

# Investigation of the Thermal Performance of Steel and Wood Framed Homes Using Infrared Thermography

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## 1 INTRODUCTION

The structural integrity and overall quality of Lightgauge Steel Framing (LSF) is well recognized amongst designers and builders in the residential construction industry as a superior building material. LSF is specified in an increasingly larger percentage of new housing starts especially where seismic and high wind loading are a consideration. It is also becoming the material of choice for consumers in the move-up or custom home market. The higher quality and dimensional stability is responsible for eliminating virtually all nailpops, squeaky floors and sticky doors and windows. The environmental benefits of LSF are also significant. Among these are the fact that steel is inert and will not contribute to poor indoor air quality, it can be manufactured using 100% scrap steel, is 100% recyclable without material property degradation and does not contribute fuel to a fire.

Based on engineering principles and performance history, it can be plainly stated that the structural integrity of steel framed homes is superior to their counterparts framed with conventional materials. There remain, however, a few issues for which little published data or performance history exists. These items are sometimes raised by home builders and municipal building officials. One of these issues is the thermal performance of lightgauge steel framed homes.

This paper will demonstrate, with the use of infrared thermography, computer modeling and actual energy consumption data, that the thermal performance of steel framed homes is as effective as similarly built homes using traditional framing materials.

## 2 THE MYTHS ABOUT THERMAL CONDUCTIVITY AND THERMAL PERFORMANCE OF LIGHTGAUGE STEEL FRAMING

### 2.1 Thermal Conductivity and Thermal Resistance

Information contained in various publications state superficially and infer that the thermal performance of LSF homes will be inherently poor because of the high conductivity of this material. The inference is that because the conductivity of steel ( $47 \text{ w/m}^\circ\text{C}$ )<sup>1</sup> is 400 times that of traditional framing materials (i.e. wood  $0.12 \text{ w/m}^\circ\text{C}$  at 19% moisture)<sup>2</sup>, the thermal performance of a building would be dramatically lower if the building is framed with steel. Since heating cost is directly related to thermal performance the suggestion is that the difference in heating costs would be of the same proportions as the differences in conductivity.

These references fail to recognize that thermal conductivity is a material property and it is only one of several factors in determining thermal resistance of a building component. It should be emphasized that *resistivity* given by:

$$\text{Resistivity (d)}=R/A$$

where: R is the thermal resistance of a material  
A is the cross sectional area perpendicular to the heat flow

rather than resistance is a more meaningful indicator of thermal performance because heat flow is proportional to resistivity. Since steel framing members are dimensionally much thinner (up to 40 times thinner) than traditional framing members the reduced thickness increases the resistance to heat flow.

The challenge of further reducing the heat flow through steel framing members led to some innovative, thermally efficient, steel stud designs by Dofasco (see **Figure 1**). In the early 1980's Dofasco patented the thermal stud which utilized perforations in the web of the stud to increase the heat path length (see **Figure 2**). This design modification resulted in a 45% improvement in thermal resistance.<sup>2</sup>

## 2.2 Components and Assemblies

No one will argue that steel is more thermally conductive than some other building materials. However, the steel framing is only one of several components in a residential building assembly. The resistivity of each of these will contribute to the overall thermal resistance of the assembly in proportion to the area occupied by each material. In the case of lightgauge steel framed walls, the area occupied by the steel framing members is <0.5% because the thickness of these members is typically 0.9mm (0.036"). For assemblies framed with "2 by" material this value is 19%. Steel framing incorporates a rigid insulative sheathing on the exterior of the stud surface. This layer provides an effective thermal barrier to mitigate the effects of thermal bridging at the stud locations. Application of a rigid exterior sheathing is believed to be a good thermal detail for any light framed assembly.<sup>3</sup>

## 2.3 Calculating Thermal Resistance

The thermal resistance of the assembly is based on the individual contributions of each component within the assembly. The Model National Energy Code of Canada-1995 (MNEC-1995) allows this to be determined in one of three ways:

- i) Hand calculation
- ii) Computer modeling
- iii) Physical testing

These methods incorporate the effect of thermal bridging by the framing members. This is a more accurate representation of the actual thermal resistance of an assembly since a framing member bridging the interior and exterior surfaces will provide a path of lower resistance for heat flow than through the cavity which contains batt or cellulose insulation. This *effective R-value* is a better indicator of the thermal performance of an assembly.

**2.3.1 Calculation Method:** The current MNEC-1995 method for calculating the effective R-value depends on the framing material. For traditional solid wood framing, the calculation uses a simple parallel path method which combines the resistance through the framing member and the resistance through the spaces between the members in proportion to the area occupied by each component.

$$RSI_{PPM} = \frac{100}{\frac{\%area \text{ with framing}}{RSI_F} + \frac{\%area \text{ without framing}}{RSI_I}}$$

where:  $RSI_{PPM}$ = effective thermal resistance (by parallel path method)  
 $RSI_F$ = thermal resistance through framing  
 $RSI_I$ = thermal resistance through insulation

For steel framed assemblies, the R-value is calculated using the parallel path and isothermal planes methods with the accepted result lying approximately two-thirds of the way between the two (favouring the more conservative value given by the isothermal planes method).

$$RSI_{IPM} = (R_I - R_{IF}) + \frac{100}{\frac{\%area\ with\ framing}{RSI_F} + \frac{\%area\ without\ framing}{RSI_{IF}}}$$

where:  $RSI_{IPM}$ = effective thermal resistance (by isothermal planes method)  
 $RSI_I$ = thermal resistance through insulation  
 $RSI_{IF}$ = thermal resistance through insulation between framing  
 $RSI_F$ = thermal resistance through framing

Comparison to actual test data shows that the calculation method used for wood assemblies can over estimate the thermal performance of such assemblies while the method applied to steel assemblies consistently underestimates the results obtained by testing.<sup>4</sup>

ASHRAE suggests that the true thermal resistance of any assembly lies somewhere between the lower bound set by the Isothermal Planes Method and the upper bound set by the Parallel Path Method.<sup>5</sup> Several studies have attempted to identify what this ratio should be with the majority concluding that it should be the arithmetic mean of both methods regardless of the type of framing material.<sup>6,7,8</sup>

**2.3.2 Computer Modeling:** Enermodal Engineering developed the computer model FRAME which has been accepted by the MNEC for predicting the effective R-value for building assemblies. This is a two-dimensional finite volume heat transfer model that was initially developed for windows and doors and then later expanded to include walls. The model was verified against guarded hot box tests on full scale wall assemblies. The simulation produces temperature profiles and total heat flow across the face and through the thickness of the assembly along with the effective thermal resistance results.

The capability of combining the individual assemblies to obtain an overall value, one which would represent an effective R-value for the whole system, needs to be developed.

**2.3.3 Physical Testing:** When the appropriate facilities are available, the preferred method of determining an effective R-value for a building assembly is by physical testing. This method is limited by the resources available as there are many common building assemblies, and testing each one would be a rather large undertaking. Physical testing in a controlled environment, is perhaps the best method of determining the thermal performance of a system because it incorporates the effects of combining the various assemblies, details and connections found in a building. In the meantime, predictive methods remain the most practical and can be supplemented by field data from studies on fully built homes.

### 3 THERMAL MEASUREMENTS, MODELING AND ANALYSIS

#### 3.1 Infrared Thermography

Infrared thermography is used at Dofasco as a research and investigative tool to monitor the temperature of steel product or steel processing equipment. Infrared cameras are fixed in position to monitor the thermal processing of steel and form part of the quality control that has earned Dofasco QS-9000 certification.

The infrared camera used at Dofasco for research purposes, is a hand held AGEMA Thermovision 470 and is operated by an infrared thermography specialist, specifically trained in the science. This tool and operator assisted in the infrared inspection of several homes in the Toronto area.

## 3.2 Thermal Imaging

A field study of seven steel and wood framed homes was performed to determine their thermal performance relative to one another. The subject homes were in Toronto, Canada (average degree days below 18°C=4000) and monitoring took place in February of 1997. The steel framed homes were selected so that a comparable model in wood framing was available in close proximity, in most cases on the same street with the same orientation. **Table 1** summarises the types of homes included in this study along with a description of the wall assembly and estimated effective R-value.

For this portion of the study, the AGEMA Thermovision 470 infrared camera was used to record infrared (IR) images from the interior surfaces of outside walls of the homes. Thermal images were recorded on opaque wall surfaces, at lintels over wall openings, attic ceiling to wall connections, at the location of multiple members and at the floor to sill plate connection. These were identified as the points where the effects of the framing on heat transfer would be most prevalent. Any anomalies such as missing or damp insulation, were also noted. Recorded infrared images were then analyzed with IRWin which converted the IR information to temperature readings.

All the homes examined were occupied and although relatively new, the homes had weathered at least two winter seasons. Included are R-2000 homes built using wood framing and steel framing by Fifthshire Homes Ltd. Inspection of the homes took place in the evening without influence of solar gain. Several hours prior to beginning the inspection, the thermostats in the homes were set at 20°C. At least one steel home and its wood counterpart were inspected on the same evening in order to maintain consistency in the outside temperatures and wind effects during the inspections. For this study the outside temperatures ranged from -6 °C to -12 °C and no wind.

In this investigation, the temperature differentials were used to compare the heat transfer at different construction details against a control, usually a spot between the framing members away from wall openings. **Table 2** summarises these values for the different homes and various details. The infrared imaging revealed that the temperature differential at framing components in opaque walls, built-up members and sill connections was minor and they were comparable in both systems. The differences were also below the critical 3°C that is required to create the *ghosting* condition.<sup>9</sup> Ghosting is a condition where the framing components become noticeable as a result of airborne particles settling on the cooler surfaces of a wall. The severity depends on air borne particles such as dust and smoke, as well as time. In extreme conditions condensation can form on cooler surfaces, which would accelerate the appearance of ghosting.

IR imaging revealed some details in steel framing that perform significantly better than their wood counterparts. In particular the lintels above wall openings. Since this detail can be better insulated in the case of steel, there is less heat transfer through lintels in steel framed homes than in wood framed homes (see **Figure 3**). The average temperature differentials measured in this location were 5 times lower in steel than in wood.

Less can be said about the attic ceiling to wall connection. In the case of steel framing, infrared imaging shows localized temperature drops at the points where the steel truss or ceiling joist members meet in line with the wall framing member (see **Figure 4**). The temperature differentials measured however, were not sufficient to create conditions for ghosting. For wood roofs there is a lower temperature band that encircles the entire perimeter of the home (see **Figure 5**). This band is caused by the uninsulated top two wall plates to which the ceiling member is connected. Further study is required to understand the impact this detail has on overall thermal performance of the building.

Infrared imaging has demonstrated that similar performance with respect to heat transfer can be expected at the various framing components within opaque walls for both steel and wood framed homes. Lintels in steel framed homes will perform better because of the ability to incorporate a greater amount of insulation at this detail. The ceiling to wall connection requires further study to quantify its contribution. In addition the temperature differentials measured were not sufficient to create conditions for ghosting in either system.

### 3.3 Computer Modeling

The model FRAME is capable of analyzing a number of assembly configurations (eg. opaque walls, corners, sill plates). The simulations are performed by drawing a cross section of the specimen using a CAD interface and applying boundary conditions to the structure (see **Figure 6**). **Table 3** summarises the simulated effective R-values for a typical opaque wall assembly. The results show that the effective R-values are similar when framed in steel or wood. In other assemblies such as lintels over wall openings, the steel assembly has a higher effective R-value than its wood counterpart.

The simulated temperature profiles show that the temperature drop between a point on the framing member and the midpoint between the framing members are similar for both framing systems. The temperature difference is sufficiently low that conditions for ghosting are avoided. This relates well to the observations made with thermal imaging.

An attempt to correlate the IR data with the effective R-value predicted by FRAME for the homes studied was successful to a point. For the opaque wall and lintel assemblies FRAME predicted the temperature differentials very well but the 2-D limitations of this model was not effective when dealing with the 3-D heat transfer at the attic ceiling to wall connection. Further work in refining the simulation for this detail is required.

### 3.4 Energy Consumption

As the saying goes “The proof is in the pudding”. No amount of modeling or inspection can replace the information provided by the actual energy consumed by a home. Computer models and instruments do a good job in predicting performance, but this does not reflect real life conditions where sub-trades are involved in building the assemblies and installing the insulating components. A small error in this process can create large discrepancies between actual and predicted outcomes.

Fifthshire Homes Ltd. a premier builder of Envirodesic and R-2000 homes in Toronto Ontario, has been building for over 20 years, the last three years exclusively with LSF. Joe Vella, Vice President, realizes the importance of attention to detail. He applies a minimum R5 of Expanded Polystyrene on the exterior of his steel frames, and a CFC and HCFC free two-component polyisocyanurate foamed into the cavities between steel framing members. After drywalling is complete, a blower door test is conducted. On average, the air leakage rate of the R-2000 homes built by Fifthshire is 1.0 air changes per hour (acph). The maximum allowable air leakage for a home to be certified as R-2000 is 1.5 acph. Prior to using steel, Fifthshire built wood frame R-2000 homes in a similar fashion using batt insulation in the wall cavities.

For their own analysis, Fifthshire obtained one year of gas utility meter readings for 6 homes constructed in the past 5 years. All homes used natural gas as the heating energy and all homes had the same high efficiency heating equipment. The houses selected were in the same subdivision and built by Fifthshire to the same nominal R-value. The results did not surprise Fifthshire. The average gas consumed for heating the steel homes, weighted by floor area, was approximately 7% lower than the weighted average for the wood framed homes (see **Table 4**).

The reason for this lies in the performance of the **system** and attention to detail by the builder. It is unrealistic to expect that by predicting the thermal resistance of an opaque wall assembly one can accurately predict the energy performance of a whole house. The IR inspection identified thermal advantages to steel framing which were not previously considered. Until a proven tool is available that predicts performance of a system which incorporates the various assembly details, the most compelling proof lies in the actual energy used. Indications are that consumers have nothing to fear when it comes to using Lightgauge Steel Framing for energy efficient home.

## 4 CONCLUSIONS

1. The contribution of steel framing to the thermal resistance of a building assembly depends on the physical dimensions, geometry and make-up of the assembly as much as the conductivity of the material.
2. Infrared thermography is an effective tool in identifying local areas where heat transfer is occurring. It is also capable of determining differences in temperature within an assembly and comparing these differences to other assemblies. In this study, IR imaging showed that there is no disadvantage with respect to heat transfer through steel framed opaque wall assemblies. A definite advantage for steel was identified when used in lintels.
3. FRAME is a cost effective tool in predicting the effective thermal resistance of simple assemblies. A better understanding of FRAME or an enhancement in its capabilities is required before it can be used effectively on systems such as attic ceiling to wall connections. Additional testing is required to better correlate IR and computer modeling data. This work is currently underway at Dofasco. Simulations show that steel framed wall assemblies achieve similar effective R-values as traditional wall assemblies without the need for additional insulation.
4. Actual energy consumption figures is a more reliable indicator of the thermal performance of a building since there are factors that arise during construction that cannot be incorporated in predictive models. Based on actual gas utility readings steel framed homes are achieving at least the same energy performance as their wood counterparts with the same insulative value.

## 5 ACKNOWLEDGMENTS

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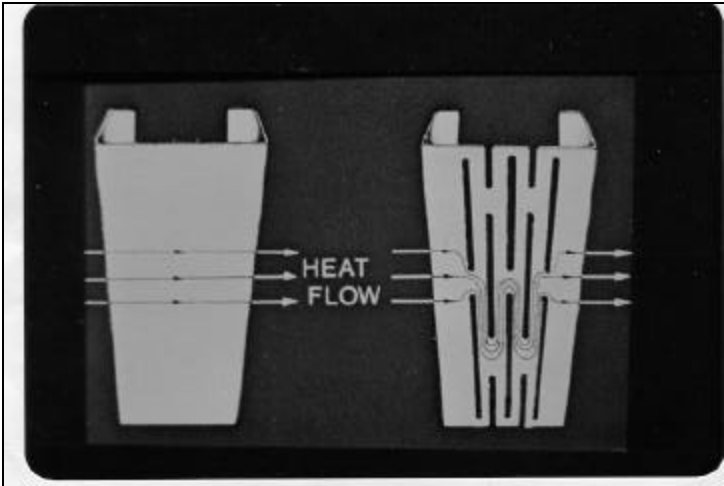
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Figure 1: Thermal Steel stud concepts developed and patented by Dofasco.



Figure 2: Thermal steel stud showing increased heat path length relative to a conventional stud.



**Table 1: Details of Homes inspected using Infrared Thermography**

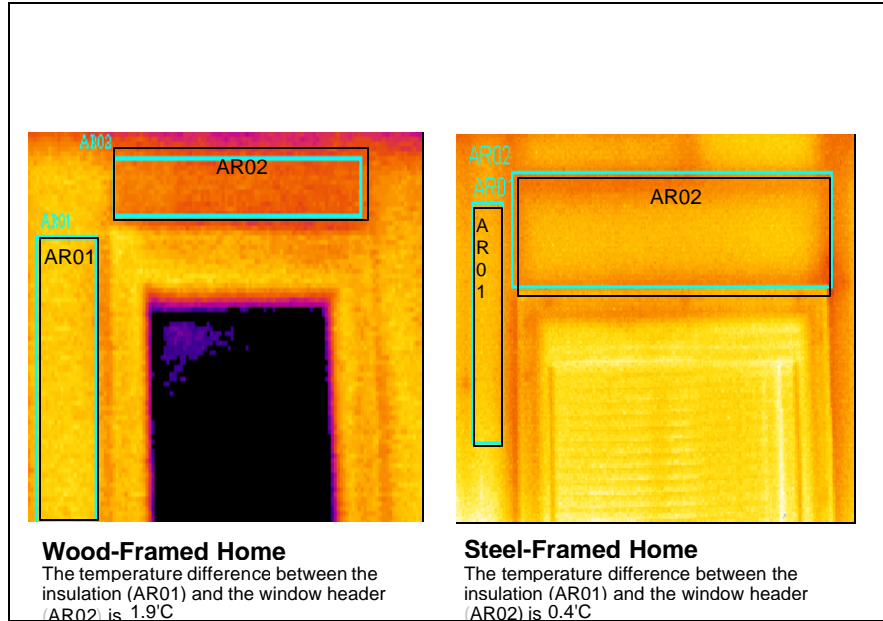
House	Framing		Exterior Finish	Exterior Insulation		Cavity Insulation		Roof Structure	Effective RSI
	Material	Dimensions (mm)		Type	RSI	Type	RSI		
Model A-S	Steel	92 x 41 1.12 (18 ga.)	Brick	EPS	0.97	GF Batt	2.29	Wood truss	3.17
Model A-W	Wood	38 x 89	Brick	EPS	0.97	GF Batt	2.29	Wood truss	3.52
Model B-S1	Steel	92 x 41 1.12 (18 ga.)	Brick	EPS	1.23	Foam	2.29	Steel built-up	3.17
Model B-S2	Steel	92 x 41 1.12 (18 ga.)	Brick	EPS	1.23	Foam	2.29	Steel built-up	3.17
Model B-W	Wood	38 x 89	Brick	Glass clad	1.23	GF Batt	2.11	Wood built-up	3.52
Model C-S	Steel	92 x 41 1.12 (18 ga.)	Stucco	EPS	1.23	Foam	2.29	Steel built-up	3.35
Model D-W	Wood	38 x 140	Brick	Glass clad	0.97	GF Batt	3.52	Wood built-up	3.52

effective R-value as determined by FRAME

**Table 2: Summary of average temperature differentials over framing members as determined by Infrared Thermography**

	T Clear Wall (°C)	T Lintel Area (°C)	T Sill Plate (°C)	T Multiple Members (°C)
Model A-steel framed	-1.3	-0.1	-1.7	-1.5
Model A-wood framed	-1.1	-1.4	-3.0	-1.4
Model B-steel framed	-1.5	-0.4	-1.3	-1.1
Model B-wood framed	-0.9	-1.4	-2.1	-2.1

**Figure 3:** Thermal images of a wood framed and steel framed lintel. Images were obtained from two identical homes, one steel framed one wood framed, located on the same street, and inspected on the same evening with outside temperature of  $-6^{\circ}\text{C}$ , and no wind.



**Figure 4:** Thermal image of a ceiling wall connection in a steel framed home showing localized areas of lower temperature

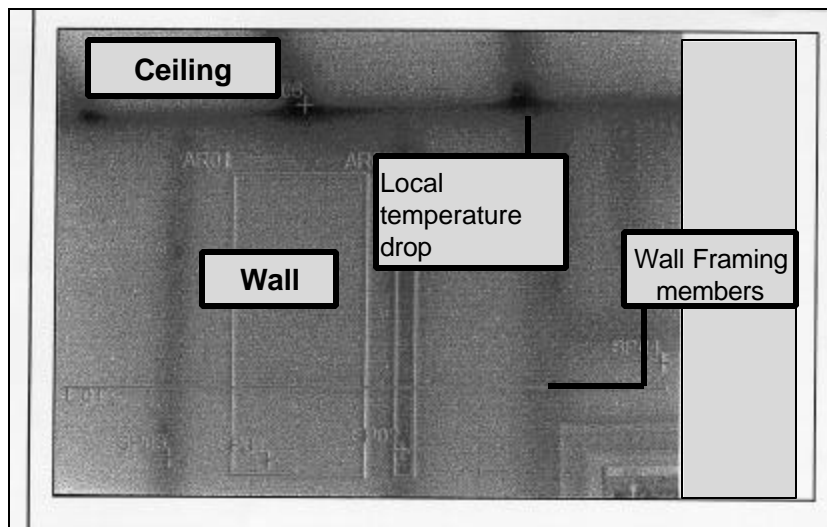


Figure 5: Thermal image of ceiling wall connection in a wood framed home showing a lower temperature band.

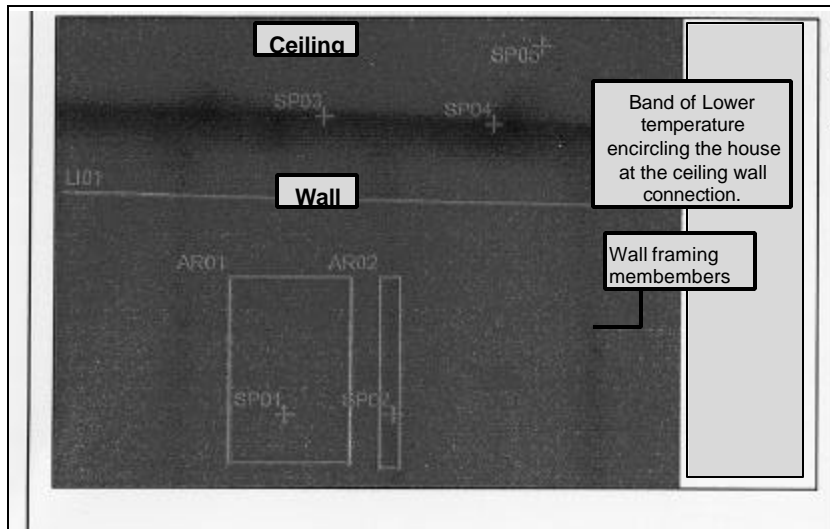
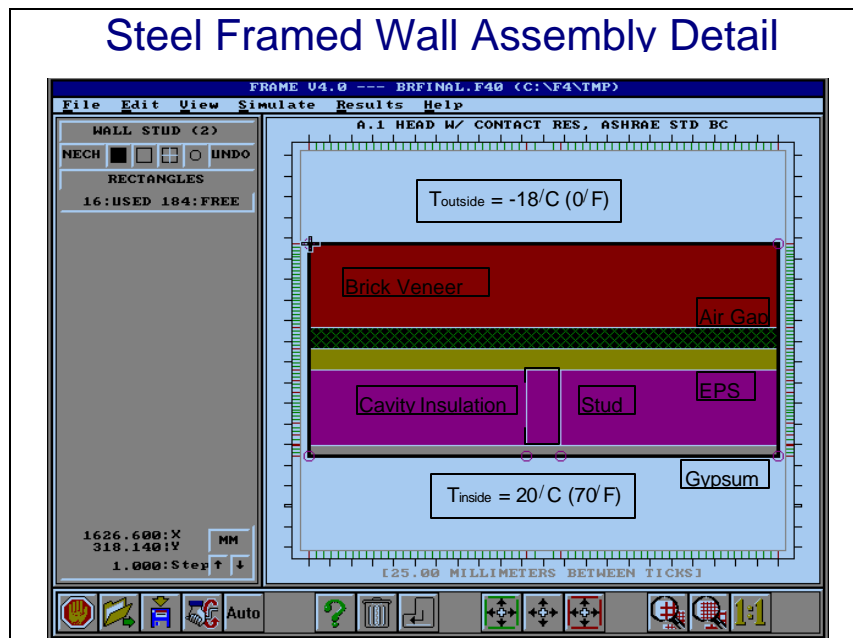


Figure 6: CAD based drawing of assembly detail used by FRAME to simulate effective R-value.



**Table 3: Summary of FRAME simulations performed on various assemblies.**

Assembly	Effective R-value (RSI)		- T at framing component	
	Steel Framing	Wood Framing	Steel Framing	Wood Framing
Exterior Walls with glass fibre batt, R7 exterior insulation, 1" air gap, brick veneer	Steel Framing 41 x 92	Wood Framing 38 x 140 no exterior insulation	Steel Framing 92 x 41	Wood Framing 38 x 140 no exterior insulation
	3.15	3.22	1.1	0.9
Exterior Walls with glass fibre batt, R 5 exterior insulation, 1" air gap, brick veneer	Steel Framing 41 x 92	Wood Framing 38 x 89	Steel Framing 41 x 92	Wood Framing 38 x 89 (nominal)
	2.85	3.19	1.5	0.8

**Table 4: Natural gas consumed for heating.**

House	Natural Gas Consumption (cu. Meters)	Weighted average (cu. Meters)
Steel Framed 214 m <sup>2</sup> (2300 s.f.)	1573	1769
Steel Framed 200 m <sup>2</sup> (2150 s.f.)	1736	
Steel Framed 214 m <sup>2</sup> (2300 s.f.)	1995	1888
Wood Framed 195 m <sup>2</sup> (2100 s.f.)	1721	
Wood Framed 230 m <sup>2</sup> (2480 s.f.)	2152	
Wood Framed 223 m <sup>2</sup> (2400 s.f.)	1760	

1. Gas consumed for heating only during heating season September-April inclusive.
2. Number of degree days = 3309
3. Occupancy loads were similar
4. Same high energy efficient heating system installed
5. All homes are R-2000 certified with 1.0 acph at 50Pa