TOWARD A NATIONAL OPAQUE WALL RATING LABEL

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ABSTRACT

The persistent interest in residential energy efficiency and rising demand for alternatives to dimensional wood-frame wall constructions has increased the popularity of steel frame, left-in-place foam/forms, low-density concretes, structural insulated core panels, engineered wood wall framing, concrete block with insulated core, and a variety of hybrid wall systems. The full market consideration of these wall systems is inhibited, in part, by the lack of an acceptable, scientifically valid, uniform thermal performance comparison procedure.

Currently, most of the simplified calculation procedures readily available to decisionmakers for selecting building wall systems are based on the parallel path calculations used for conventional wood-frame systems. This approach requires the user to enter a framing factor (ratio of stud area to whole opaque exterior wall area). The framing factor usually is estimated, seldom verified against actual site construction, and frequently underestimated. Framing factors vary from 15% to 40% of the opaque exterior wall area, yet lower values down to 0% are commonly used. Unfortunately, the wall energy efficiency usually is marketed solely by the misleading "clear wall" R-value (exterior wall area containing only insulation and necessary framing materials for a clear section with no fenestrations, corners or connections between other envelope elements such as roofs, foundations, and other walls), or, even worse, "center-of-cavity" R-value (R-value estimation at a wall cross-sectional point containing the most insulation), which converts to a 0% framing factor and does not account for any of the framing material thermal shorts through the insulation.

This paper proposes for consideration as a nationally accepted consensus methodology a procedure for estimating the whole opaque wall R-value (whole-wall R-value), independent of system type and construction materials. The methodology is based on results from a three-dimensional heat conduction model capable of accurately simulating heat flow in a variety of wood, metal, and masonry systems. These simulation results lead to a "whole-wall" R-value that includes the thermal performance of not only the "clear wall" area, with insulation and structural elements, but also typical envelope interface details, including wall/wall (corners), wall /roof, wall/floor, wall/door, and wall/window connections. Results from these detailed computer simulations are combined into a single "whole-wall" R-value estimation and compared with simplified "center-of-cavity" and "clear wall" R-values.

Background

One mission of the U.S. Department of Energy's Office of Building Technology is to work with private industry to accelerate the application of energy-efficient building wall systems. One initiative is to develop scientifically supported performance data on enhanced, energy-efficient wall systems and disseminate this information in an easy-to-use form to enable home builders and buyers to make informed wall selections. The development of an opaque whole-wall thermal performance evaluation procedure also will help the Department of Energy (DOE) reach its building energy-efficiency goals. A logical progression from the development of the database and evaluation procedure described in this paper is for the building industry to develop a national consensus whole-wall thermal performance rating label. This will establish in the marketplace a more realistic energy savings indicator for consumers faced with the decision of what wall system to select for their building.

A nationally accepted wall evaluation procedure will provide consumers with experimentally based information with which to determine the thermal performance differences between common dimensional lumber systems, which historically represent about 90% of the market (HUD 1993), and alternatives. At least one of the alternative systems anticipates attaining 25% of the residential wall market by the year 1997 (Nisson 1994). In 1992, 500 new homes were framed with steel; in 1993, 13,000 homes also were steel-framed; and, in 1994, it was expected that 40,000 homes would be steel-framed (Dennis 1995).

A number of innovative wall systems offer advantages that will continue to gain acceptance as the cost of

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dimensional lumber rises, framing lumber quality continues to decline, availability fluctuates, and consumers' confusion about the environmental correctness of harvesting "old growth" wood as a building material remains. One constraint to greater acceptance of advanced walls is that there is no nationally accepted method of comparing the whole-wall thermal performance of different systems to each other and to wood-frame construction. Industries that are interested in establishing this uniform rating procedure are steel frame, foam/block, low-density concrete block, structural insulated core panels, straw bale, engineered wood wall framing, concrete block with insulated cores, and hybrid systems.

Several relatively new thermal performance terms are used throughout this paper. They are

- *Center of Cavity R-value:* R-value estimation at a point in the wall's cross-sectional R-value containing the most insulation.
- *Clear wall R-value:* R-value of the exterior wall area containing only insulation and necessary framing materials for a clear section with no fenestrations, corners, or connections between other envelope elements such as roofs, foundations, and other walls.
- *Interface details:* A set of common structural connections between the exterior wall and other envelope components, such as wall/wall (corners), wall/roof, wall/floor, window header, window sill, door jamb, door header, and window jamb, that make up a representative residential whole-wall elevation.
- *Whole-wall R-value:* R-value estimation for the whole opaque wall including the thermal performance of not only the "clear wall" area, with insulation and structural elements, but also typical envelope interface details, including wall/wall (corners), wall/roof, wall/floor, wall/door, and wall/window connections.

The most commonly used calculation procedures for conventional residential wood-frame construction tend to overestimate the actual field thermal performance of many of today's popular housing designs, which feature large fenestration areas and floor plans with lots of exterior wall corners. This leads to the need for a thermal performance indicator to represent the whole wood-frame wall including thermal shorts created at wall interfaces with other envelope components. For this procedure to gain popular acceptance it must be accurate yet simple enough to be understood by home buyers and builders, and permit thermal performance comparisons of alternative wall systems to wood-frame walls.

Currently, in the typical thermal evaluation of wood-frame wall systems, the wood framing effect (percentage reduction of clear wall area R-value to that estimated at the center-of-cavity) is handled by conducting a simple parallel-path calculation for the cavity and stud area. The area ratio between framing and cavity is almost always suggested by an authoritative source, such as the latest *ASHRAE Handbook—Fundamentals* (ASHRAE 1993a), or a building energy code compliance document that references an older version of the *ASHRAE Handbook*. Then the resulting whole-wall thermal transmittance is compared to the desired value prescribed by either an enforced building energy code, volunteer home energy rating program, or standard. Sometimes only the center-of-cavity insulation material R-value is used for comparison to alternatives. With today's residential buildings increasingly constructed with materials such as metal, stress-skin-insulated core panels, and novel composites, a more accurate rating is necessary. Opaque envelopes can no longer be compared by frequently misleading "center-of-cavity" insulation material or clear wall R-values. The development of more accurate consumer-understandable wall labels will spur greater market acceptance of energy-efficient envelope systems.

The benefit of advanced systems with only a few thermal shorts compared to conventional wood-frame systems will be clearly discernible by comparing whole-wall thermal performance ratings. The large market share currently held by dimensional wood-frame systems, in part, reflects the misleading and inflated thermal performance ratings currently assigned them. The effect of extensive thermal shorts on performance is not accurately reflected in commonly used simplified energy calculations that are the current bases for consumer wall thermal comparisons.

Major energy-consuming appliances and windows now have labels that clearly tell consumers the energy cost implications of their purchase. The National Fenestration Rating Council (NFRC) is implementing a voluntary energy-efficiency label for fenestration products. However, when it comes to walls, a dominant architectural feature of buildings, the consumer, along with designers, builders, and manufacturers, is uncertain at the least and misled at the worst about the energy implications of opaque wall systems. In addition to more representative R-values, opaque wall labels also have the potential to identify the impact of thermal mass, airtightness, and moisture tolerance (inherent moisture control attributes that minimize the potential for moisture problems).

The broader national objective of maximizing sustainability (encompassing environmental life-cycle cost, which includes energy efficiency, recyclability, embodied energy, environmental sensitivity, etc.) also adds to the urgency of developing this accurate whole-wall thermal rating procedure. In the near future, consumer information on energy efficiency may finds itself buried in a growing list of "added value environmental features." This paper describes the technical basis for an industry- and consumer-acceptable whole-wall thermal performance rating procedure based on experimental measurements and validated computer simulations.

Introduction

Currently the marketplace is not fully accounting for the thermal shorts that exist in building walls. This results in the consumer not realizing the full energy cost savings anticipated by complying with energy code formulas and standards or even meeting the requirements of home energy rating systems. In addition, several building trends suggest that unless more careful consideration is given to whole-wall thermal performance, even more energy-saving opportunities will unintentionally be lost. With the improvement in window efficiency, the potential exists for residential structures to have more windows. When more windows are installed in a building, the more framing is needed, the greater the framing factor, and the higher the overall thermal transmittance of the opaque wall. With metal-frame construction gaining popularity in residential construction, the thermal shorts potentially resulting from the relatively higher thermal conductivity of metal compared to wood can mean much more severe heat loss than can be accounted for by traditional simplified calculations.

Why are the effects of interface details important? First of all, they are needed to properly baseline the thermal performance of common residential wood-framing systems and to more comprehensively evaluate alternatives. Second, their inclusion creates incentives for alternative wall system manufacturers to focus on the whole wall, including the critical connections to other parts of the building, not just the "clear wall."

Interface details make a difference. The consequences of poorly selected connections between envelope components are severe. Taking into account the interface details can have an impact on as much as 50% of the overall wall area. For some conventional wall systems the whole-wall R-value can be as much as 40% less than what is measured for the clear wall section. With the increasing use of alternatives to dimensional lumber-based systems (such as metal-frame and masonry systems for residential construction), this procedure highlights the importance of using interface details that minimize thermal shorts. Local heat loss through some wall interface details may double that estimated by simplified design calculation procedures that focus only on the clear wall. Poor interface details also may cause excessive moisture condensation and lead to stains and dust markings on the interior finish, which reveal envelope thermal shorts in an unsightly manner. This moist surface area can encourage the propagation of molds and mildews, which can lead to poor indoor air quality.

The whole-wall steady-state R-value, is the first element of at least four that are needed to consider all of the physical attributes of a wall system that affect whole-wall thermal performance. The other three elements listed in Figure 1 are the thermal mass benefits verified by dynamic hot-box measurements and modeling, airtightness measurement, and moisture tolerance, either modeled or measured using small laboratory test systems (Desjarlais et al. 1994). For some systems all four of the factors are important; for others, only the first is relevant. A fifth factor, which is not listed because of the uncertainty of how to calculate it accurately, is sustainability. As this field matures it may be desirable to add this element.

1. Whole Wall R-value

2. Thermal Mass Benefit

3. Airtightness

4. Moisture Tolerance

Figure 1 *Four elements of whole-wall performance.*

The individual wall system results from this procedure will help gain system-specific acceptance by code officials, building energy-rating programs such as the EPA Energy Star Buildings, building designers, and builders. In addition, each individual system evaluation will contribute toward a larger effort to build an easily accessible database of advanced wall systems. A user-friendly computer-accessed database is under development that could be used by the public to make whole-wall thermal performance comparisons. This database eventually will encompass all the critical wall performance elements listed in Figure 1. The package initially is being developed for access on the Internet and eventually a periodically updated report. Features of the package will include:

- An easily accessible archive of experimental results for all tested wall systems, including downloadable drawings.
- A database of material thermal properties.
- An easy-to-use interface to a computer-generated database or program that allows the determination of the whole-wall thermal performance rating for a wide variety of building envelope systems. This feature eventually will have the potential to develop custom ratings to reflect building-specific thermal, structural, and cost conditions.

It has been demonstrated that the first element, whole-wall R-value, of residential wall systems can be determined using a computer model (Childs 1993). More than 40 types of building wall systems already have been analyzed by this method (Kosny and Desjarlais 1994; Kosny and Christian 1995a; Kosny 1994). This approach requires a level of expertise in three-dimensional, finite difference heat transfer modeling that is beyond what normally is available in residential building design and construction offices. Therefore, the preferred approach for making this procedure available is a user-friendly interface to a three-dimensional computer model database that incorporates this methodology for determining a whole-wall R-value for residential buildings. The interface will allow users to define the building envelope in terms familiar to the industry rather than in the more complex three-dimensional analytical models. This database retrieval tool will build upon specific experimental hot-box results, allowing easy modification for particular details and computation of the whole-wall rating for the specific system. The user of this program will see the effect of interface detail improvements and be able to use them in envelope system design-cost optimization. This proposed evaluation procedure is based on not only a computer model, but also a synthesis of experimental measurements and validated computer simulation, significantly strengthening its accuracy and building market acceptance potential.

The first two performance elements involve (1) testing full-scale walls under steady-state and dynamic hot-box conditions, (2) three-dimensional finite-difference computer modeling, and (3) thermal analysis of alternative interface details. Hot-box wall tests are used to validate and calibrate two- and three-dimensional computer simulations. A steady-state whole-wall R-value is derived for each system. To account for thermal mass impacts, if any, customized tables and figures are generated to reflect dynamic thermal mass benefits compared to low-mass systems (Christian 1991). This information may be needed to demonstrate compliance to the Council of American Building Officials' Model Energy Code (MEC) (CABO 1995) and ASHRAE/BSR Standard 90.2-1993 (ASHRAE 1993b).

PROCEDURES TO EVALUATE WALL PERFORMANCE

Whole Wall R-Value

A calculation procedure and ASTM C 236 or ASTM C 976 (ASTM 1989) test are proposed as a starting point for a consensus methodology for estimating whole-wall R-value, independent of construction type. A clear wall section, 8 ft by 8 ft (2.4 m by 2.4 m), is tested in a guarded hot box. Experimental results are compared with two- and, if needed, three-dimensional heat conduction model predictions, based on finite-difference methods. The comparison will lead to a calibrated model. This procedure can be performed on any type of clear wall assembly: metal, masonry, wood, etc. After the model of the test wall is calibrated, simulations are made of the "clear wall" area with insulation and structural elements and eight wall interface details: corner, wall/roof, wall/foundation, window header, window sill, door jamb, door header, and window jamb, which make up a representative residential whole-wall elevation. Results from these detailed computer simulations are combined into a single whole-wall steady-state R-value estimation and compared with simplified calculation procedures and results from other wall systems. A reference wall elevation must be adapted to weigh the impacts of each interface detail. The building shown in Figure 2 is used to establish this reference wall.

For each wall system for which the whole-wall R-value is to be determined, all details commonly used and recommended (outside corner, wall/floor, wall/flat ceiling, wall/cathedral ceiling, door jamb, window jamb, window sill, and door header) must be available. The detail descriptions should include drawings, with all physical dimensions, and thermal property data for all material components contained in the details. If critical material component thermal conductivities are not available, it may be desirable to measure individual material conductivities, particularly if the clear wall hot-box data do not agree with the computer model predictions.

Although not necessary for every wall system, calibration of the model by hot-box measurement of a clear wall test section would enhance its credibility. The clear wall comparison of the experimental measurements and the model predictions minimizes the likelihood of systemic modeling errors throughout the wall detail simulations. The procedure requires (1) building a test wall in a hot-box frame; (2) instrumenting the test wall; (3) testing at steady-state conditions; (4) preparing a laboratory test data summary report, which includes a comparison to results of an uncalibrated model of the clear wall; (5) calibrating the model with "clear wall" hot-box results (key material components with uncertain thermal conductivity may have to be measured if model and experiment do not agree); (6) modeling the eight details (see sample set; Figures 3 through 10) making up a typical residential wall elevation and determine the area of influence of each detail; (7) calculating whole-wall R-value; (8) conducting parametric thermal analysis to improve details and whole-wall R-value; and (9) preparing a paper report and an electronic report for the advanced wall database.

Thermal Mass Benefit

Wall systems with significant thermal mass, have the potential to reduce building annual heating and cooling energy requirements, depending on the climate, below that required by standard wood-frame construction with similar steady-state R-value. A procedure has been developed to measure and generate metrics that reflect

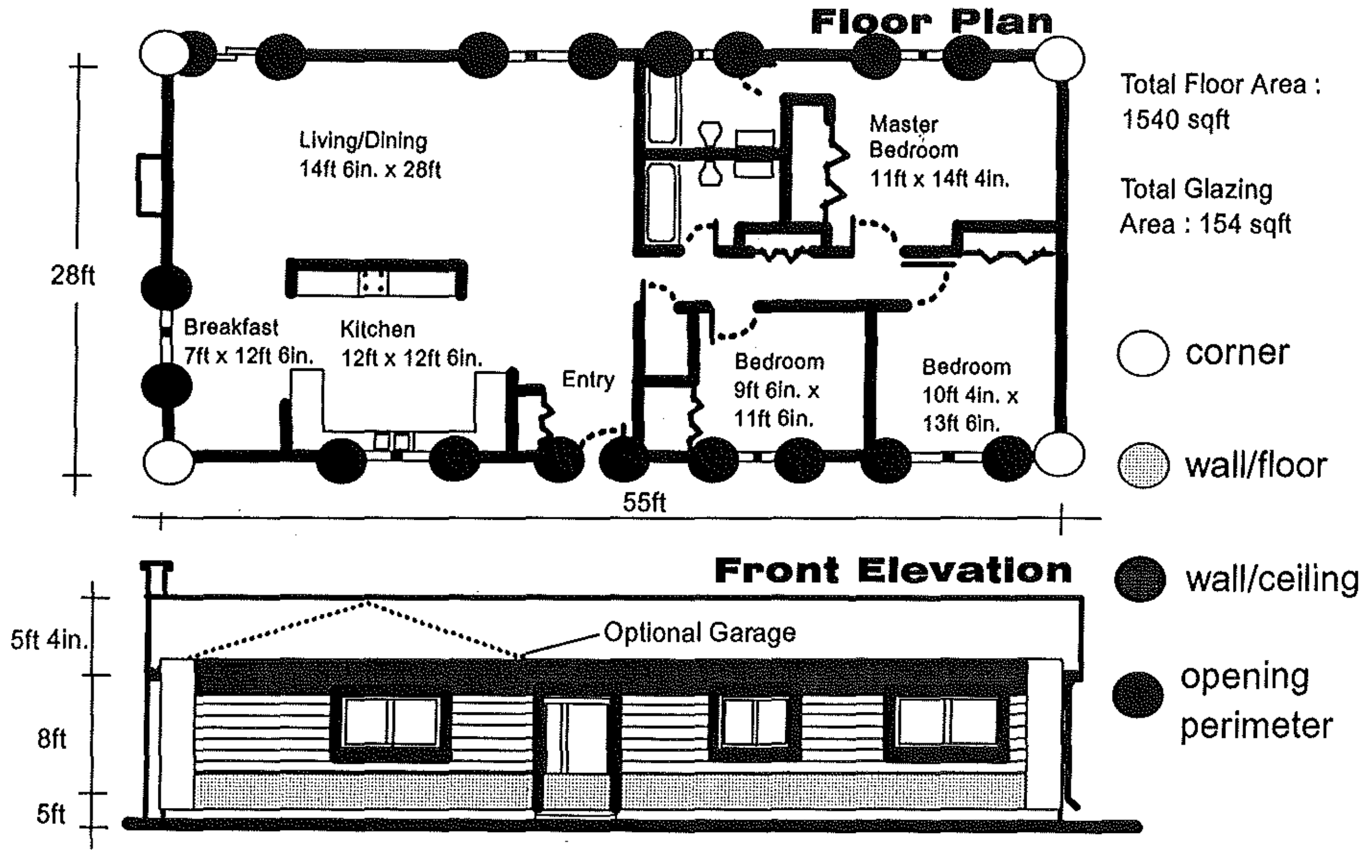

Figure 2 *Floor plan and elevation of one-story ranch house.*

this thermal mass benefit by providing an MEC-formatted table (Christian 1991). The procedure is as follows:

1. Conduct a dynamic hot-box test to determine dynamic response factors.

2. Run the three-dimensional model and compare it to dynamic hot-box test results from step 1 and generate response factors.

3. Run an "equivalent wall" program, which generates a simplified uniform layer wall that has the same dynamic thermal behavior as the actual complex wall tested in step 1. This task will generate a list of thermophysical properties for each uniform layer (R-value, thermal capacitance, and thickness).

4. Compare response factors for the three-dimensional wall generated in step 2 to the response factors of the simplified, one-dimensional wall generated in step 3. If there is an acceptable match, a set of envelope system thermophysical properties that can be used directly in whole-building simulation models is now available to define the energy-saving benefits of the thermal mass in different climates and building types compared to standard wood-frame walls.

5. A whole-building simulation program such as DOE2 will be run for the "equivalent wall" and standard-code-compliant wood-frame wall on a standard building in six U.S. climates. The mass effect will be determined by comparing the annual energy consumption comparison from the standard house (such as the one shown in Figure 2, using the "equivalent wall") to that resulting from the identical house with wood-frame walls.

6. A report is prepared containing (a) a set of uniform layer thermophysical properties for use in whole-building simulation and (b) code-compliance tables: Council of American Building Officials (CABO) MEC thermal transmittance of the components of the opaque wall area and customized whole-wall thermal conductance, U_w.

Tables for this specific wall system will be derived using the hot-box-validated measurements described above. The same procedure will be used to develop the generic tables found in the MEC for all thermal mass walls with more than 6.0 Btu/ft (19 W/m^2) of wall thermal capacitance (CABO 1995). The existing MEC lists generic U_w tables listed as Table No. 502.1.2a required U_w (with insulation placed on the exterior of the wall mass);

2b (with insulation placed on the interior of the wall mass); and 2c (with integral insulation and mass mixed) (CABO 1995). The Energy Policy Act of 1992 suggests all states consider the adoption of this code. This customized table can be used to show code officials' compliance with the prescriptive U_w requirements in the MEC that are based on wood-frame constructions. Finally, a figure compliant with ASHRAE Standard 90.2, customized to replace the applicable figure in the prescriptive portion of this code, will be developed.

Airtightness

A combination of ASTM standards (C236 or C976 [ASTM 1989]) or E1424 and E283 (ASTM 1995) will be used to measure the air leakage and heat loss through wall assemblies under simulated wind conditions ranging from 0 to 15 mph (24 kph). Varying the differential pressures from 0 to 25 to 50 Pa should simulate the extremes to which a wall is exposed in a real building. However, because many of the leakage paths through an exterior wall of a residential building occur at the wall connections and not through the typical clear wall, comprising the 8-ft by 8-ft (2.4-m by 2.4-m) test section, the test specimen will be modified to contain one light switch and one duplex outlet connected with 14-gauge wiring and possibly other details. With heat loss in a building reaching as high as 40% due to infiltration (NAIMA 1994), including this performance parameter would be important, but the workmanship quality on the construction site compared to a laboratory specimen must be considered. A second complicating factor is that, over time, materials may shrink, crack, etc., and this will change the leakage over time. Procedures to measure this wall performance element are not as well developed as the first two and will need to be verified.

Moisture Tolerance

The wall moisture behavior, like the benefit of thermal mass, is a function of climate and building operation. The likelihood of annual moisture accumulation due to vapor diffusion of a particular wall system can be estimated by computer simulation. Moisture accumulation due to airflow into the wall is more difficult. The air pressure equalization effectiveness of any rain/drain screen inherent in the wall systems can be measured by monitoring the pressure difference across the rain/drain cavity from the exterior to the inside. One important feature to have in a long-lasting wall assembly is the ability for the wall to dry itself out if it should be built wet or pick up moisture due to a leak in the course of its in-service life. The drying rate can be modeled and measured in the laboratory. The potential for moisture accumulation (an undesirable characteristic) over specific full annual climatic cycles also can be modeled by heat and mass transfer codes such as MOIST and MATCH (Desjarlais et al. 1994). This element most likely will be addressed for each system by a modeling activity, except for periodic model validations by physical experiments conducted in laboratory hot boxes.

Whole Wall R-values

Eighteen system whole-wall R-values have been estimated by a finite-difference computer model (Childs 1993). For all 18 of the systems, the procedure described above for calculating whole-wall R-value has been followed. The model used is a generalized three-dimensional heat conduction code to analyze building envelopes. It can solve steady-state and/or transient heat conduction problems in one-, two-, or three-dimensional Cartesian, cylindrical, or spherical coordinates (Childs 1993). Multiple materials and time- and temperature-dependent thermal conductivity, density, and specific heat can be specified. The boundary conditions, which may be surface-to-environment or surface-to-surface, may 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 may be variable along each axis. The model solves transient problems by using any one of several finite-difference schemes: Crank-Nicolson implicit procedure, classical implicit procedure, classical explicit procedure, or Levy explicit method.

The accuracy of the modeling was validated using 28 test results of masonry, wood-frame, and metal stud walls (Kosny and Christian 1995b). Considering that the precision of the guarded hot box is reported to be approximately ±8% (ASTM C236 [ASTM 1989]), the ability of the model to reproduce the experimental data was found to be within the accuracy of the test method.

The rotatable guarded hot box (RGHB) is an envelope testing apparatus that is designed in accordance with ASTM C 236 (ASTM 1989). The RGHB accepts test specimens that are up to 13 ft by 10 ft (4 m by 3 m) with a metering chamber that is approximately 8 ft by 8 ft (2.4 m by 2.4 m). The RGHB has three particularly unique features: (1) it accommodates assemblies up to 24 in. (61 cm) thick, (2) test specimens can be rotated to permit thermal performance measurement at any angle from vertical to horizontal position (0 degrees to 180 degrees), and (3) dynamic guarded hot-box tests can be conducted on high-thermal-mass wall systems.

The RGHB climate chamber temperature can be controlled from −10°F to 140°F (−23°C to 60°C) and the air velocity from 0 mph to 15 mph (24 kph). The RGHB metering chamber temperature can be controlled from 70°F to 140°F (21°C to 60°C) and the air velocity from 0 mph to 1 mph (1.6 kph). The instrumentation inventory available consists of 200 type-T thermocouple-temperature sensors, 10 thermopile-type heat flux transducers, two air velocity meters, two pressure transducers, and eight other voltage output-type sensors. The test apparatus is fully automated:

TABLE 1 Whole Wall R-Value Database

No.	System Description	Clear Wall R-value for Windows h·ft²·°F/Btu	Clear Wall R-value for Windows m²·K/W	Whole Wall R-value h·ft²·°F/Btu	Whole Wall R-value m²·K/W	$(R_{ww}/R_{cw}) \times 100\%$
1.	12-in. (30-cm) Two-core insul. units — concrete 120 lb/ft³ (1920 kg/m³), EPS inserts — 1-7/8-in. (4.8-cm) thick, grout fillings 24-in. (60-cm) o.c.	3.7	0.64	3.6	0.63	97.3
2.	12-in. (30-cm) Two-core insul. units-wood concrete 40 lb/ft³ (640 kg/m³), EPS inserts — 1-7/8-in. (4.8-cm) thick, grout fillings 24-in. (60-cm) o.c.	9.4	1.65	8.6	1.52	91.7
3.	12-in. (30-cm) Cut-web insul. units-concrete 120 lb/ft³ (1920 kg/m³), EPS inserts— 2-1/2-in. (6.4-cm) thick, grout fillings 16-in. (40-cm) o.c.	4.7	0.82	4.1	0.73	88.2
4.	12-in. (30-cm) Cut-web insul. units-wood concrete 40 lb/ft³ (640 kg/m³), EPS inserts — 2-1/2-in. (6.4-cm) thick, grout fillings 16-in. (40-cm) o.c.	10.7	1.88	9.2	1.61	85.6
5.	12-in. (30-cm) Multicore insul. units-polystyrene beads concrete 30 lb/ft³ (480 kg/m³), EPS inserts in all cores.	19.2	3.38	14.7	2.59	76.6
6.	EPS block-forms poured in place with concrete, block walls 1-7/8-in. (4.8-cm) thick.	15.2	2.68	15.7	2.77	103.3
7.	2x4 wood stud wall 16-in. (40-cm) o.c., R-11 batts, ½-in. (1.3-cm) plywood-exterior, ½-in. (1.3-cm) gypsumboard-interior.	10.6	1.86	9.6	1.69	90.9
8.	2x4 wood stud wall 24-in. (60-cm) o.c., R-11 batts, ½-in. (1.3-cm) plywood-exterior, ½-in. (1.3-cm) gypsumboard-interior.	10.8	1.91	9.9	1.74	91.2
9.	2x6 wood stud wall 24-in. (60-cm) o.c., R-19 batts, ½-in. (1.3-cm) plywood-exterior, ½-in. (1.3-cm) gypsumboard-interior.	16.4	2.88	13.7	2.41	83.7
10.	Larsen Truss walls — 2x4 wood stud wall 16-in. (40-cm) o.c., R-11 batts + 8-in. (20-cm) thick Larsen trusses insulated by 8-in. (20-cm) thick batts, ½-in. (1.3-cm.) plywood-exterior, ½-in. (1.3-cm) gypsumboard-interior.	40.4	7.12	38.5	6.78	95.3
11.	Stress skin panel wall, 6-in. (15-cm) thick foam core + ½-in. (1.3-cm) OSB boards, ½-in. (1.3-cm) plywood-exterior, ½-in. (1.3-cm) gypsumboard-interior.	24.7	4.35	21.6	3.80	87.5
12.	4-in. (10-cm) metal stud wall, 24-in. (60-cm) o.c., R-11 batts, ½-in. (1.3-cm) plywood-exterior + 1-in. (2.5-cm) EPS sheathing + ½-in. (1.3-cm) wood siding, ½-in. (1.3-cm) gypsumboard-interior. NAHB Energy Consv. House Details.	14.8	2.60	10.9	1.91	73.5
13.	3-1/2-in. (8.9-cm.) Metal stud wall, 16-in. (40-cm.) o.c., R-11 batts, ½-in. (1.3-cm.) plywood-exterior +½-in. (1.3-cm.) wood siding, ½-in. (1.3-cm.) gypsumboard-interior	7.4	1.31	6.1	1.08	82.6
14.	3-1/2-in. (8.9-cm.) Metal stud wall, 16-in. (40-cm) o.c., R-11 batts, ½-in. (1.3-cm) plywood-exterior + ½-in. (1.3-cm) EPS sheathing + ½-in. (1.3-cm) wood siding, ½-in. (1.3-cm) gypsumboard-interior. AISI Manual Details.	9.9	1.74	8.0	1.42	81.3
15.	3-1/2-in. (8.9-cm) metal stud wall, 16-in. (40-cm) o.c., R-11 batts, ½-in. (1.3-cm) plywood-exterior + 1-in. (2.5-cm) EPS sheathing + ½-in. (1.3-cm) wood siding, ½-in. (1.3-cm) gypsumboard -interior. AISI Manual Details.	11.8	2.07	9.5	1.67	80.5
16.	3-1/2-in. (8.9-cm) metal stud wall, 24-in. (60-cm) o.c., R-11 batts, ½-in. (1.3-cm) plywood-exterior + ½-in. (1.3-cm) wood siding, ½-in. (1.3-cm) gypsumboard-interior. AISI Manual Details.	9.4	1.66	7.0	1.24	74.8
17.	3-1/2-in. (8.9-cm) metal stud wall, 24-in. (60-cm) o.c., R-11 batts, ½-in. (1.3-cm) plywood-exterior + ½-in. (1.3-cm) EPS sheathing + ½-in. (1.3-cm) wood siding, ½-in. (1.3-cm) gypsumboard-interior. AISI Manual Details.	11.8	2.08	8.9	1.57	75.6
18.	3-1/2-in. (8.9-cm) metal stud wall, 24-in. (60-cm) o.c., R-11 batts, ½-in. (1.3-cm) plywood-exterior + 1-in. (2.5-cm) EPS sheathing + ½-in. (1.3-cm) wood siding, ½-in. (1.3-cm) gypsumboard -interior. AISI Manual Details.	13.3	2.35	10.2	1.80	76.5

the chamber temperatures and air velocities are computer controlled at steady conditions or in 200-step cycles. Data collection and processing are performed in real time. The system was designed for a precision of better than ±3% and a bias of less than ±5%. Estimates of the error bands will be generated with all test results.

The procedure described above for deriving the whole-wall R-value was followed for the 18 wall systems listed in Table 1. The column labeled "clear wall" R-value represents the model's simulation results of just the flat portion of the opaque wall with insulation and necessary structural elements unaffected by any interface details. The column labeled "whole-wall R-value" includes the influence of not only the clear wall but also all necessary wall interface details. The comparison of these two values gives one a good overall perspective of the importance of wall interface details for both conventional wood, metal, masonry, and several high-performance wall systems. Frequently, the opaque wall thermal performance is simply described at the point of sale as the "clear wall" value. This means that the whole-wall R-value could be overstated from –3.3% to 26.5%, as shown by the last column in Table 1 "$(R_{ww}/R_{cw}) \times 100\%$." Recognize that these differences can change by selecting different interface details with varying degrees of thermal shorts.

Numerous comparisons can be made using the data in Table 1 to illustrate the importance of using a whole-wall R-value (R_{ww}) to select the most energy-efficient wall system. The difference between the clear wall and whole-wall R-value could be argued to be representative of the energy-saving potential of adopting the rating procedure proposed in this paper. With most building owners thinking they have the higher clear wall value rather than the value more representative of reality, whole R-value.

Systems 5 and 6 show two different high-performance masonry units. If one uses the clear-wall R-value to choose the one with the highest R-value, one would pick system 5, the low-density concrete multicore insulation unit, because its R-value is 19.19 h·ft²·°F/Btu (3.38 m²·K/W) compared to 15.22 h·ft²·°F/Btu (2.68 m²·K/W) for system 6, EPS block-forms. However, if one uses the whole-wall R-value as the criterion for choosing the most efficient system, one would choose just the opposite because system 6 has the higher value [15.72 h·ft²·°F/Btu (2.77 m²·K/W)] compared to 14.69 h·ft²·°F/Btu (2.59 m²·K/W). Another observation is that the whole-wall R-value for system 6, the foam-form system, actually is higher than the clear-wall values by more than 3%. This illustrates the effect of the high thermal resistance of the interface details.

Systems 7, 8, and 9 are all conventional wood-frame systems. Note that the details impact the whole-wall R-value more for 2×6 walls than for 2×4 walls. The ratio of R_{ww}/R_{cw} is about 90% for the 2×4 walls and 84% for the 2×6 walls.

System 10, the Larsen Truss, is the best-performing system displayed in Table 1. Not only is the clear-wall R-value high [40 h·ft²·°F/Btu (7.12 m²·K/W)], but the whole wall R-value is minimally impacted by the addition of details being considered [38.5 h·ft²·°F/Btu (6.78 m²·K/W)].

Comparing system 11, the 6-in. (15-cm) stress-skin-panel wall, to the conventional 2×6 wood-frame wall, shows system 9, that the stress-skin-panel clear-wall R-value [25 h·ft²·°F/Btu (4.35 m²·K/W)] is 51% higher than that of the 2×6 wall [16 h·ft²·°F/Btu (2.88 m²·K/W)]. When details are included in the whole-wall R-value, the percentage improvement is even greater-58% 21.59 h·ft²·°F/Btu (3.8 m²·K/W) to 13.69 h·ft²·°F/Btu (2.41 m²·K/W). This is an example of the advanced systems will generally benefit from a performance criterion that reflects whole-wall rather than the commonly used simplified clear-wall values.

Systems 12 through 18 listed in Table 1 are all metal. On average, the whole-wall R-value for these seven systems is 22% less than the clear-wall values. Metal can be used to build energy-efficient envelopes, but not by using techniques common to wood-frame construction. The conventional metal residential systems reflected in Table 1 do not fare as well when the whole-wall R-value is used as the reference compared to all other systems displayed in Table 1. For example, if one is considering either system 6 (EPS block forms) or system 12 (a 4-in. metal stud wall), the clear-wall R-value is about the same, 15 h·ft²·°F/Btu (2.64 m²·K/W); however, if the comparison is made using the whole-wall R-value, the EPS foam-block system has a 45% higher value, 15.72 h·ft²·°F/Btu (2.77 m²·K/W) to 10.86 h·ft²·°F/Btu (1.91 m²·K/W).

Table 2 shows a comparison of the center-of-cavity R-values instead of clear wall R-values of five common residential frame systems to the whole-wall R-values. This suggests that when the realtor describes the wall to a potential home buyer by stating the R-value of insulation across the cavity, the whole-wall R-value actually may be overstated by 26.6% to 58.1%. If one is comparing the thermal performance differences between metal (system 13) and wood (system 7) frames using center-of-cavity R-values, one would conclude there is no difference because both have center-of-cavity R-values of about 14 h·ft²·°F/ Btu (2.5 m²·K/W). However, when the whole-wall R-value is used as the criterion for comparison, the 2×4 wood wall system is 56% better [9.58 h·ft²·°F/Btu (1.69 m²·K/W)], compared to 6.14 h·ft²·°F/Btu (1.08 m²·K/W) for the metal system.

These comparisons are not meant to imply one type of construction is always better than another. They are based on representative details. Whole-wall R-values could change significantly if certain key interface details were changed. The intent of making these sample comparisons is simply to point out the importance of having the whole-wall R-value available to the marketplace for guiding wall designers, manufacturers, and buyers to more energy-efficient systems.

TABLE 2 **Whole Wall R-Value Compared to Center-of-Cavity R-Value**

No. System Description	Center-of-Cavity R-value h·ft²·°F/Btu	Center-of-Cavity R-value m²·K/W	Whole Wall R-value h·ft²·°F/Btu	Whole Wall R-value m²·K/W	$(R_{ww}/R_{cav}) \times$ 100%
7. 2×4 wood stud wall 16-in. (40-cm.) o.c., R-11 batts, ½-in. (1.3-cm.) plywood-exterior, ½-in. (1.3-cm.) gypsumboard -interior.	13.6	2.40	9.6	1.69	70.2
8. 2×4 wood stud wall 24-in. (60-cm.) o.c., R-11 batts, ½-in. (1.3-cm.) plywood-exterior,½-in. (1.3-cm.) gypsumboard -interior.	13.6	2.40	9.9	1.74	73.4
12. 4-in. (10-cm.) Metal stud wall, 24-in. (60-cm.) o.c., R-11 batts, ½-in. (1.3-cm.) plywood-exterior + 1-in. (2.5-cm) EPS sheathing + ½-in. (1.3-cm.) wood siding, ½-in. (1.3-cm.) gypsumboard-interior. NAHB Energy Consv. House Details.	19.6	3.46	10.9	1.91	55.3
13. 3-1/2-in. (8.9-cm.) Metal stud wall, 16-in. (40-cm.) o.c., R-11 batts, ½-in. (1.3-cm.) plywood-exterior + ½-in. (1.3-cm.) wood siding, ½-in. (1.3-cm.) gypsumboard-interior. AISI Manual Details.	14.6	2.58	6.1	1.08	41.9
15. 3-1/2-in. (8.9-cm.) Metal stud wall, 16-in. (40-cm.) o.c., R-11 batts, ½-in. (1.3-cm.) plywood-exterior + 1-in. (2.5-cm) EPS sheathing + ½-in. (1.3-cm.) wood siding, ½-in. (1.3-cm.) gypsumboard-interior. AISI Manual Details.	18.6	3.28	9.5	1.67	50.8

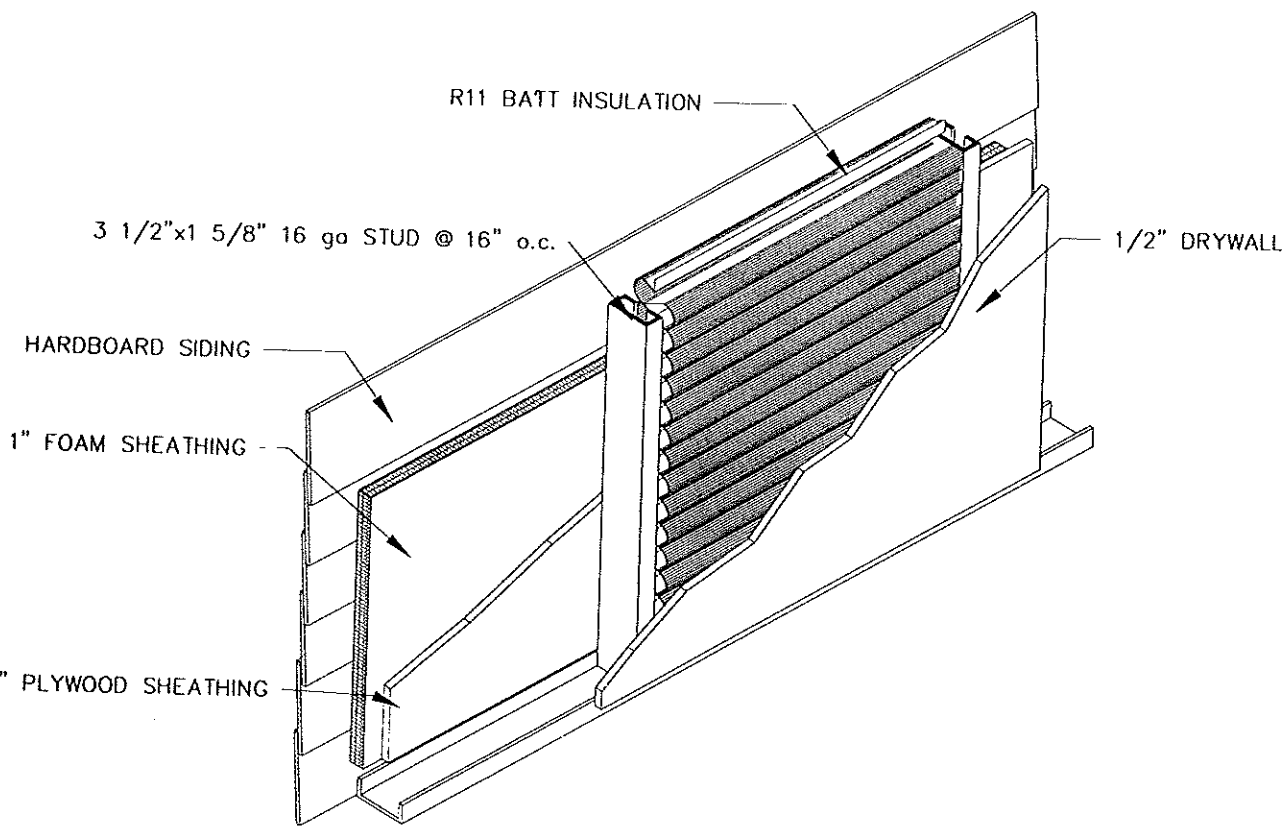

Figure 3 *Clear-wall section detail (AISI 1993).*

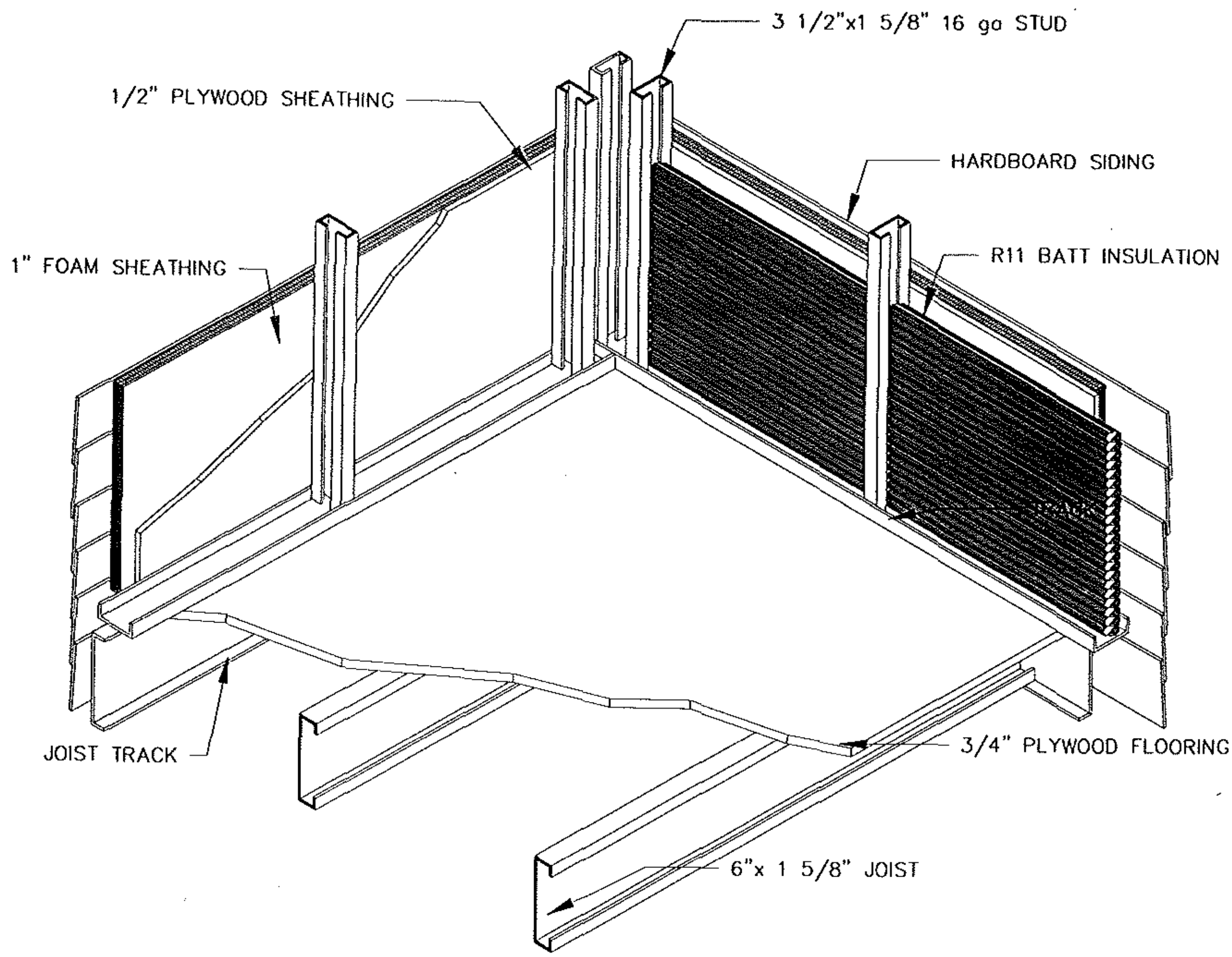

Figure 4 *Corner detail (USG 1992).*

Detailed Example of how the Whole Wall R-value is derived: Metal Frame Wall

To produce the data in Tables 1 and 2, the thermophysical properties and detailed geometries of all the clear wall and interface details are needed. The general rule was to use *ASHRAE Handbook* material properties and "recommended" details by the wall system manufacturer or representative association design guides. To illustrate one example set of details are shown in Figures 3 through 10 for System 15, which is a 3½-in. (8.9-cm) metal frame. These are taken from AISI (1993) and other sources that are used by architects, engineers and builders (USGC 1992; Hoke 1988). Figure 3 shows the clear-wall section detail, with 16-gauge studs at 16 in. (40 cm) o.c. and 1 in. (2.5 cm) thick foam sheathing. Figure 4 depicts a separated three-stud corner detail. Racking resistance is obtained by the use of ½-in. (1.3-cm) plywood sheathing. Figure 5 is the roof-to-wall detail, which shows a built-up header of 6-in. (15.2-cm) joists. A similar detail was used in the NAHB/AISI Resource Conservation House as specified in the blueprints for this demonstration house in Bowie, Md. Figure 6 shows the wall-to-foundation detail, which also was used on the NAHB steel-frame house. Note that the 1-in. (2.5-cm) foam sheathing and concrete forms with 4 in. (10.1 cm) of EPS minimize the thermal short in this area. Figures 7 through 10 show the added framing for windows and doors. In general, the details selected were representative of those used in residential metal-frame structures that meet structural requirements and give some consideration to reducing thermal shorts at the wall interface with other envelope components.

The details shown for system 15 were used to obtain the geometries needed as input to the model program. Selection of other details may indeed yield different results. Figure 11 is a bar graph showing the effective R-value for an area containing each of the eight details for systems 15 and 13 and the area-weighted whole-wall R-value. Note that in all cases the details for the two systems shown have lower values than the clear wall (labeled "clear wall" in Figure 11). The dark bars represent system 15 with the sheathing which has a whole-wall R-value that is 80.5% of the clear-wall R-value. The lighter bars display similar results for system 13, without foam sheathing. Relative to system 15 with insulated sheathing, the details do

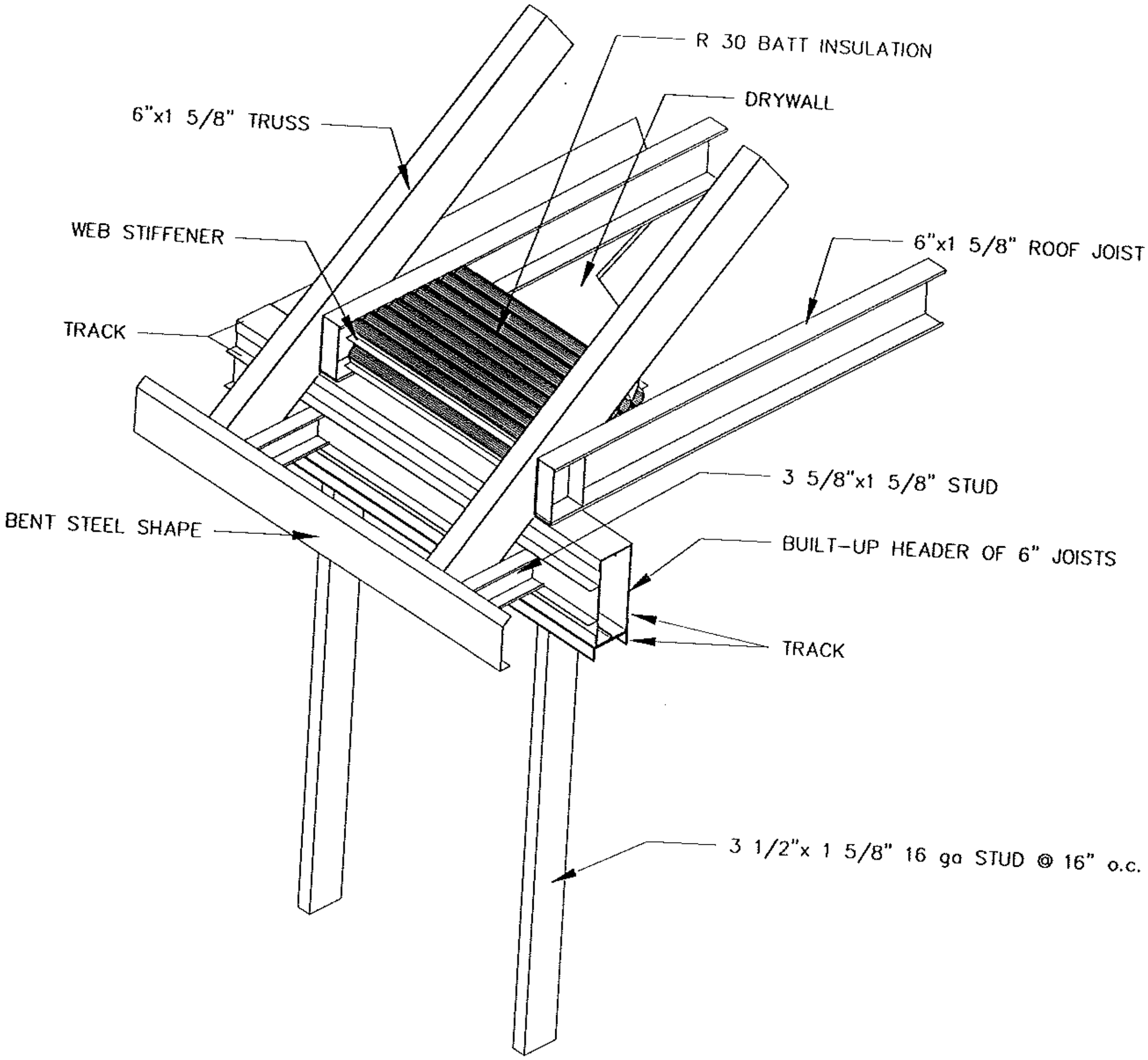

Figure 5 *Roof-to-joist detail (Hoke 1988).*

not compromise the clear wall R-value as severely. The whole-wall R-value is 82.6% of the clear-wall value. The impact of sheathing helps increase the absolute apparent R-value of all details but does not eliminate the thermal shorting.

The physical area influenced by each of the details can be seen in Figure 2. The thermal shorts through the details extend their influence into a larger opaque wall area than that area comprising the physical details. Figure 12 shows the percentage of the entire exterior opaque wall area influenced by each of the wall details described in Figures 3 through 10. Note that the presence of the details impacts 32% of the opaque exterior wall area. This impact is determined by examining the isothermal plots resulting from steady-state simulation of heat transfer across these assemblies. Because the apparent R-values are smaller than the clear-wall R-values, the net heat transfer assigned to each detail ends up proportionally much larger than its area of influence. The 32% area comprising the influence of the details accounts for a higher percentage of heat loss, 45%. The results for metal-frame wall systems can vary. This is only meant to illustrate how the whole-wall R-values were calculated and then displayed in Table 1.

Sensitivity to Prototype Building wall Elevation

To accurately derive a representative whole-wall R-value, the procedure described in this paper would have to be followed for each specific house, modeling each typical thermal short, determining the area of influence of

TABLE 3 **Sensitivity of Whole-Wall R-Value to Fenestration Area, 10% to 20% Window/Floor Area**

No.	System Description	Whole Wall R-value for Windows of 10% of Floor Area		Whole Wall R-value for Windows of 20% of Floor Area		$(R_{ww}/R_{cw}) \times 100\%$	
		h·ft²·°F/Btu	m²·K/W	h·ft²·°F/Btu	m²·K/W	for 10%	for 20%
1.	12-in. (30-cm.) Two-core insul. units- concrete 120lb/ft³ (1920 kg/m³), EPS inserts—1-7/8-in. (4.8-cm.) thick, grout fillings 24-in. (60-cm.) o.c.	3.6	0.63	3.5	0.62	97.3	96.0
2.	12-in. (30-cm.) Two-core insul units-wood concrete 40lb/ft³ (640 kg/m³), EPS inserts—1-7/8-in. (4.8-cm.) thick, grout fillings 24-in. (60-cm.) o.c.	8.6	1.52	8.3	1.46	91.7	88.0
3.	12-in. (30-cm.) Cut-web insul. units- concrete 120lb/ft³ (1920 kg/m³), EPS inserts—2-1/2-in. (6.4-cm.) thick, grout fillings 16-in. (40-cm.) o.c.	4.1	0.73	3.9	0.69	88.2	84.0
4.	12-in. (30-cm.) Cut-web insul. units-wood concrete 40lb/ft³ (640 kg/m³), EPS inserts—2-1/2-in. (6.4-cm.) thick, grout fillings 16-in. (40-cm.) o.c.	9.1	1.61	8.6	1.52	85.6	80.6
5.	12-in. (30-cm.) Multicore insul. units-polystyrene beads concrete 30lb/ft³ (480 kg/m³), EPS inserts in all cores.	14.7	2.59	14.5	2.55	76.6	75.4
6.	EPS block-forms poured in place with concrete, block walls 1-7/8-in. (4.8-cm.) thick.	15.7	2.77	15.7	2.77	103.3	103.4
7.	2×4 wood stud wall 16-in. (40-cm.) o.c., R-11 batts, ½-in. (1.3-cm.) plywood-exterior, ½-in. (1.3-cm.) gypsumboard-interior.	9.6	1.69	9.4	1.65	90.9	88.8
8.	2×4 wood stud wall 24-in. (60-cm.) o.c., R-11 batts, ½-in. (1.3-cm.) plywood-exterior, ½-in. (1.3-cm.) gypsumboard-interior.	9.9	1.74	9.6	1.69	91.2	88.7
9.	2×6 wood stud wall 24-in. (60-cm.) o.c., R-19 batts, ½-in. (1.3-cm.) plywood-exterior, ½-in. (1.3-cm.) gypsumboard-interior.	13.7	2.41	12.5	2.2	83.7	76.2
10.	Larsen Truss walls—2x4 wood stud wall 16-in. (40-cm.) o.c., R-11 batts + 8-in. (20-cm) thick Larsen trusses insulated by 8-in. (20-cm.) thick batts, ½-in. (1.3-cm.) plywood-exterior, ½-in. (1.3-cm.) gypsumboard-interior.	38.5	6.78	38.4	6.77	95.3	95.1
11.	Stress Skin Panel Wall, 6-in. (15-cm.) thick foam core + ½-in. (1.3-cm.) OSB boards, ½-in. (1.3-cm.) plywood-exterior, ½-in. (1.3-cm.) gypsumboard-interior.	21.6	3.8	21.2	3.74	87.5	86.0
12.	4-in. (10-cm.) Metal stud wall, 24-in. (60-cm.) o.c., R-11 batts, ½-in. (1.3-cm.) plywood-exterior, + 1-in. (2.5-cm) EPS sheathing + ½-in. (1.3-cm.) wood siding, ½-in. (1.3-cm.) gypsumboard-interior, NAHB Energy Consv. House Details.	10.9	0.63	9.7	1.70	73.5	65.4
13.	3-1/2-in. (8.9-cm.) Metal stud wall, 16-in. (40-cm.) o.c., R-11 batts, ½-in. (1.3-cm.) plywood-exterior +½-in. (1.3-cm.) wood siding, ½-in. (1.3-cm.) gypsumboard-interior	6.1	1.08	5.8	1.03	82.6	78.3
14.	3-1/2-in. (8.9-cm.) Metal stud wall, 16-in. (40-cm.) o.c., R-11 batts, ½-in. (1.3-cm.) plywood-exterior + ½-in. (1.3-cm) EPS sheathing + ½-in. (1.3-cm.) wood siding, ½-in. (1.3-cm.) gypsumboard-interior, AISI Manual Details.	8.0	1.42	7.5	1.32	81.3	76.1
15.	3-1/2-in. (8.9-cm.) Metal stud wall, 16-in. (40-cm.) o.c., R-11 batts, ½-in. (1.3-cm.) plywood-exterior + 1-in. (2.5-cm) EPS sheathing + ½-in. (1.3-cm.) wood siding, ½-in. (1.3-cm.) gypsumboard-interior. AISI Manual Details.	9.5	1.67	8.8	1.54	80.5	74.5
16.	3-1/2-in. (8.9-cm.) Metal stud wall, 24-in. (60-cm.) o.c., R-11 batts, ½-in. (1.3-cm.) plywood-exterior + ½-in. (1.3-cm.) wood siding, ½-in. (1.3-cm.) gypsumboard-interior. AISI Manual Details.	7.0	1.24	6.6	1.16	74.8	69.6
17.	3-1/2-in. (8.9-cm.) Metal stud wall, 24-in. (60-cm.) o.c., R-11 batts, ½-in. (1.3-cm.) plywood-exterior + ½-in. (1.3-cm) EPS sheathing + ½-in. (1.3-cm.) wood siding, ½-in. (1.3-cm.) gypsumboard-interior. AISI Manual Details.	8.9	1.57	8.2	1.45	75.6	69.8
18.	3-1/2-in. (8.9-cm.) Metal stud wall, 24-in. (60-cm.) o.c., R-11 batts, ½-in. (1.3-cm.) plywood-exterior + 1-in. (2.5-cm) EPS sheathing + ½-in. (1.3-cm.) wood siding, ½-in. (1.3-cm.) gypsumboard-interior. AISI Manual Details.	10.2	1.80	9.4	1.65	76.5	70.3

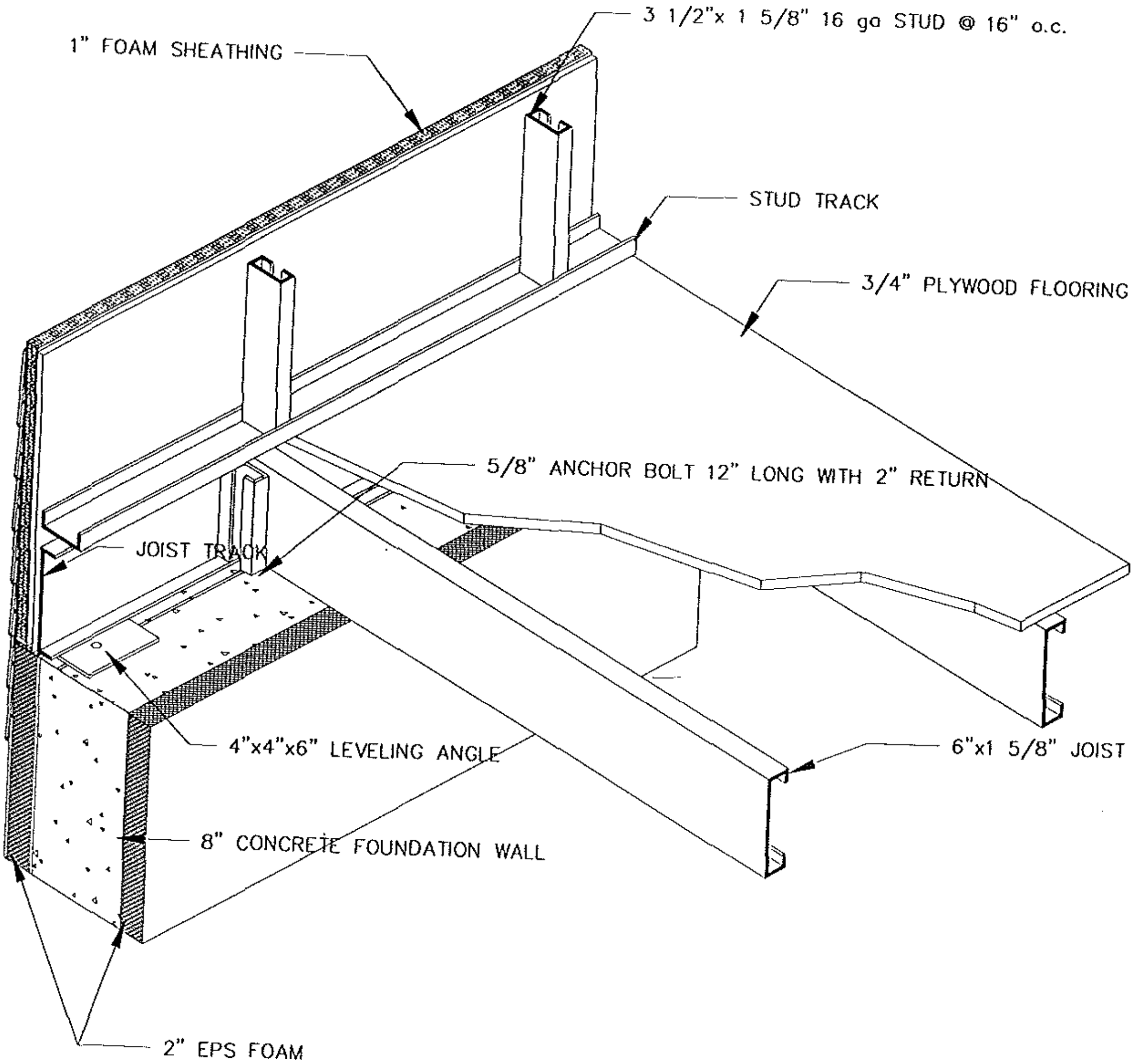

Figure 6 *Wall-to-foundation detail, used on NAHB resource conservation house.*

each short, calculating an apparent R-value representing each short, and weighting each one by area to produce the whole-wall R-value. This may be too complex to be done on each house plan. Instead, it is proposed that a representative house be used just to have a common basis for which to include typical details. One obvious point of discussion is, what is a representative house? To begin to answer this question the authors ran a sensitivity study on the house shown in Figure 2. The focus was on the most significant thermal shorts that occur around windows and doors. The base case has a window area equal to 10% of the floor area. In Table 3 we compare the whole-wall R-values assuming 20% window area for each of the 18 systems. The average decrease in the ratio of clear-wall to whole-wall R-value is 3.9%. This varied within a range of +0.1% for system 6 (foam forms) to 8.1% for system 12 (the NAHB 4-in. metal-frame wall). If systems are severely impacted by the interface details this sensitivity illustrates that it makes them look even worse. Even by almost doubling the amount of thermal shorting in a typical wall elevation the net ranking of R_{ww}/R_{cw} remains almost identical for the 18 different cases shown in Table 3 using 10% glass area compared to a similar ranking using 20%.

A second sensitivity study of the reference wall elevation was conducted by using a building with a more compact floor plan. It had 17 exterior wall corners instead of only four for the base building shown in Figure 2. Table 4 shows the whole-wall R-value calculation differences using the base building shown in Figure 2 compared to the one shown in Figure 13. The addition of 13 corners reduced the R_{ww}/R_{cw} by an average of 3.4% for the five systems examined. The relative ranking of these five systems did not change as a result of wall using a different house plan. Perhaps if a highly conductive corner detail were selected, the use of a reference building with substantially more corners would make a more significant difference.

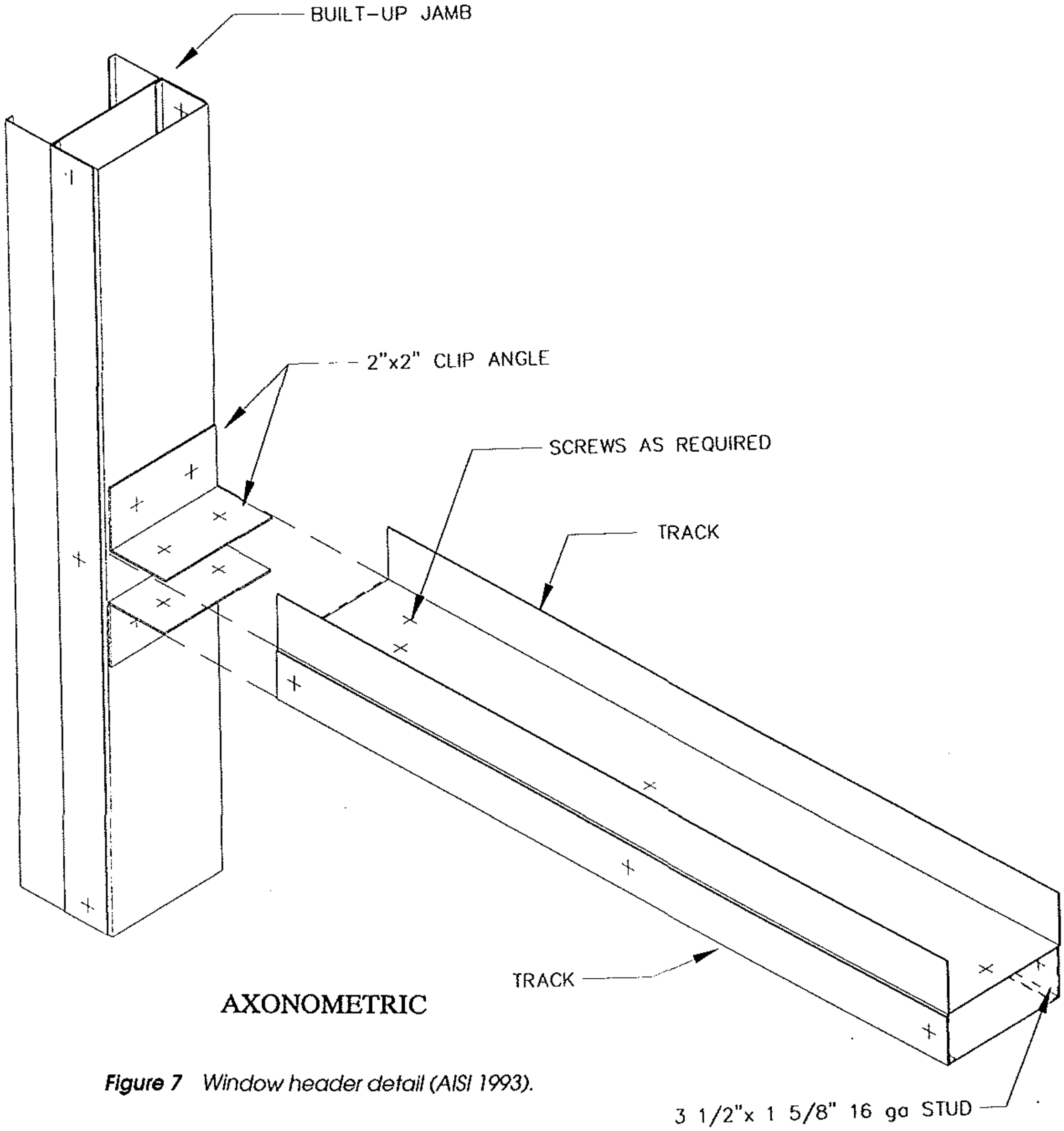

Figure 7 *Window header detail (AISI 1993).*

TABLE 4 **Sensitivity of Whole-Wall R-Value to Reference Wall Elevation**

System #	System Name	Clear Wall R-value h·ft²/Btu (m²·k/w)	Base Case Whole Wall R-value h·ft²/Btu (m²·k/w)	Base Case $R_{ow}/R_{cw} \times$ 100%	NAHB "B" House Whole Wall R-value h·ft²/Btu (m²·k/w)	NAHB "B" House $R_{ww}/R_{cw} \times$ 100%
3	Cut-web CMUs 120 lb concrete	4.7 (0.82)	4.1 (0.73)	88.2	3.3 (0.58)	83.4
5	Multicore CMUs	19.2 (3.38)	14.7 (2.59)	76.6	14.3 (2.52)	74.6
11	Stress Skin Panel	24.7 (4.35)	21.6 (3.80)	87.5	20.4 (3.6)	82.8
13	3 ½ in. Metal Stud No EPS	7.4 (1.31)	6.1 (1.08)	82.6	6.0 (1.06)	80.5
15	3 ½ in. Metal Studs 1 in. EPS	11.7 (2.07)	9.5 (1.67)	80.5	9.0 (1.59)	77.0

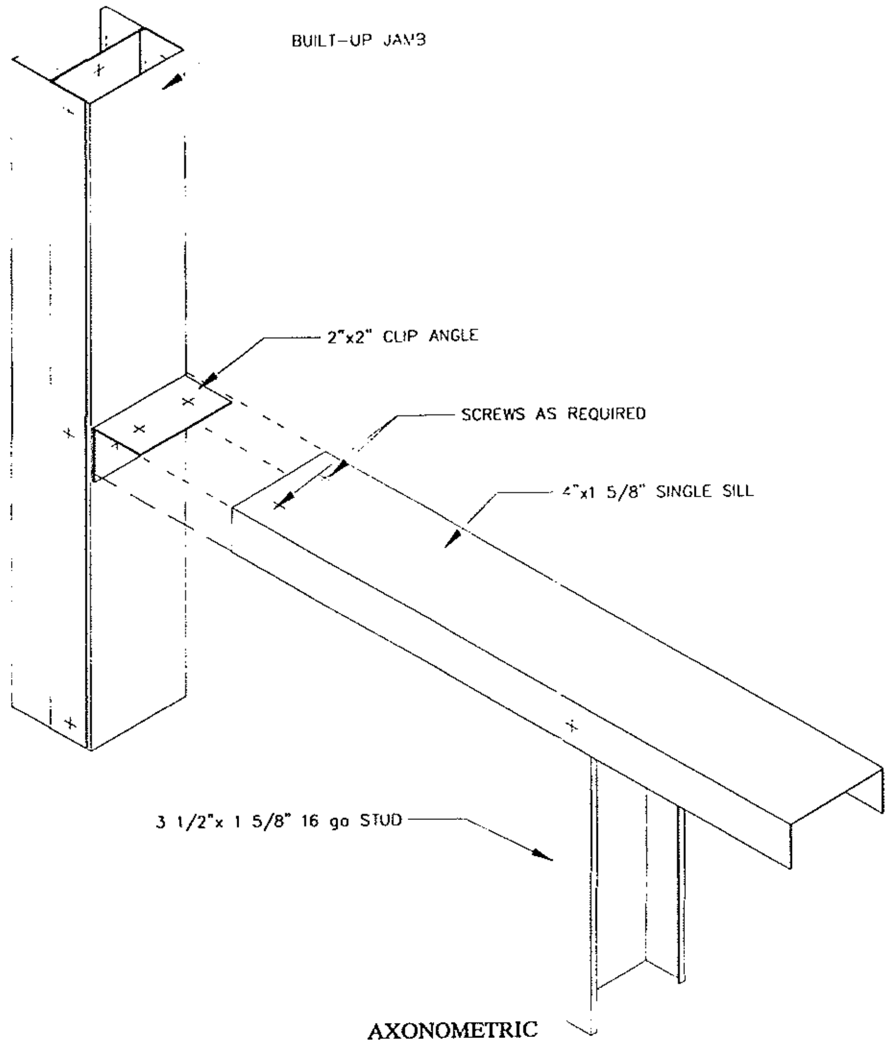

Figure 8 *Window still detail (AISI 1993).*

The observation that can be made by examining the effect of whole-wall R-value calculations for different prototype walls is that it does not seem to make much difference what type of reference wall is selected. The absolute R-values do change but if the whole-wall R-value is going to be used to make more realistic comparisons between systems, the fact that details are explicitly incorporated into the calculations seems to be more important than the selection of a reference wall elevation.

Conclusion

A new procedure is proposed for comparing the thermal performance differences between diverse types of wall systems. This procedure ultimately will include four elements: whole-wall R-value, thermal mass benefits, airtightness, and moisture tolerance. The whole-wall R-value procedure described in this report should be considered for adoption in ASHRAE Standard 90.2 (ASHRAE 1993b), MEC (CABO (1995), and HERS (Home Energy Rating System) (DOE 1995). In addition, many of the code compliance documents that are available to show builders how to comply with applicable codes, standards, and energy-efficiency incentive programs would benefit by using this whole-wall R-value comparison procedure. As the database of advanced wall systems is being assembled, it will be made available initially on the Internet and eventually on distributed computer programs, as well as periodic written reports.

The whole-wall R-value is a better criterion than the center-of-wall and much better than the center-of-cavity R-value methods used to compare most types of wall systems. The value includes the effect of the wall interface details used to connect the wall to other walls, windows, doors, ceilings, and foundations. A reference wall elevation is proposed as the basis by which to weigh the effects of the most common types of details used for different wall systems. This paper shows that for relative ranking of good to bad choices, the actual reference wall elevation selected for weighing the interface details into the whole-wall R-value is less important than at least having a procedure that considers the eight most significant types of thermal shorts found in typical residential wall constructions.

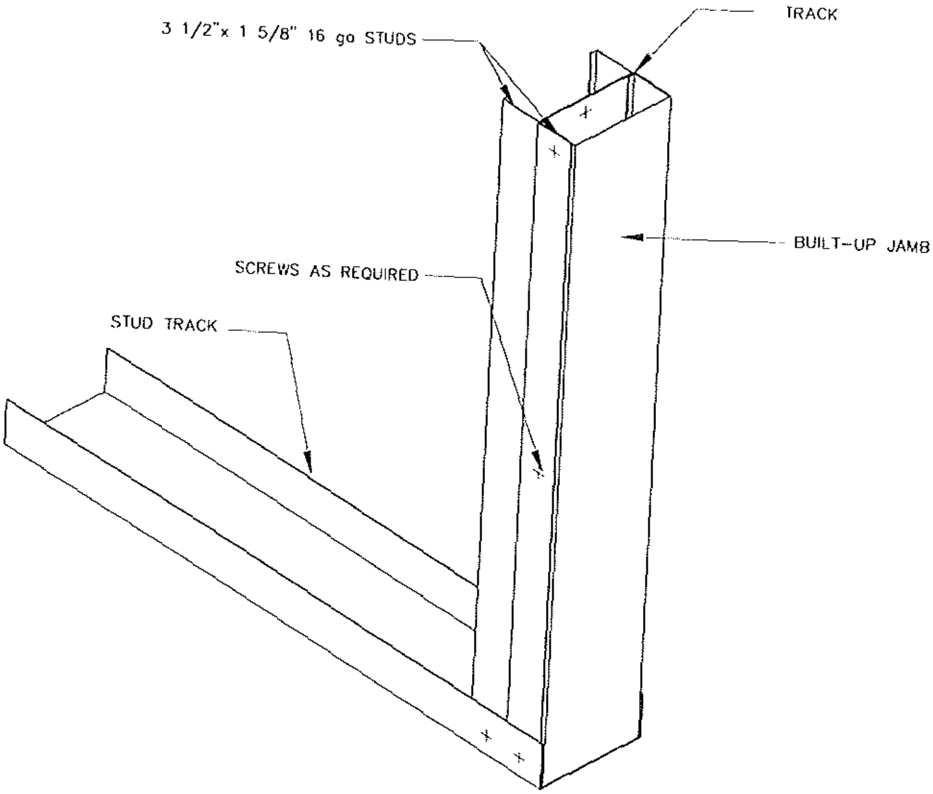

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Figure 9 *Door jamb detail (AISI 1993).*

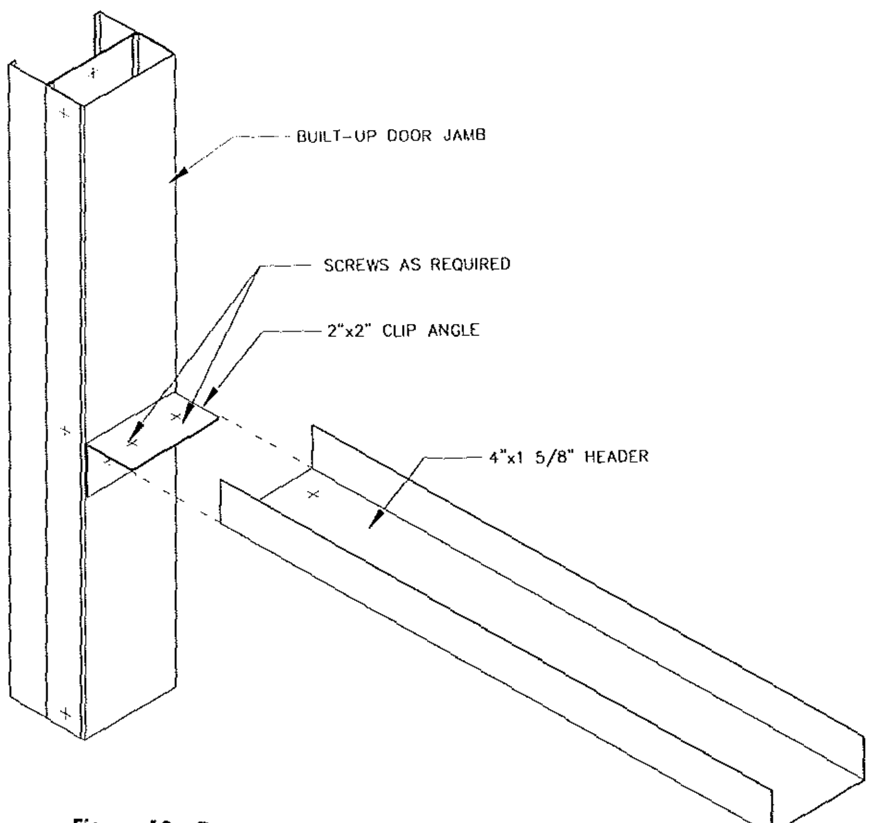


Figure 10 *Door header detail (AISI 1993).*

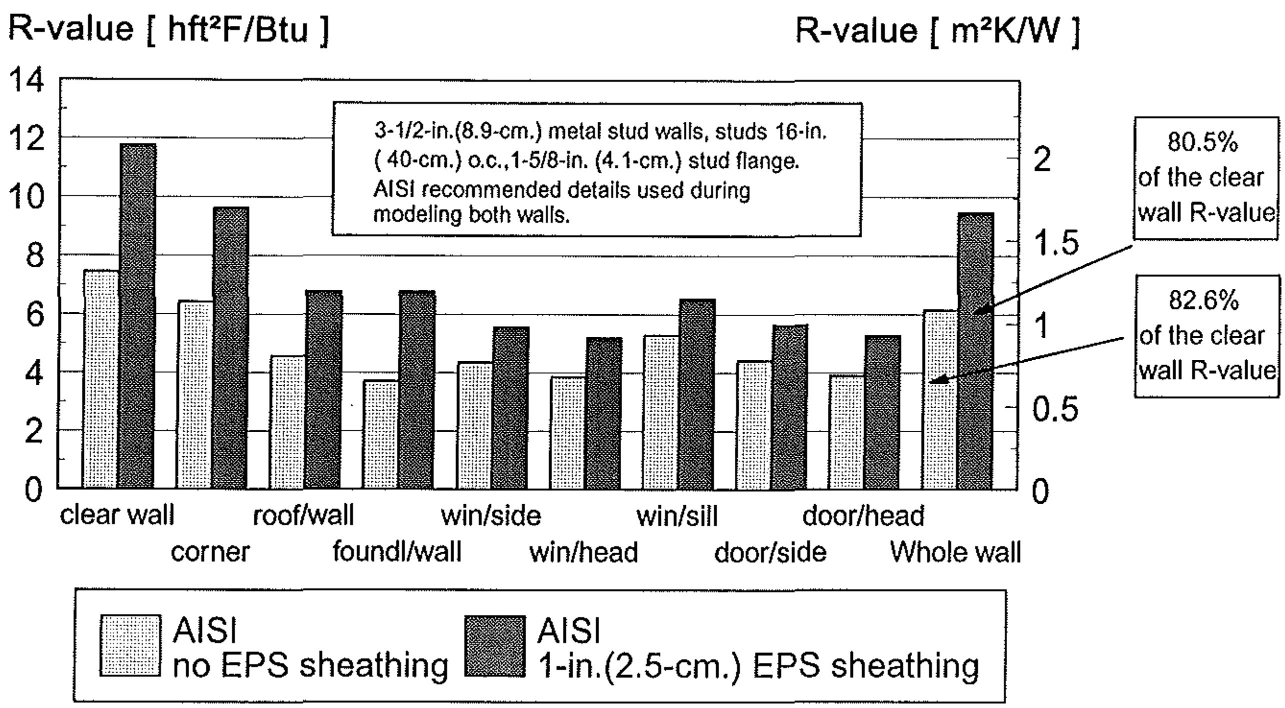


Figure 11 *Whole-wall thermal analysis for metal stud wall systems.*

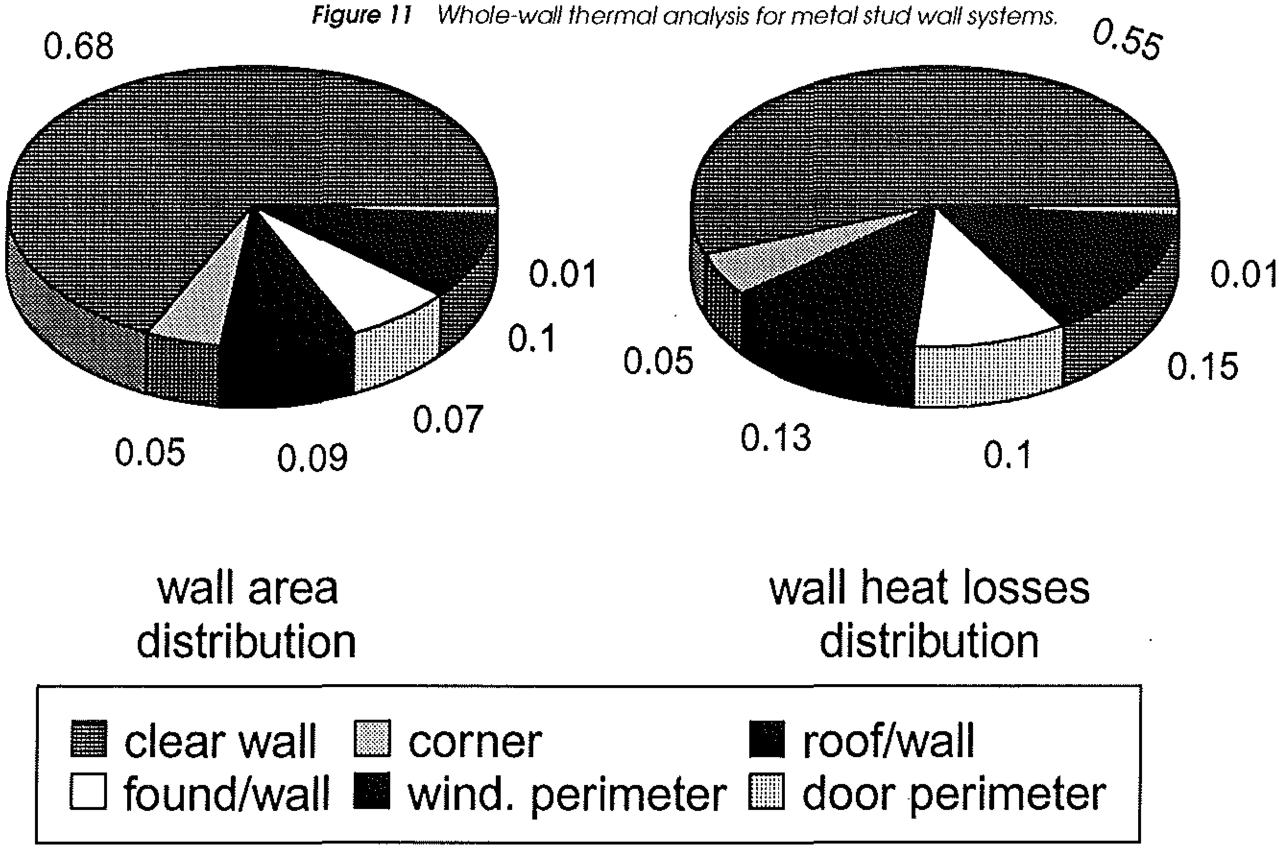
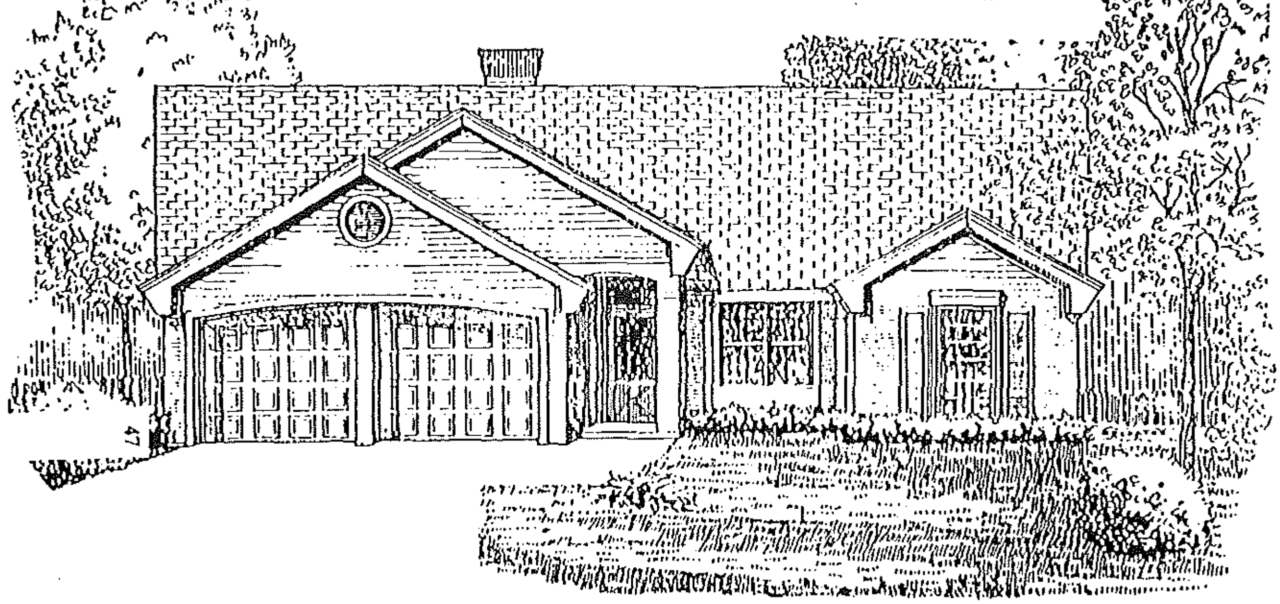


Figure 12 *Percentage of whole-wall area thermally influenced by wall details and distribution of heat losses through wall details for metal stud wall.*

Problem B -- Ranch House



Total living space—1198 sq. ft.

SAMPLE PROBLEM #1

Workshest Specifications:

- Walls: Area = 1566.5 sf
  - insulation
  - sheathing
- Roof/Attic: Area = 1210 sf
  - Trusses, 24" O.C.
  - insulation
- Roof/Cathedral: Area = 315 sf
  - Rafters
  - insulation
- Windows:
  - Area = 116 sf
- Doors:
  - Front: Area = 20.5 sf
  - Patio: Area = 41 sf
  - Utility: Area = 20.5 sf
- Slab-On-Grade:
  - Perimeter = 184 ft.
  - insulation

  - OR -
- Basement:
  - Area = 1300 sf
  - construction
  - insulation

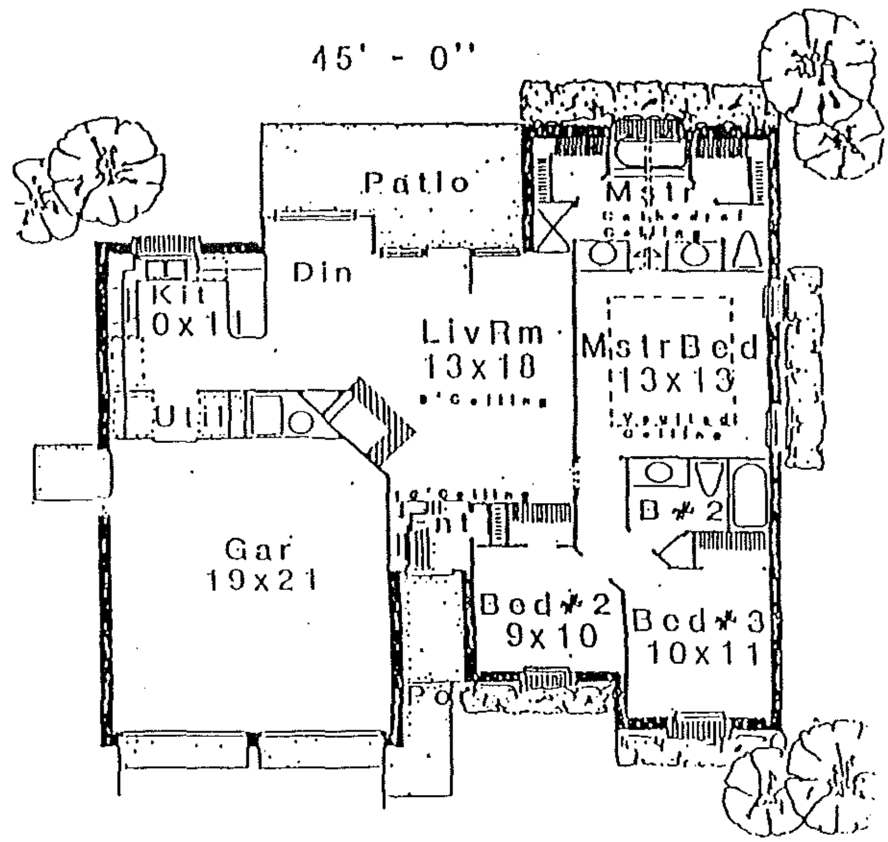


Figure 13 *Ranch house used by NAHB model energy code.*

For builders and building owners to appreciate the added thermal benefits of many of the alternatives to conventional wood-frame wall construction, it is necessary to use a whole-wall R-value. The market focus on clear-wall, or even worse center-of-cavity R-value, is misleading and inhibiting the market penetration of high-performance wall systems into the residential construction industry. The use of a whole-wall R-value could guide decisionmakers to select wall systems that have whole-wall R-values 25% to 50% higher than for wall systems that have significant thermal shorting (high misleading center-of-cavity and clear-wall R-values compared to whole-wall R-value). If this insight into the true wall thermal performance changes the wall selection from poor thermal performers to more energy-efficient systems, this could lead to a 25% reduction in annual space heating and cooling loads resulting from unnecessary heat flux through the opaque wall of new residential buildings.

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References

AISI. 1993. *Residential steel framing manual for architects, engineers and builders, low-rise residential construction details, RG-934.* Washington, D.C.: American Iron and Steel Institute.

ASHRAE. 1993a. *1993 ASHRAE handbook—Fundamentals.* Atlanta, Ga.: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. 1993b. *ASHRAE Standard 90.2-1993, Standard energy-efficient design of new low-rise residential buildings.* Atlanta, Ga.: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASTM. 1989. *Annual book of ASTM standards,* section 4, construction, vol. 04.06, thermal insulation; environmental acoustics. Philadelphia, Pa.: American Society for Testing and Materials.

ASTM. 1995. *Annual book of ASTM standards,* section 4, construction, vol. 04.07, building seals and sealants; fire standards; building constructions. Philadelphia, Pa.: American Society for Testing and Materials.

CABO. 1995. *Model energy code,* 1995 ed. Falls Church, Va.: Council of American Building Officials.

Childs, K.W. 1993. *Heating 7.2 manual.* ORNL Report ORNL/TM-12262. Oak Ridge, Tenn.: Oak Ridge National Laboratory.

Christian, J.E. 1991. Thermal mass credits relating to building envelope energy standards. *ASHRAE Transactions* 97(2).

Dennis, W.F. 1995. The resurgence of steel. *ASTM Standardization News* 23(2): 36-41.

Desjarlais, A., D.M. Kyle, P.W. Childs, and J.E. Christian. 1994. Laboratory measurements of the drying rates of low-slope roofing systems. *Proceedings of the Low-Slope Reroofing Workshop.* ORNL Conf. 9405206. Oak Ridge, Tenn.: Oak Ridge National Laboratory.

DOE. 1995. Voluntary home energy rating system guidelines. *Federal Register* 60(142). Washington, D.C.: Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy.

Hoke, J.R., Jr. 1988. *Architectural graphic standards.* New York, N.Y.: John Wiley & Sons for the American Institute of Architects.

HUD. 1993. Alternatives to lumber and plywood in home construction. Prepared by NAHB Research Center, Upper Marlboro, Md., for the U.S. Department of Housing and Urban Development (now Housing and Human Services).

Kosny, J. 1994. Wooden concrete—High thermal efficiency using waste wood. *Proceedings of the American Council for an Energy-Efficient Economy 1994 Summer Study on Energy Efficiency in Buildings,* Berkeley, Calif.

Kosny, J., and J.E. Christian. 1995a. Thermal evaluation of several configurations of insulation and structural materials for some metal stud walls. *Energy and Buildings,* Summer.

Kosny, J., and J.E. Christian. 1995b. Reducing the uncertainties associated with using the ASHRAE zone method for R-value calculations of metal frame walls. *ASHRAE Transactions* 101(2).

Kosny, J., and A.O. Desjarlais. 1994. Influence of architectural details on the overall thermal performance of residential wall systems. *Journal of Thermal Insulation and Building Envelopes* 18(7).

NAIMA. 1994. The effect of insulation on air infiltration. *Roofing/Siding/Insulation* 71(9). North American Insulation Manufacturers Association.

Nisson, N. 1994. Research center seeking ways to fix thermal problems in steel framing. *Energy Design Update* (Cutter Information Corp.) 14(3).

USG (United States Gypsum Co.). 1992. Drywall steel framed systems. System Folder SA-923-1992 Edition, 092501/USG-3.