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Steel-Framed Buildings: Impacts of Wall Detail Configurations on the Whole Wall Thermal Performance

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DISCLAIMER

STEEL-FRAMED BUILDINGS; IMPACTS OF WALL DETAIL CONFIGURATIONS ON THE WHOLE WALL THERMAL PERFORMANCE

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ABSTRACT

The main objective of this paper is the influence of architectural wall details on the whole wall thermal performance. Whole wall thermal performance analysis was performed for six light gage steel-framed wall systems (some with wood components). For each wall system, all wall details were simulated using calibrated 3-D finite difference computer modeling. The thermal performance of the six steel-framed wall systems included various system details and the whole wall system thermal performance for a typical single-story ranch house.

Currently, predicted heat losses through building walls are typically based on measurements of the wall system clear wall area using test methods such as ASTM C 236 or are calculated by one of the procedures recommended in the ASHRAE Handbook of Fundamentals that often is carried out for the clear wall area exclusively. In this paper, "clear wall area" is defined as the part of the wall system that is free of thermal anomalies due to building envelope details or thermally unaffected by intersections with other surfaces of the building envelope. Clear wall experiments or calculations normally do not include the effects of building envelope details such as corners, window and door openings, and structural intersections with roofs, floors, ceilings, and other walls. In steel-framed wall systems, these details typically consist of much more structural components
than the clear wall. For this situation, the thermal properties measured or calculated for the clear wall area do not adequately represent the total wall system thermal performance. Factors that would impact the ability of today's standard practice to accurately predict the total wall system thermal performance are the accuracy of the calculation methods, the area of the total wall that is clear wall, and the quantity and thermal performance of the various wall system details.

The whole wall thermal analysis method used in this paper was developed as a part of a whole wall rating procedure. For several wall technologies, local R-values for all wall interface details and the whole wall R-value, together with three dimensional CAD rendered images for wall interface details are presented under the following Internet address: **http://www.cad.ornl.gov/roofs+walls**.

The main objective of this paper was to find a relationship between structural and material configurations of the steel-framed wall details and the whole wall thermal performance. It was

found that even small changes in clear wall or wall detail configuration can bring significant improvements in whole wall thermal performance. Also, this research confirmed that wall systems using steel framing which incorporate wood components are much more thermally effective than conventional steel-framed wall system.

Key Words: energy, heat transfer, thermal resistance, calculation procedure, walls, steel studs.

INTRODUCTION

Traditional thermal calculations as applied to cold-formed steel-framed wall systems can be very misleading if based only on the measured or calculated thermal performance of the clear wall area. Thermal performance of the clear wall area (part of the wall system that is free of thermal anomalies due to building envelope subsystems or thermally unaffected by intersections with other surfaces of the building envelope) can be different (worse or better) than the whole wall thermal performance [1,2]. In steel-framed wall systems, wall details have significantly different configurations than that of the clear wall. In such circumstances, the thermal properties measured or calculated for the clear wall area do not adequately represent the total wall system thermal performance.

Thermal measurements of wall systems are typically carried out by apparatus such as the one described in ASTM C 236, Standard Test Method for "Steady-State Thermal Transmission Properties of Building Assemblies by Means of a Guarded Hot Box" [3]. A relatively large (approximately 8 x 8 ft or larger) cross-section of the clear wall area of the wall system is used to determine its thermal performance. Thermal anomalies such as steel studs are typically included in the tested configuration. The precision of this test method on a R-15.8 hft^2F/Btu (2.8 m^2K/W) specimen is reported to be 8 percent at 75F (24C) [3]. Even if the test method were perfect, it is apparent that what is being measured only constitutes a portion of the wall system; details are rarely included as part of a series of measurements to ascertain the overall wall system thermal performance.

The influence of wall details on the whole wall thermal performance has been addressed (mostly based on theoretical calculations and computer modeling) by several research projects which focused on different types of wall constructions [1,2,4,5,6,7,8]. Also, in several papers, this subject was associated with the wall thermal bridge thermal analysis [9,10,11]. The work by T. W. Petrie [4] and 1996 ASHRAE research project [8] where wall interface details were analyzed is based on the test results. However in these two projects, the whole wall analysis was not performed and only single wood-framed and masonry wall systems' details were considered. Steel-framed wall interface details have not been tested to date, and for these systems only analytical data is available.

The most widely used analytical techniques for estimating wall system thermal performance are described in Chapter 24 of the ASHRAE Handbook of Fundamentals [9.12]. These techniques as well as the ASTM test procedure for quantifying the thermal performance of wall systems have obvious shortcomings. Building envelope details such as window and door frames, along with the additional structural support that these subsystems require, are ignored. Also, the impact of construction details such as wall corners and floor and ceiling interfaces with the wall system are overlooked. This procedure can lead to errors in determining the energy efficiency of the building envelope. In addition, these techniques de-emphasize the importance of energy-efficient design of the wall details. Since envelope system designers can not claim performance benefits due to innovative detailing, the building community is less likely to concern itself with novel detailing concepts. To address these uncertainties associated with the practice of evaluating only the clear wall area and the simplifications in the calculation methods, analytical experiments using a 3-D finite difference model have been performed on six steel-framed wall systems. Using a standard building elevation, these results have been combined to compute the actual amount of clear wall area and to determine the overall system thermal performance. The whole wall thermal analysis method used in this paper was developed as a part of a whole wall rating procedure [1,2].

The main finding of this work is that, in steel-framed wall systems, the wall details have significantly different configurations than that of the clear wall. The thermal properties measured or calculated for the clear wall area do not adequately represent the total wall system thermal performance. Another important finding is that small changes in the clear wall or wall detail configuration can bring significant improvements in the whole wall thermal performance. Also, this research confirmed thesis that wall system using steel studs and wood horizontal components is much more thermally effective than conventional 100% steel-framed wall system.

ANALYSIS METHODOLOGY

A heat conduction computer code Heating 7.2, developed by Oak Ridge National Laboratory [13], was used for thermally analyzing clear wall areas, wall subsystems, and exterior wall intersections with other building elements. Heating 7.2 can simulate steady-state and/or transient heat conduction problems in one-, two-, or three-dimensional Cartesian, cylindrical, or spherical coordinates. Multiple materials and time and temperature dependent thermal conductivity, density, and specific heat can be considered. The boundary conditions, which may be surface-to-environment or surface-to-surface, can be specified temperatures or any combination of prescribed heat flux, forced convection, natural convection and radiation. The boundary condition parameters can be time and/or temperature dependent. The mesh spacing can be variable along each axis. Heating 7.2 can model transient problems by using of any one of several finite-difference schemes : Crank-Nicolson Implicit, Classical Implicit Procedure, Classical Explicit Procedure, or the Levy Explicit Method. Two and three dimensional modeling was used for the clear wall areas. For wall details, 3-D modeling was applied. The resultant temperature maps were used to calculate average heat fluxes, and then wall system R-values.

The accuracy of Heating 7.2's ability to predict wall system R-values was verified by comparing Heating 7.2 simulation results with published test results for twenty-three masonry, wood frame, and steel stud walls [9]. The precision of the guarded hot box method is reported to be approximately 8 percent, the ability of Heating 7.2 to reproduce the experimental data is within the accuracy of the test method. For each wall system, models of the clear wall area, corner, roof/wall intersection, floor/wall intersection, window header, window sill, window jamb, door header, and door jamb were analyzed. Geometries of these details were obtained from AISI manual [14] or system manufacturer's design guides [15].

The influence of wall details on the overall wall thermal performance is different for every house because of the variety of architectural designs. To normalize the calculations, a standard building elevation was used to combine the thermal resistances of the various details and to compute the overall wall system thermal resistance. The standard elevation selected for this purpose is a single-story ranch style house that has been the subject of previous energy efficiency modeling studies [16]. A schematic of the house is shown in Figure 1. The house has approximately 1500 ft^2 of living area, 1328 ft^2 of exterior (or elevation) wall area, 8 windows, and 2 doors (one door is a glass slider; its impact is included with the windows). The elevation wall area includes 1146 ft^2 of opaque (or overall) wall area, 154 ft^2 of window area and 28 ft^2 of door area.

The overall thermal resistance of the wall system, R_{ws}, was computed by combining in an area weighted method the thermal resistances of the wall details and clear wall area.

$$R_{ws} = \left[\frac{A_{cw}}{R_{cw}} + \sum_{i=1}^{n} \frac{A_i}{R_i} \right]^{-1} \tag{1}$$

where:

A_{cw} is the clear wall area expressed as a percentage of the overall wall area,
R_{cw} is the clear wall thermal resistance,
A_i is the area of the ith detail expressed as a percentage of the overall wall area,
R_i is the thermal resistance of the ith detail, and n is the number of details.

DESCRIPTION OF ANALYZED STEEL-FRAMED WALL SYSTEMS

Six different configurations of steel-framed wall systems were analyzed. In all systems 3.5 in.(7.5-cm.) wide steel studs were used spaced at 16-in. (40 cm.) o.c. All walls were grouped in three categories: conventional steel stud walls, walls with foam cavity insulation containing distance spacers, and walls with wall details made of wood. For conventional steel stud walls and walls with wall details made of wood, one wall without insulating sheathing and one wall having foam sheathing were analyzed. Wall systems grouped in the first two categories were built using

AISI recommended details [14]. In two walls from the third category, only studs were made of steel. The other wall details were made using wood components. This technique is gaining popularity because it is much simpler to install windows and doors into wood-framed rough openings. Also, wooden bottom track and top plates are very often used together with steel studs for the internal partitions. The construction of the wall/roof and wall/ceiling intersections using wood components is our innovation for this paper. Schematic drawings of considered steel stud wall systems are presented in Figures 2 and 3. Two different cavity insulations are considered; R-11 hft^2F/BTU (R-1.94 m^2 K/W) fiberglass batts and sprayed insulating foam. In three wall systems 1-in. (2.5-cm.) exterior foam sheathing is assumed. In walls with foam cavity insulation, wall cavity is increased by 1-in. (2.5-cm.) by using steel hat channels or wood spacers. Thermal properties of wall materials used in computer modeling are presented in Table 1.

Table 1. Thermal properties of wall materials used in computer modeling.

Wall material:	Thermal resistivity - hft^2F/BTU -in. (mK/W)
Sprayed foam	3.44 (24.06)
Fiberglass	3.14 (21.96)
Foam Sheathing	5.00 (34. 96)
Plywood	1.25 (8.74)
Gypsum Board	0.90 (6.29
Steel	$3.2e^{-3}$ (0.02)
Wood	1.00 (6.99)

CLEAR WALL THERMAL PERFORMANCE

The calibrated finite difference computer code (described above) was used to calculate the clear wall R-values for the six wall samples. As shown in Figure 4, for conventional steel stud wall, the simulated clear wall R-value is R-7.17 hft^2F/Btu (1.26 m^2K/W). Adding a foam sheathing to this wall lifts clear wall R-value by R- 5.68 (1.0) to R-12.85 hft^2F/Btu (2.26m^2K/W). For these two walls, thermal framing effects (Appendix A) are 45% and 28%, respectively. Theses values are very close to the previously reported data for similar wall configurations [2,10]. Almost the same clear wall R-values R-7.2 and R-12.9 hft^2F/Btu (1.27 and 2.27 m^2K/W) and framing effects are computed for walls with wooden components.

The wall with hat channels and with foam cavity insulation has the simulated clear wall R-value of R-9.89 hft^2F/Btu (1.74 m^2K/W) and framing effect of 43%. For the similar wall containing wooden spacers, the simulated clear wall R-value is R-11.28 hft^2F/Btu (1.99 m^2K/W) and framing effect is 35%. The results illustrates that installing wood spacers is more efficient than using steel hat channels. The net result of these two assemblies shows that the wall containing wooden spacers has a clear wall R-value of 1.39 hft^{2}F/Btu (0.24 m^{2}K/W) higher than for the wall where steel hat channels are used.

WHOLE WALL SYSTEM THERMAL PERFORMANCE

A substantial portion of the overall wall area is ignored if typical procedures are used to determine the wall system thermal performance. In this section, we quantify the differences in thermal performance that are likely to be obtained by ignoring the wall system details. We also estimate the impact of the steel-framed wall details on overall wall system thermal resistance.

The simulation results for the clear wall and overall wall areas are summarized in Figures 5, 6 and 7, along with the differences between clear wall and overall wall R-values. For all wall configurations, the clear wall thermal resistances are larger than the overall wall R-values. In the cases of the conventional steel-framed wall systems (AISI details), the clear wall R-values are 21% higher (wall without sheathing) and 27% higher (wall with foam sheathing) than the overall wall R-values. These results are close to the previously reported data for similar wall systems [2]. They suggest that thermal redesign of the wall details in conventional steel-framed wall systems can be an effective way to improve the overall wall thermal performance.

A replacement of the steel components in wall details by similarly shaped wood profiles is an example of efficient thermal improvement in the steel-framed wall thermal performance. In this wall system (no insulating sheathing), the gap between clear wall R-value and overall wall R-value is reduced to only 6%. For systems with insulating sheathing, this gap is 12%. Overall wall R-value comparisons between conventional steel-framed wall system and steel stud system with wooden details show how misleading whole building thermal performance analysis can be when using only clear wall R-values. Both systems have almost the same clear wall R-values. However, overall wall R-value for the steel stud wall system containing wooden details and without insulating sheathing is 1.12 hft^{2}F/Btu (0.20 m^{2}K/W) higher than for the conventional steel frame wall system. For the systems with insulating sheathing, similar difference is 1.91 hft^{2}F/Btu (0.34 m^{2}K/W).

Clear wall R-value analysis, performed on two systems containing additional horizontal wall cavity spacers showed that wood spacers are more thermally effective than steel hat channels. For wall with wood spacers clear wall R-value was about 1.4 hft^{2}F/Btu (0.25 m^{2}K/W) higher than for the wall containing steel hat channels. Overall wall R-value analysis also supports this point. For the wall with hat channels and with foam cavity insulation, the simulated overall wall R-value is R-7.43 hft^{2}F/Btu (1.31 m^{2}K/W). For the similar wall system containing wood spacers, the overall wall R-value is R-8.23 hft^{2}F/Btu (1.45 m^{2}K/W).

WALL AREA AND WALL HEAT LOSS DISTRIBUTIONS

For the wall systems analyzed, Figure 8 shows average fraction of wall area that the clear wall and wall details comprise. The clear wall area represents 65% of the overall wall area and wall details represent 35% of wall area. The roof/wall and floor/wall intersections have the largest impact on the overall wall area, 7 and 11%, respectively. The window perimeter also has an appreciable effect, averaging about 10% of the overall wall area. The effect of the window framing is probably underestimated in current residential construction practice since the use of fenestration products has increased dramatically and the standard elevation's 12% of glazing area is probably too small.

The wall system details that had the smallest impact on the overall wall area are the corners and door perimeter. The areas attributed to these details are about 6 and 1%, respectively. Again, these results must be seen in the context of the selected floor plan. A single-story residence with a rectangular configuration will diminish the effects of the corners while the typical residence certainly has more than two doors.

In all analyzed wall systems, the portion of wall heat losses generated by wall details areas is higher than 35% (area of wall details) as presented on Figure 9 . In four wall systems; the two conventional steel-framed walls and the two systems containing horizontal spacers, heat losses generated by wall details are close to 50% of the whole wall heat losses. In systems containing wood components used in wall details, heat losses generated by wall details are close to 40% of the whole wall heat losses. In all systems, the wall/roof and wall/ceiling details generate from 8 to 13 and 11 to 18% of the overall wall heat losses, respectively. The window perimeter also has an appreciable effect, producing about 6 to 9% of the overall wall heat losses.

The analysis presented in Figures 8 and 9 of the wall area and wall heat loss distributions in the steel-framed walls shows clearly that it is not possible to accurately analyze building thermal performance taking into account only the clear wall portion of the wall because it génerates only about 50-60% of the total wall heat losses.

CONCLUSIONS

Using a finite difference computer code, six steel-framed wall systems with their typical details have been simulated. The finite difference computer modeling has been used to compute the amount of area that is thermally impacted by the details and the effect of the details on the overall thermal performance of the wall system. The following conclusions are presented for their usefulness in the design and performance characterization of wall systems.

1. Thermal performance of conventional steel-framed walls can be improved through a simple modification to the assembly by installing additional foam sheathing or by installing

horizontal spacers over the studs.

2. Horizontal wooden spacers are more thermally effective than steel hat channels.

3. All wall systems are a combination of clear wall area and wall details. Thermal performance cannot be accurately analyzed simply by studying the clear wall area. For the steel-framed wall systems reported in this study, as much as 35% of the overall wall area is different in construction and thermal performance than the clear wall area. We have used a fairly straightforward building elevation for this modeling. The wall area distribution of most other elevations will probably have a smaller percentage of clear wall area. Clear wall R-value should clearly not be used as the only parameter to characterize the overall thermal resistance of steel-framed wall systems.

4. In conventional steel-framed wall system wall details representing 35% of wall area generate about 50 to 60% of heat losses. A more extensive review and thermal redesign of these details is necessary. Replacement of steel components by similar wooden members in wall details can be a very effective way of the improving overall thermal performance.

REFERENCES

1. Kośny, J., Desjarlais, A. O., Influence of Architectural Details on the Overall Thermal Performance of Residential Wall Systems, Journal of Thermal Insulation and Building Envelope, July 1994.

2. Christian, J.E., Kośny, J. "Thermal Performance and Wall Rating" ASHRAE Journal - March 1996.

3. ASTM C 236-89, Standard Test Method for "Steady-State Thermal Performance of Building Assemblies by Means of Guarded Hot Box," Vol 04.06, pp. 53-63.

4. Petrie, T.W., Kośny, J. Childs, P.W., Christian, J. E., and Graves R.S., Performance of Powder-filled Evacuated Panel Insulation vs. Conventional Insulation in a Single-Wide Manufactured Home Unit,ASHRAE/DOE Thermal Performance of the Exterior envelope of Buildings Conference VI, Clearwater Beach, Fl, December 4-8,1995.

5. Adrian Tuluca, Deane Evans, Kenneth Childs, George Courville, Thomas Vonle, Ronald Tye, Dinesh Kumar, Moncef Krarti. ORNL/Sub/88-SA407/1: Catalog of Thermal Bridges in Commercial and Multi-Family Residential Construction (December 1989).

6. Albert Litvin, Martha G. Van Geem. ORNL/Sub/84-21006/2 Structural Thermal Break Systems for Buildings - Development Properties of Concrete Systems (October 1988).

7. Martha G. Van Geem. ORNL/Sub/84-21006/3: Structural Break Systems for Buildings - Heat Transfer Characteristics of Lightweight Structural Concrete Walls (December 1988).

8. ASHRAE " Building Insulation Systems Thermal Anomalies" ASHRAE Research Project 785-RP, prepared by Enermodal Engineering Ltd. and ORNL. Atlanta, June 1996

9. Kośny J., Christian J.E." Reducing the Uncertainties Associated with Using the ASHRAE Zone Method for R-value Calculatons of Steel Frame Walls" - ASHRAE Transactions 1995 v.101, Pt 2.

10. Kośny, J., Christian, J.E., Desjarlais, A.O. "Thermal Breaking Systems for Steel Stud Walls - Can Steel Stud Walls Perform as Well as Wood Stud Walls? " ASHRAE Transactions 1997. Vol.103. Pt1.

11. S. C. Larson, M. G. Van Geem. ORNL/Sub-21006/1: Thermal Break Systems for Buildings - Feasibility Study (1987).

12 . ASHRAE, ASHRAE Handbook of Fundamentals, ASHRAE, 1997.

13. Childs K.W. , "HEATING 7.2 User's Manual," Oak Ridge National Laboratory Report ORNL/TM-12262, February 1993.

14. American Iron and Steel Institute, "Residential Steel Framing Manual - Low rise Residential Construction Details." AISI publication RG-934, June 1993.

15. Personal communication with Mr. Gabriel Farkas - vice president of Icynene Inc.

16. Huang, Y.J., Ritschard, J., Bull, S., Byrne, I., Turiel, D., Wilson, C., Sui, H., and Foley, D., "Methodology and Assumptions for Evaluating Heating and Cooling Energy Requirements in New Single-Family Residential Buildings, Technical Support Document for the PEAR Microcomputer Program," Lawrence Berkeley Laboratory Report No. LBL-19128. Berkeley, CA, 1987.

Appendix A

THERMAL FRAMING EFFECT

Frequently, test and calculation results for steel-framed clear wall areas show that the measured wall R-value can be considerably lower than the center of cavity R-value that exclude the effects of thermal bridges caused by steel framing. R-value comparisons do not clearly show how effectively the wall materials are used.

The R-value reduction generated by structural components is called framing effect," *f*." The framing effect represents the reduction in potential wall thermal resistance (R-value for layers of material away from all structural framing members - center-of- cavity R-value) due to thermal bridging and can be described by equation (2):

$$f = [\ 1 - \frac{R_{simul}}{R_{c-cav}}\ ]*100\ \% \qquad (2)$$

where:

R_{simul} = simulated or experimental clear wall R-value (with framing members included), and

R_{c-cav} = R-value for layers of material away from all structural framing members (center-of-cavity R-value), excluding thermal resistances of air spaces.

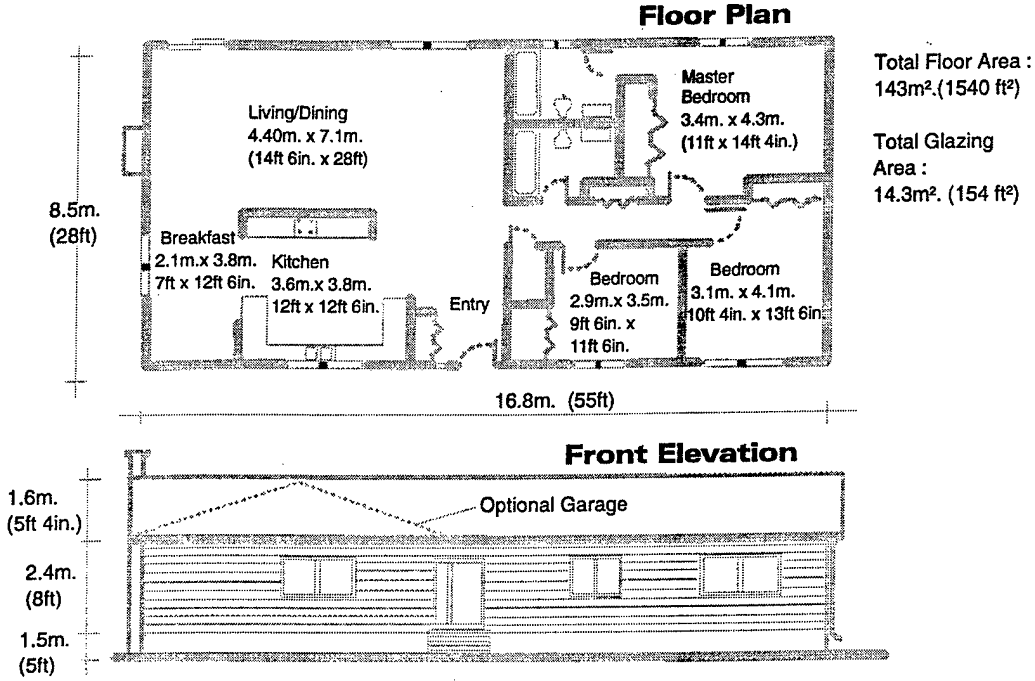

Figure 1. One story house used for the whole wall thermal performance analysis.

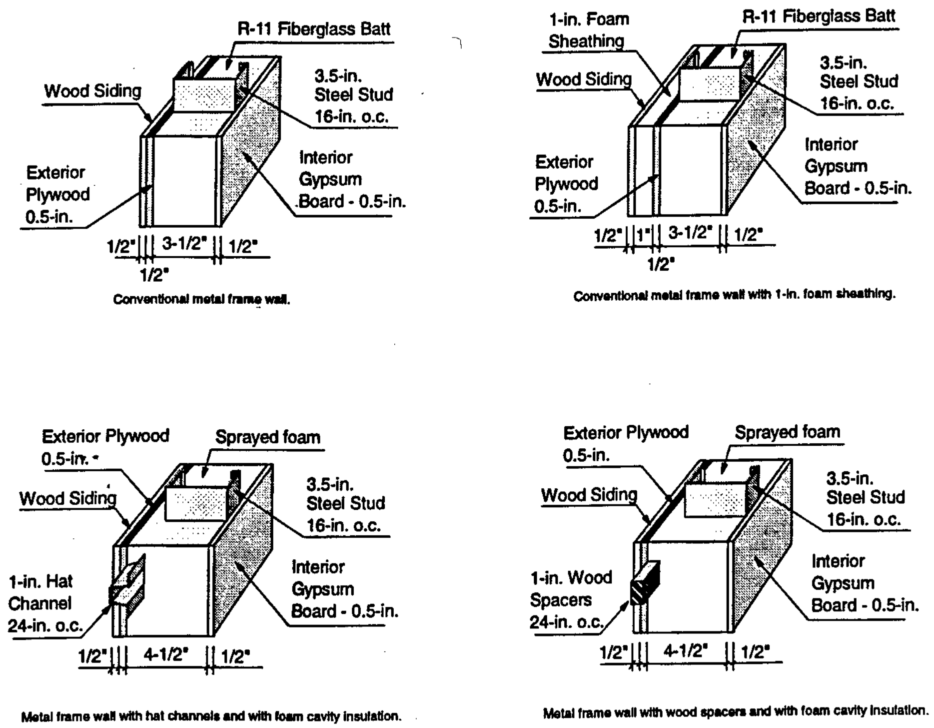

Figure 2. Schematics of conventional metal frame walls and walls using horizontal distant spacers.

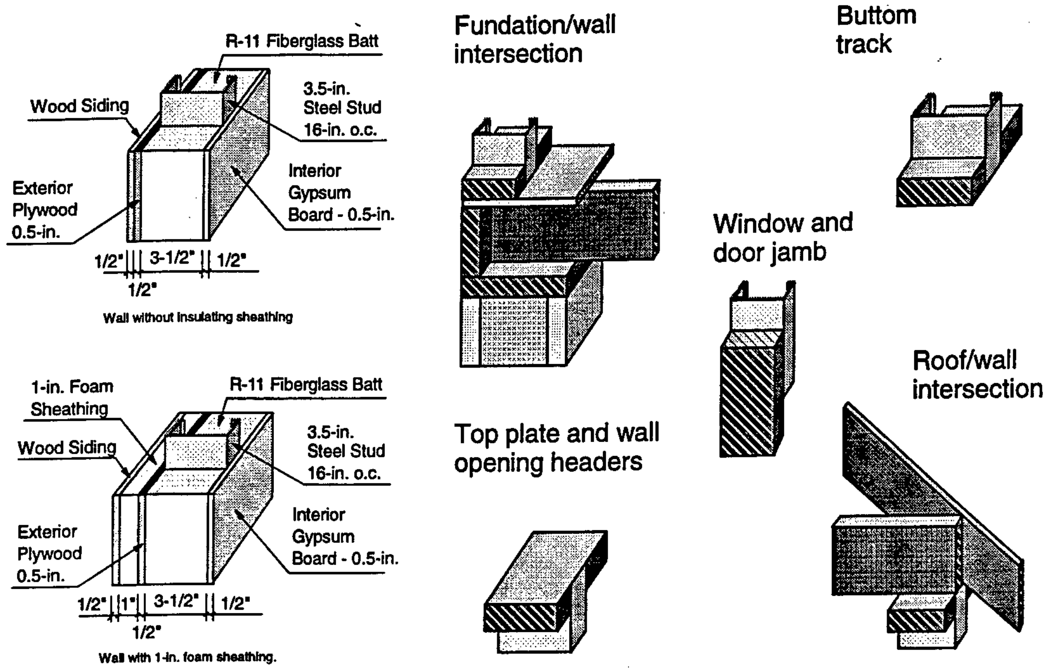

Figure 3. Schematics of metal frame walls with wood components.

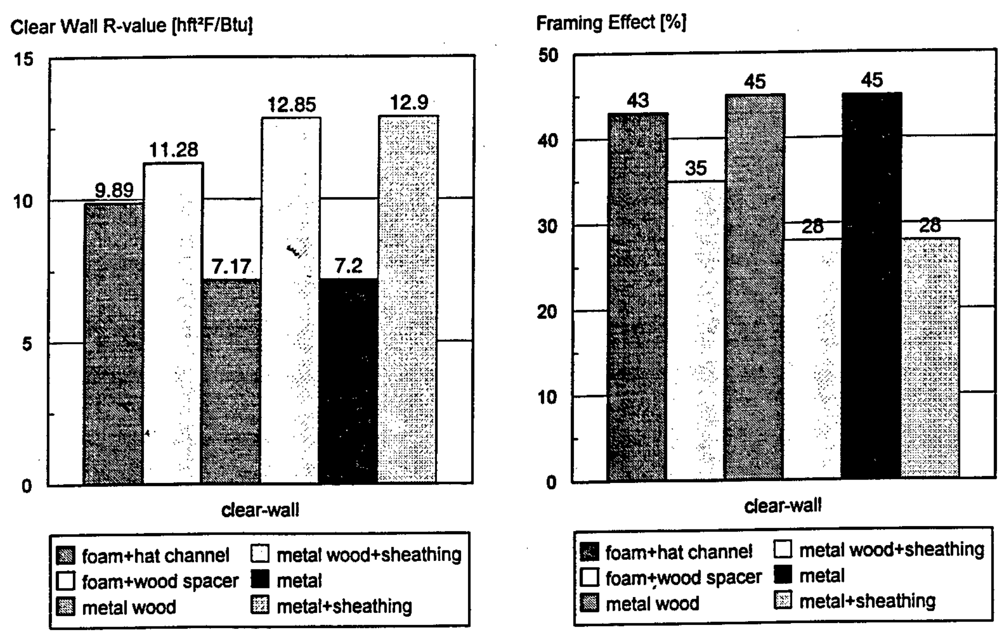

Figure 4. Clear wall R-value and framing effect for simulated metal frame walls.

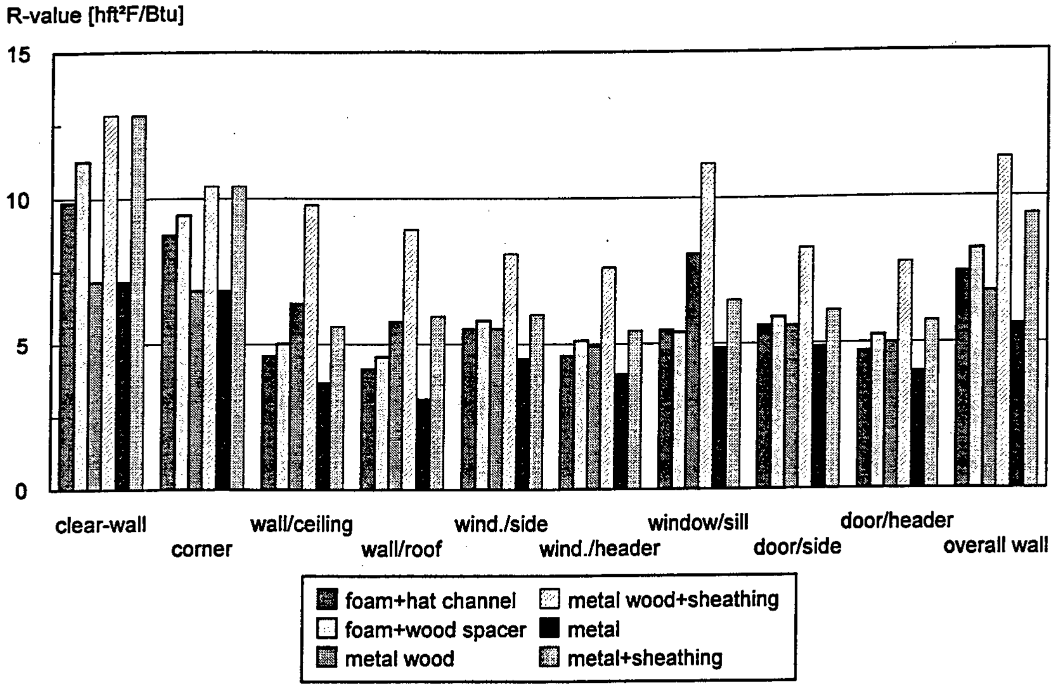

Figure 5. Wall detail R-values for different types of metal frame walls.

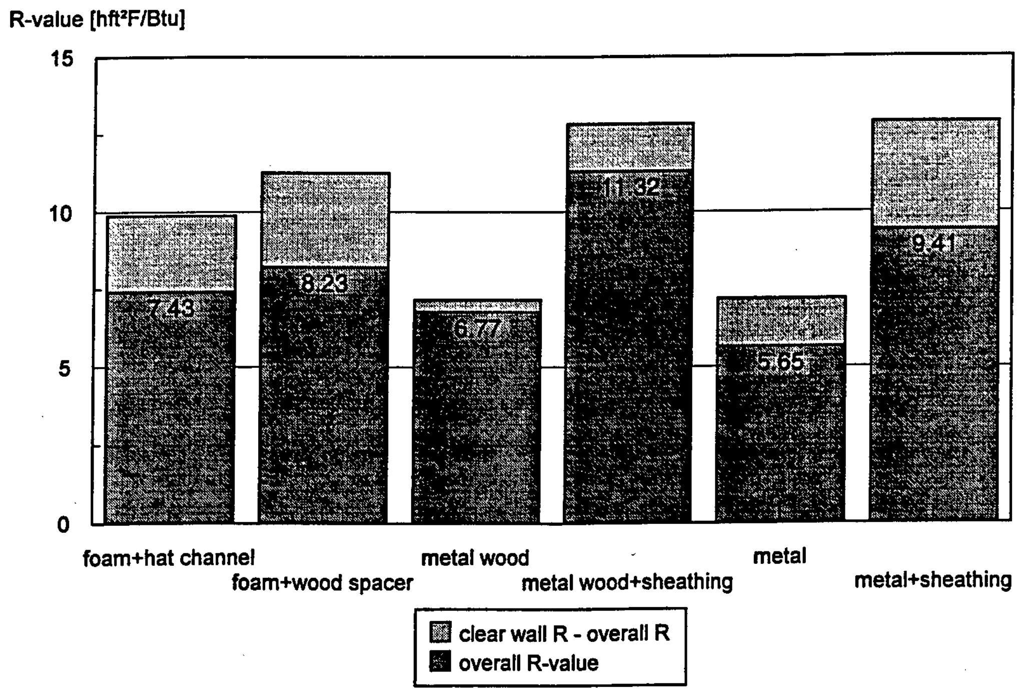

Figure 6. Overall wall R-values for different types of metal frame walls.

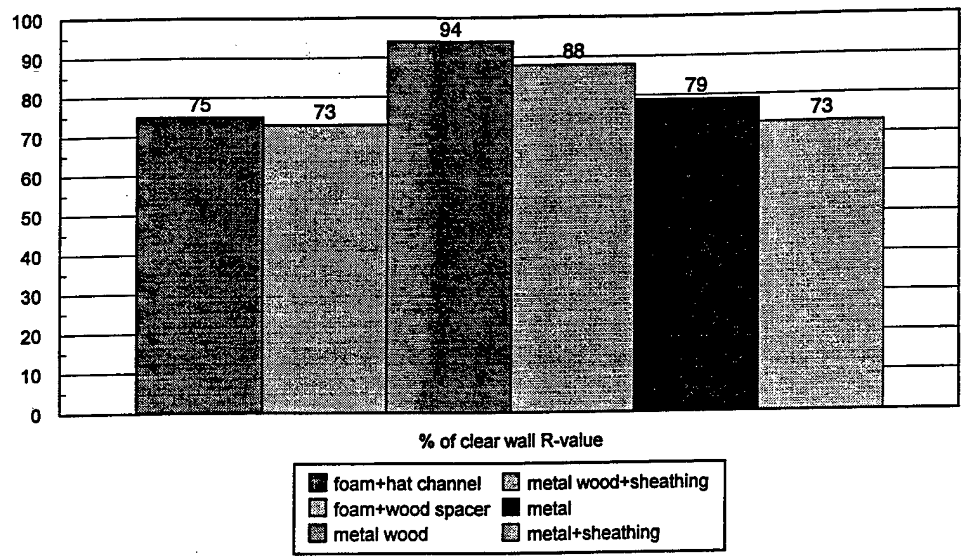

Figure 7. Relation between clear wall R-values and overall wall R-values for different types of metal frame walls.

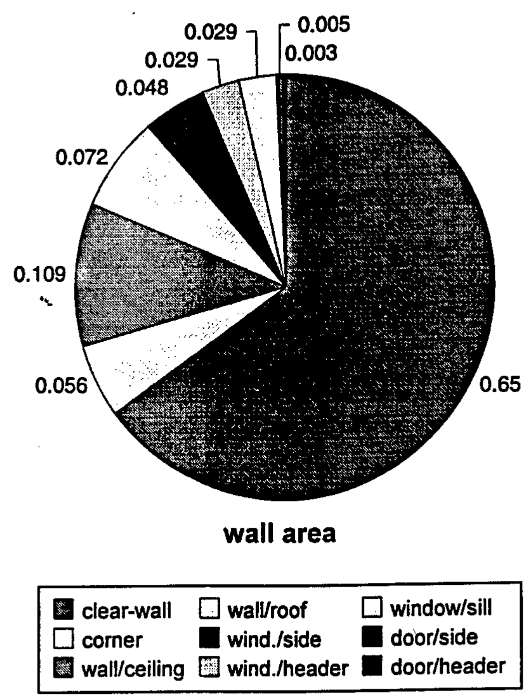

Figure 8. Wall area distribution in simulated metal frame walls.

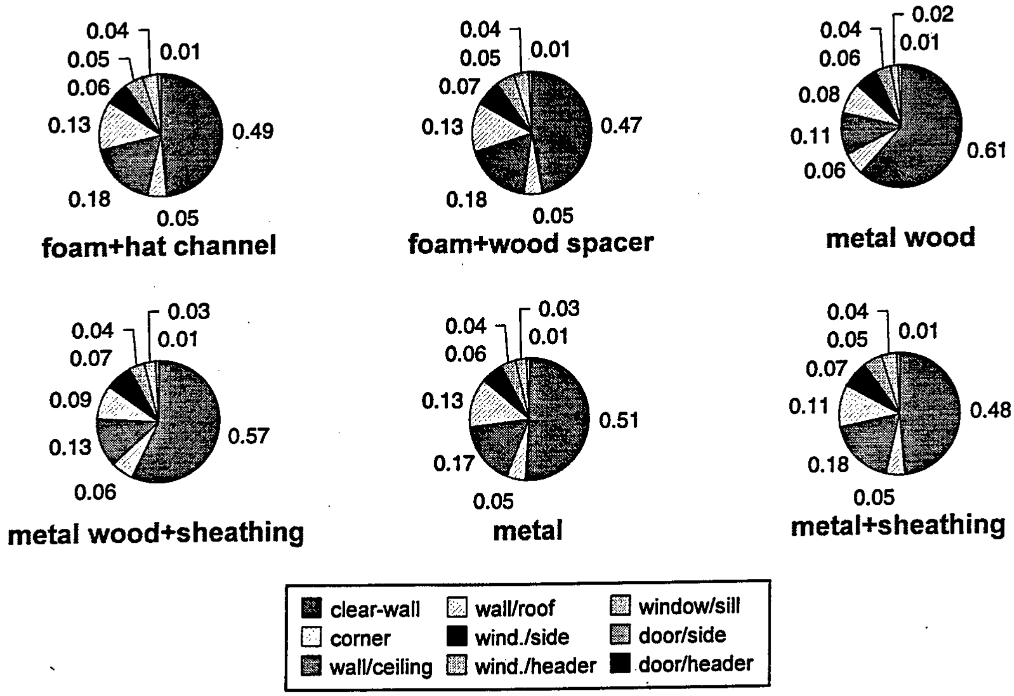

Figure 9. Wall heat losses distribution in simulated metal frame walls.

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