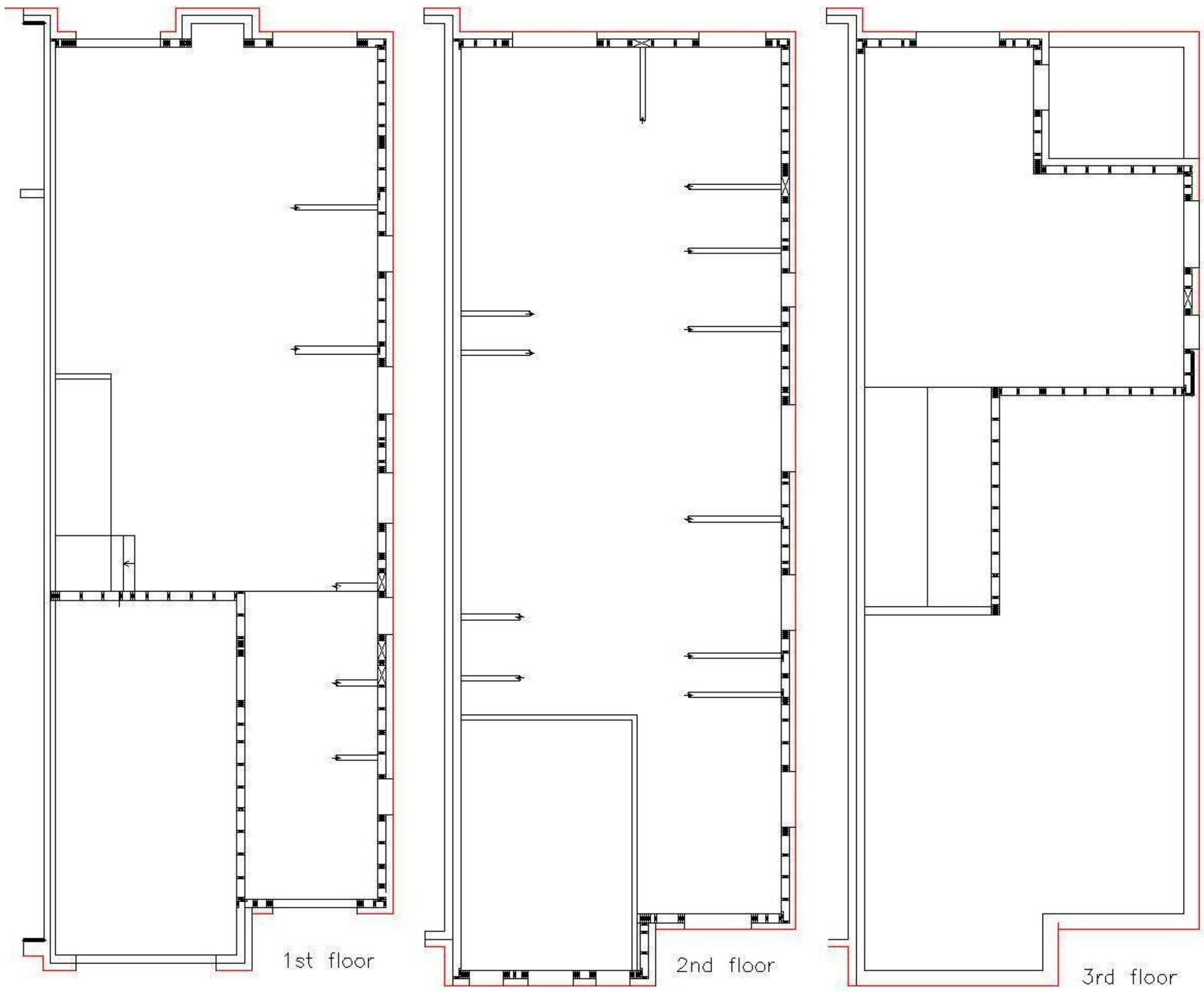


Semi-detached house SDH7 heat loss floor plan –floor above parking garage.

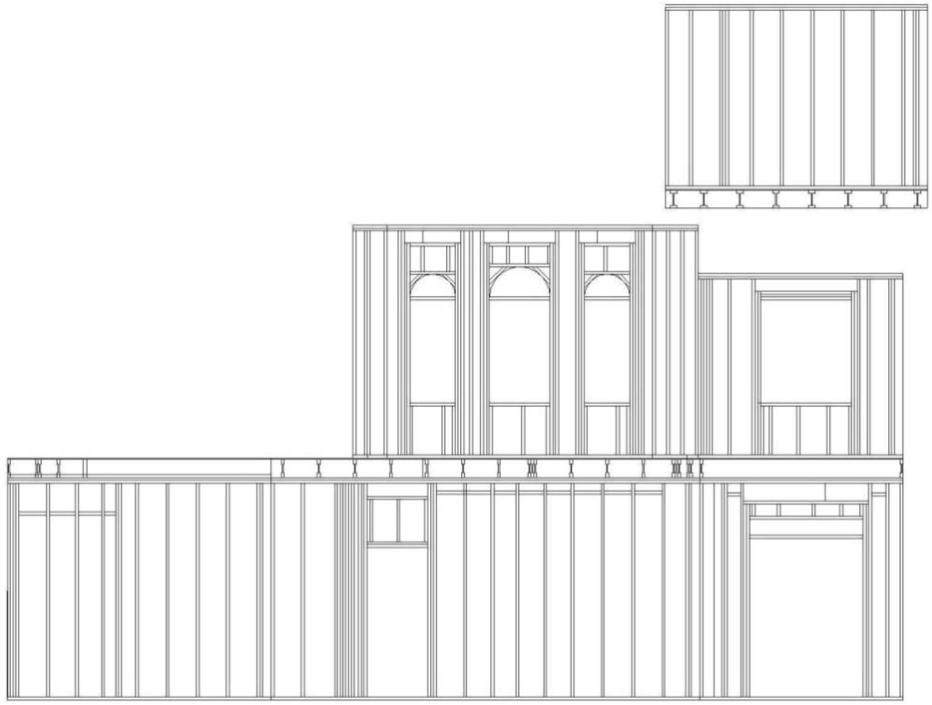
Floor area m^2	Framing area m^2	floor framing factor %
22.25	**2.05**	**9.2%**

The areas of the floor and the framing and the total framing factor

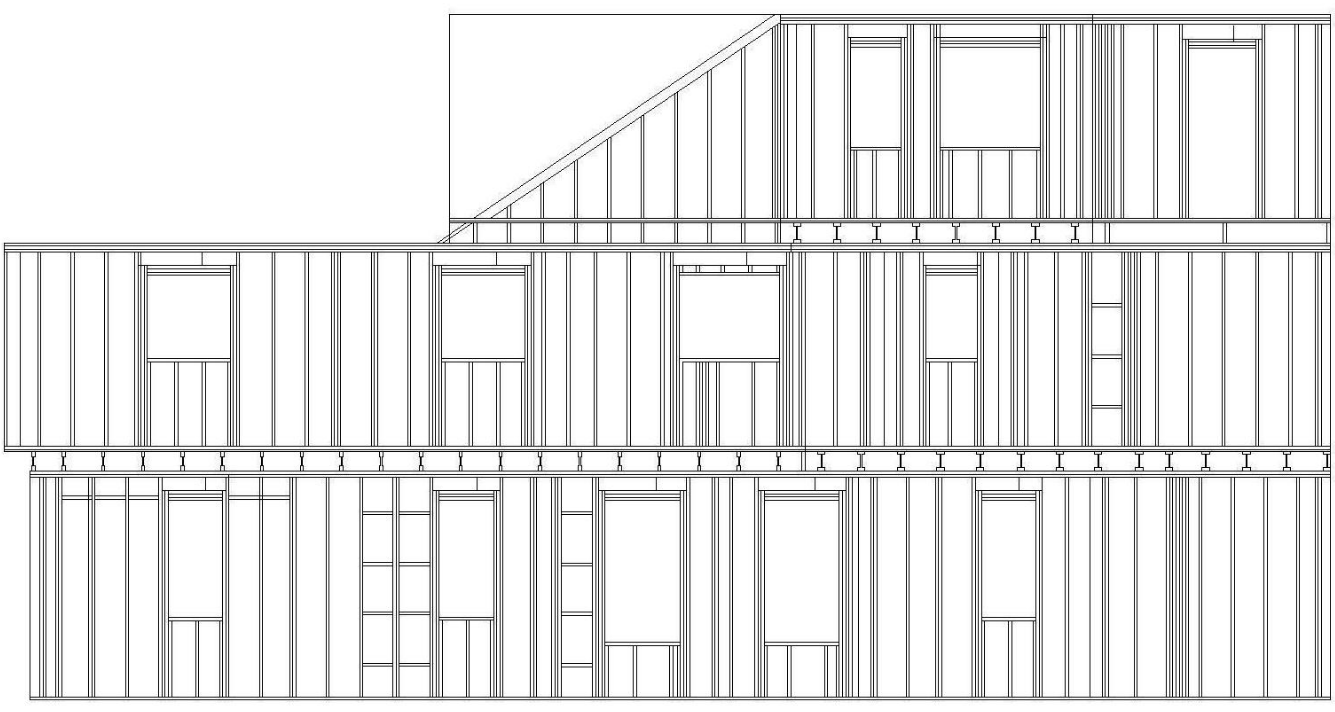
Semi-detached house /SDH 8



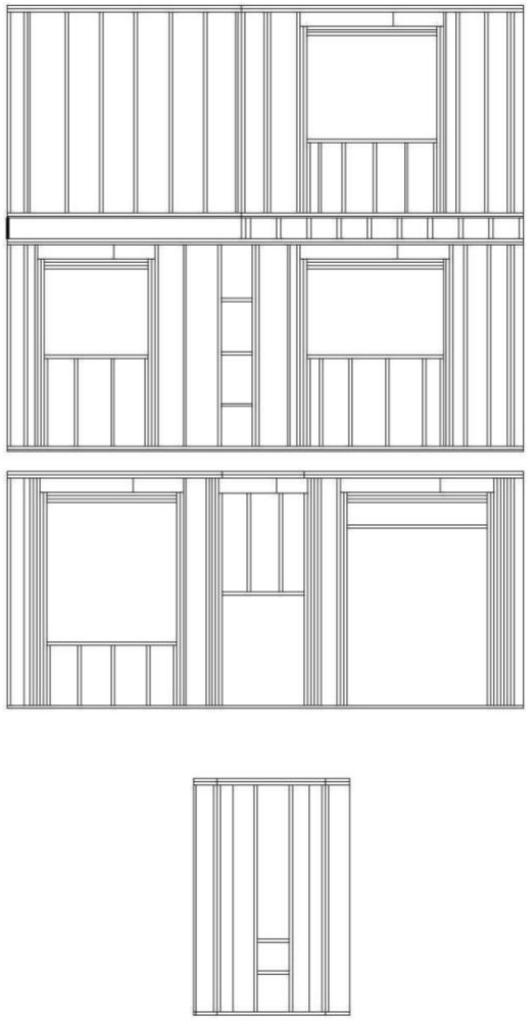
The first, the second, and the third floors for semi-detached house (SDH8) with the as- built studs



Semi-detached house SDH8 front (extended) elevation with the as-built studs



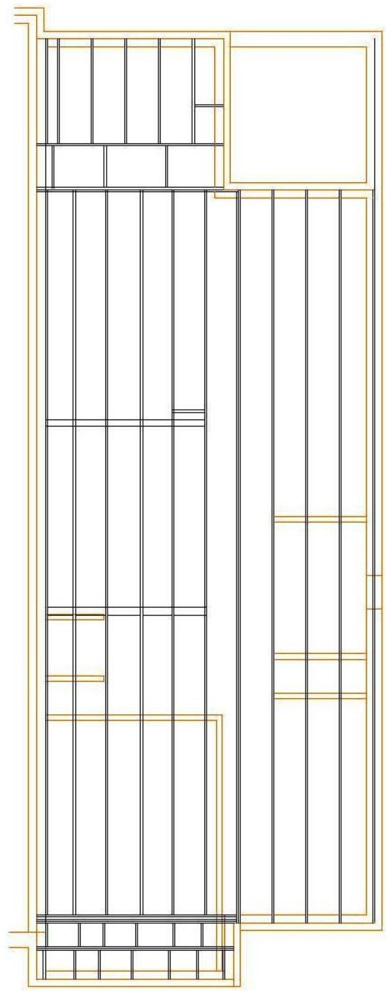
Semi-detached house DH8 east-side elevation with the as-built studs



Semi-detached house DH8 back-side (north) elevation with the as- built studs

SDH 8			
	Wood area m²	**Wall area m²**	**Framing factor**
Front	59.5	18.5	31.1%
Side/east	103	29.7	28.8%
Back	39.4	14.6	37.1%
Side/ west	N/A	N/A	N/A
total	201.8	62.8	31.1%

Semi-detached house DH8 summary of wall framing factor calculations



Semi-detached house SDH8 framing plan for the ceiling

Ceiling area m^2	Framing area m^2	Ceiling framing factor %
94.6	7.8	8.3%

The areas of the ceiling and the framing and the ceiling framing factor

Semi-detached house SDH8 heat loss floor plan –floor above parking garage.

Floor area m^2	Framing area m^2	floor framing factor %
24.1	**3**	**12.5%**

The areas of the floor and the framing and the total framing factor