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Guidelines for Using ASHRAE 90.2-1993 with Insulating Concrete Forms

by Martha G. Van Geem

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Guidelines for Using ASHRAE 90.2-1993 with Insulating Concrete Forms

by
Martha G. Van Geem*

1. INTRODUCTION

Insulating concrete forming systems (ICF) are used to build energy-efficient structural concrete walls. ICFs are panels, planks, or hollow blocks usually made of expanded polystyrene (EPS) or extruded expanded polystyrene (XPS) insulation. The ICFs are erected at the job site and filled with concrete. The walls uniquely combine the thermal mass of concrete with the high thermal resistance of rigid insulation to provide an energy efficient system in any climate.

This manual guides ICF users through the provisions of a national energy standard and its code version, ASHRAE 90.2-1993, Energy-Efficient Design of New Low-Rise Residential Buildings(1,2). The manual describes three methods of complying with the standard and thermal properties of ICF walls needed to show compliance. A separate manual is available for showing compliance with the CABO Model Energy Code(3).

The standard pertains to all single family residences and multi-family residences with three or less stories above grade. Generally, the standard covers congregate residences with complete facilities including kitchens. This includes apartments, condominiums, dormitories, rooming houses, sorority and fraternity houses. The standard does not include hotels, motels, nursing homes, hospitals, barracks, and jails.

The standard sets requirements for maximum energy loss through walls, roofs, and floors. It also sets requirements for heating and air-conditioning equipment, domestic hot-water heaters, and over-all energy-efficiency. The standard does not cover lighting requirements. This manual focuses on the the requirements for walls. An ASHRAE 90.2 User's Manual(4) is also available.

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2. ICF SYSTEMS

ICFs filled with concrete are ideal as exterior walls in residences for basements and above grade walls. ICFs are available from more than 20 manufacturers and their use in the United States is growing. The Portland Cement Association has helpful information on selecting and using ICFs. Compared to conventional frame construction, ICF walls are more energy efficient, durable, stronger, quieter, and more resistant to natural disasters.

CATEGORIES OF ICF SYSTEMS

The features of ICF systems vary between manufacturers, but fall into seven general categories(5). The systems are differentiated by the type of insulation unit, the shape of the cavity, and the method of connecting the two sides of insulation.

Units are generally divided into panels, planks, and blocks, as shown in Fig.1. Panels can be as large as 4 by 8 feet. Planks are generally 8 feet long and 8 to 12 inches high. Block systems have edges with teeth or tongue and groove so they interlock.

Three basic cavity shapes are flat, grid, or post-and-beam as shown in Fig. 2. Walls with flat panels have concrete of uniform thickness. Thermal properties of these walls can be calculated. Grid or post-and-beam walls have concrete and insulation that varies in thickness. A grid system resembles a waffle or screen with interconnecting vertical and horizontal concrete sections. A "waffle" grid system has thin layers of concrete between the vertical and horizontal members. A "screen" grid system, shown in Fig. 3, has foam insulation between the vertical and horizontal member. A post-and-beam system has concrete sections spaced at greater distances than the grid system. Thermal properties of grid and post-and-beam walls are more complex to calculate than flat systems and thermal testing is recommended.

The third major difference between ICF systems is the type of connector between the inside and outside panel. Figure 4 shows panels with connectors of steel or plastic ties, or a foam insulation web. Plastic ties are less conductive than steel and allow for a more optimal use of the insulation. Systems with insulation webs resemble conventional concrete block, with the block material being insulation rather than concrete.

These basic features combine to produce the seven basic ICFs shown in Figs. 5 through 11. Although dimensions vary, the two insulation layers are generally 2 in. thick, and the concrete is 4 to 6 in. thick for above-grade applications and 6 to 10 inches thick for basements.

ENERGY EFFICIENCY

An ICF wall combines thermal resistance, thermal mass, and airtightness to achieve a highly energy efficient wall. The combination of thermal resistance from the insulation and thermal mass provided by the concrete produces a wall superior to one with only insulation or only thermal mass. Generally, walls constructed of concrete are considered mass walls, and those constructed of wood or metal studs are considered low mass walls.

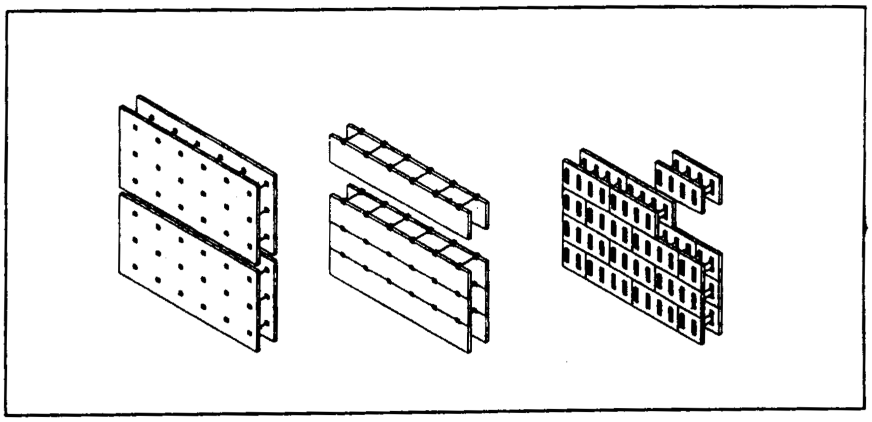

Fig. 1 Panel, Plank, and Block Systems

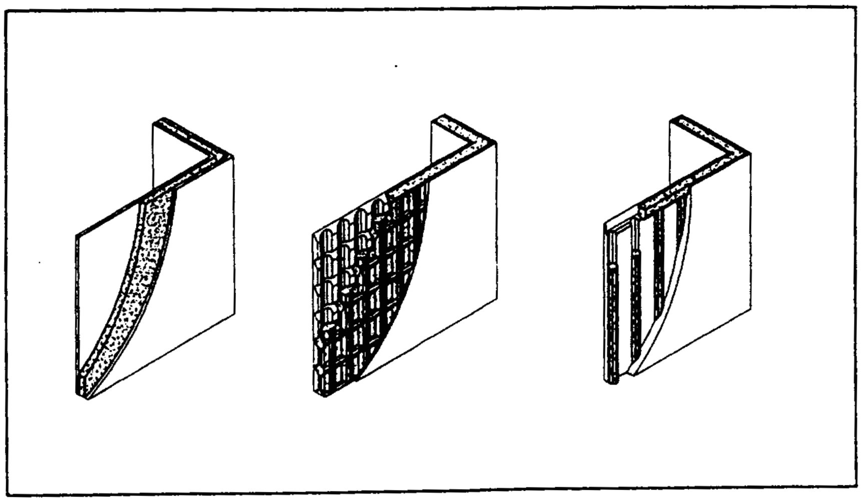

Fig. 2 Flat, Grid, and Post-and-Beam Systems

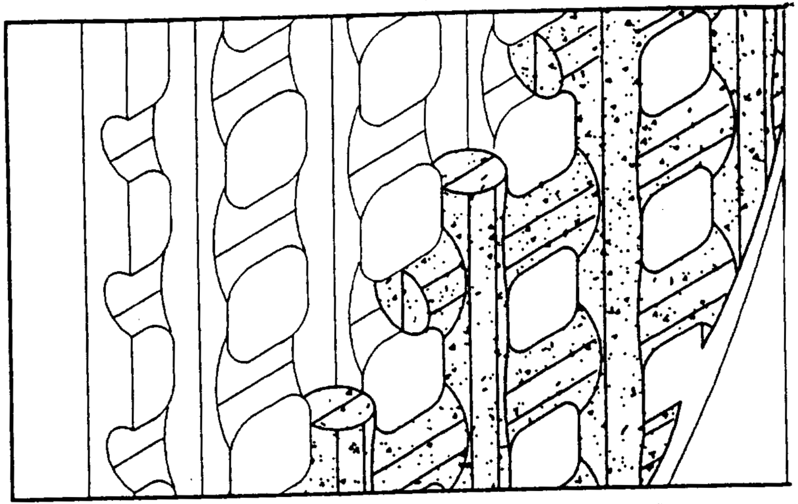

Fig. 3 Cutaway View of a "Screen" Grid System

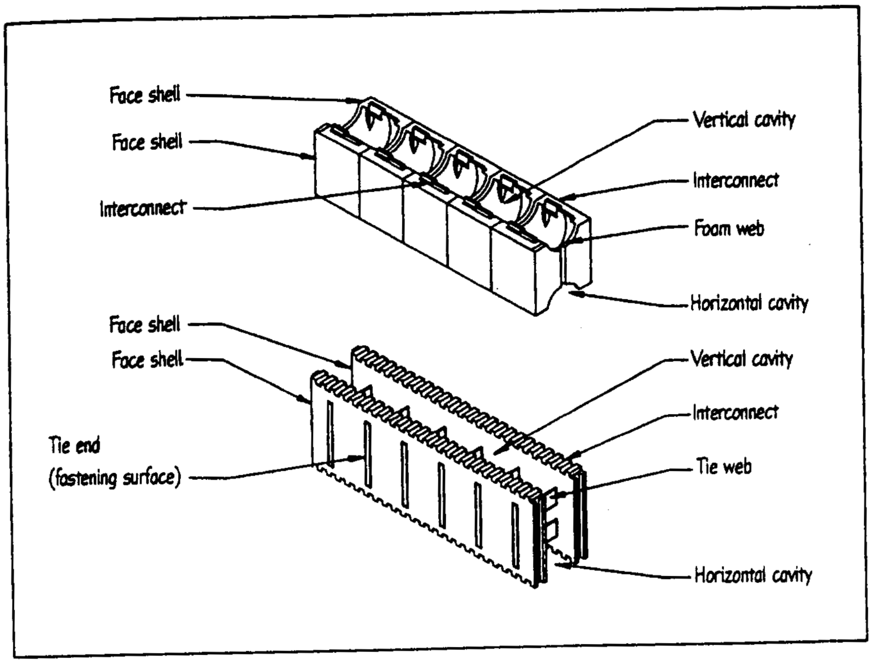

Fig. 4 Parts of ICF Units

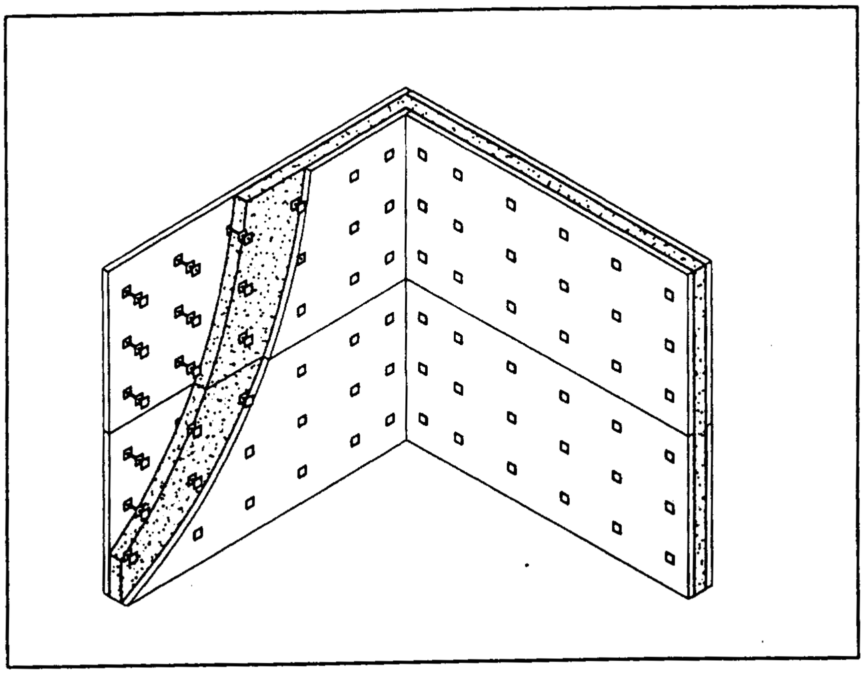

Fig. 5 Cutaway View of a Wall Created with a Flat Panel System

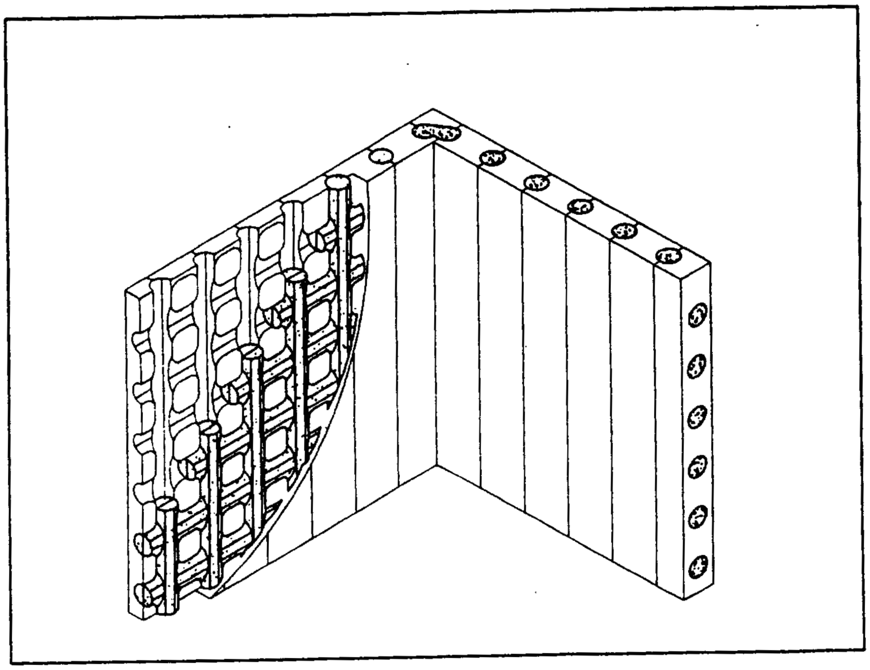

Fig. 6 Cutaway View of a Wall Created with a "Screen" Grid Panel System

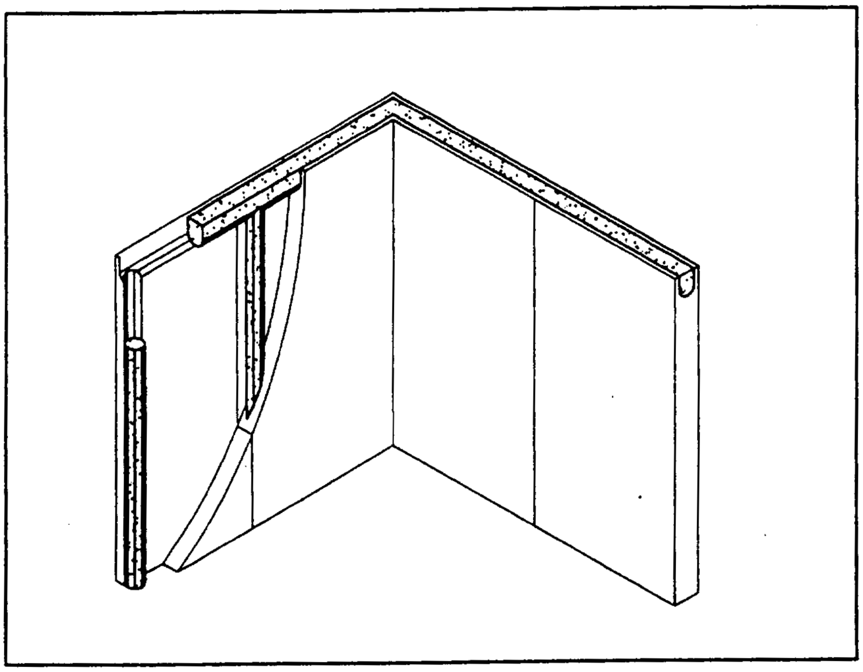

Fig. 7 Cutaway View of a Wall Created with a Post-and-Beam Panel System

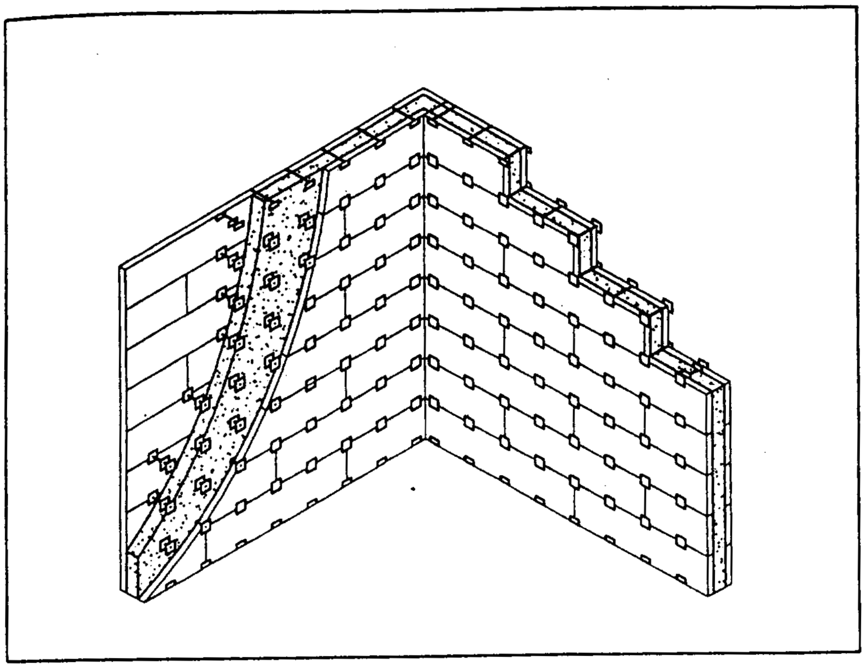

Fig. 8 Cutaway View of a Wall Created with a Flat Plank System

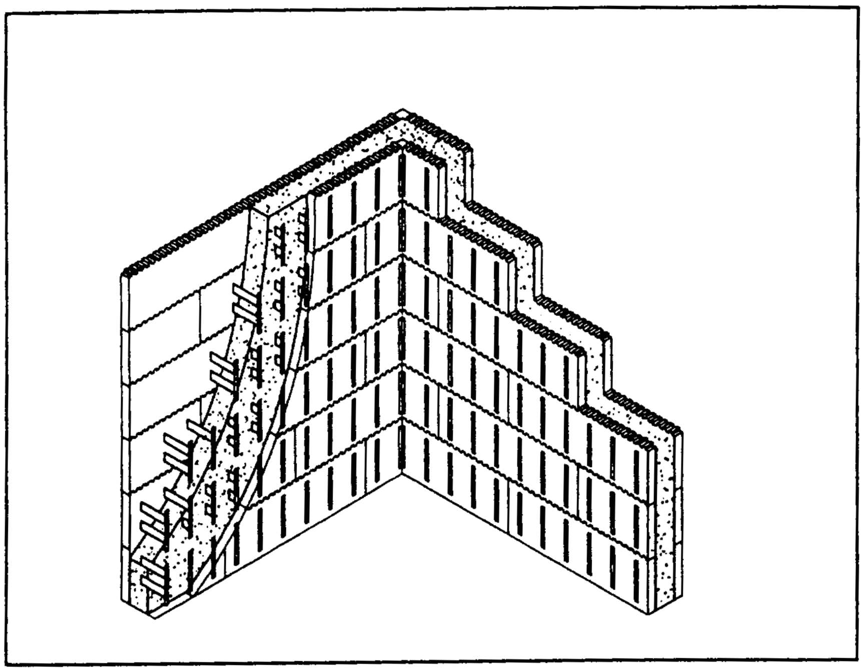

Fig. 9 Cutaway View of a Wall Created with a Flat Block System

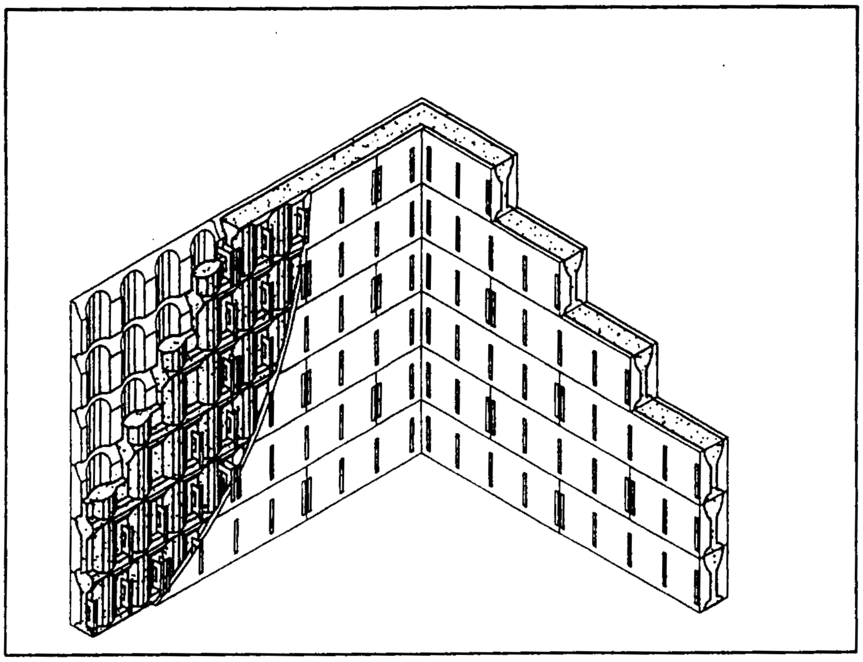

Fig. 10 Cutaway View of a Wall Created with a "Waffle" Grid Block System

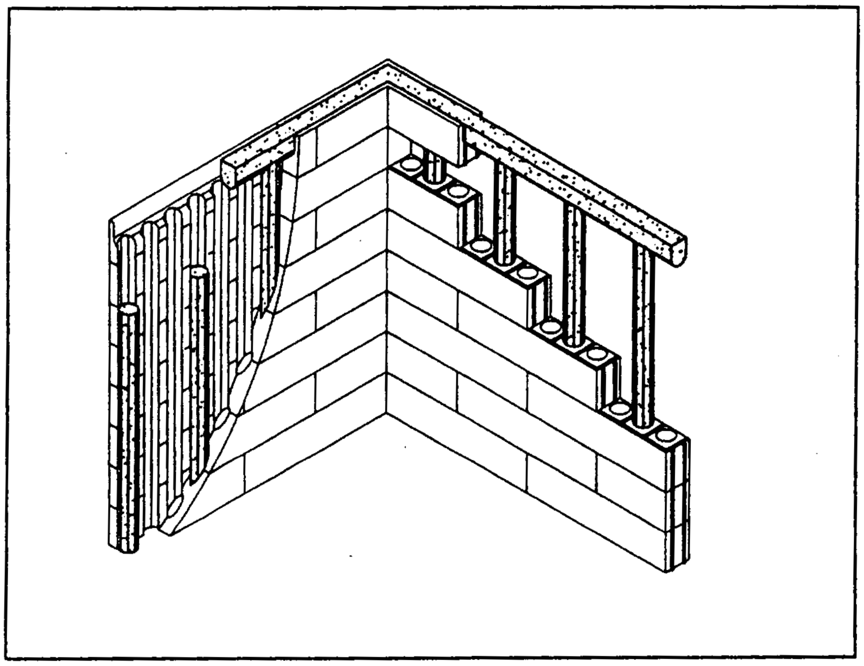

Fig. 11 Cutaway View of a Wall Created with a Post-and-Beam Block System

Background on Thermal Resistance and Thermal Mass

Thermal resistance (R-value) is a physical property of a material related to the resistance to heat flow through a wall with a constant temperature on one side, say 75°F, and a constant temperature on the other, say 40°F. If temperatures on each side of a wall were always constant, R-values would be an accurate measure of energy savings. But, walls are subject to fluctuations in temperature every day. Materials such as concrete have thermal mass which slowly absorbs the hot or cold energy from temperature fluctua-tions, and holds it for much longer periods of time than less massive materials. This energy storage delays and reduces heat transfer through a thermal mass building component, leading to three important results.

First, there are lower peaks in the heating and cooling requirements, since mass slows the response time and moderates indoor temperature fluctuations. Second, a massive building uses less energy than a similar low mass building due to the reduced heat transfer through the massive elements. Third, thermal mass can shift energy demand to off-peak time periods when utility rates may be lower or night ventilation can be used.

The impact of thermal mass on building envelope performance varies with climate at the building site. In some climates, thermal mass buildings have better thermal performance than low mass buildings, regardless of the level of insulation in the low mass building. Mass has the greatest benefit in climates with large daily temperature fluctuations above and below the balance point of the building. For these conditions, the mass can be cooled by natural ventilation during the night, and then be allowed to "float" during the warmer day. On a warm day when outdoor temperatures are at their peak, the inside of the building remains cool, because the heat has not yet penetrated the mass.

Thermal resistance (R-value) is a popular measure of energy savings because it is relatively easy to measure and calculate. Since frame walls have very little mass, their performance is well-predicted from R-values calculations. However, R-values do not take into account the effects of thermal mass, and by themselves, are inadequate in describing the heat transfer properties of an ICF wall with significant amounts of thermal mass. Thus, R-values do not provide a good measure of actual energy use which is the real underlying concern.

Thermal Mass of ICF Walls

An ICF wall with a nominal 6-in. thick concrete core has considerable thermal mass. This thermal mass enables the concrete to absorb, store, and later release significant amounts of heat.

The thermal lag in a 5-½-in. thick concrete wall is approximately 3 to 4 hours. This is the time delay from a peak outdoor temperature until the indoor side of the wall responds to the peak temperature and requires peak heat or air-conditioning (Fig. 12). A frame wall has a thermal lag of 1 to 2 hours.

Shift in Peak Period

HVAC equipment design in warm climates are dominated by a peak afternoon air conditioning load. In most warm climates, peak outdoor temperatures including the effects of sun on wall surfaces typically occur at 4 PM in April and 5 PM in August. A thermal lag of 3 to 4 hours, as occurs in a concrete wall, results in the warmest inside wall temperature occurring at 7 to 8 PM in April and 8 to 9 PM in August.

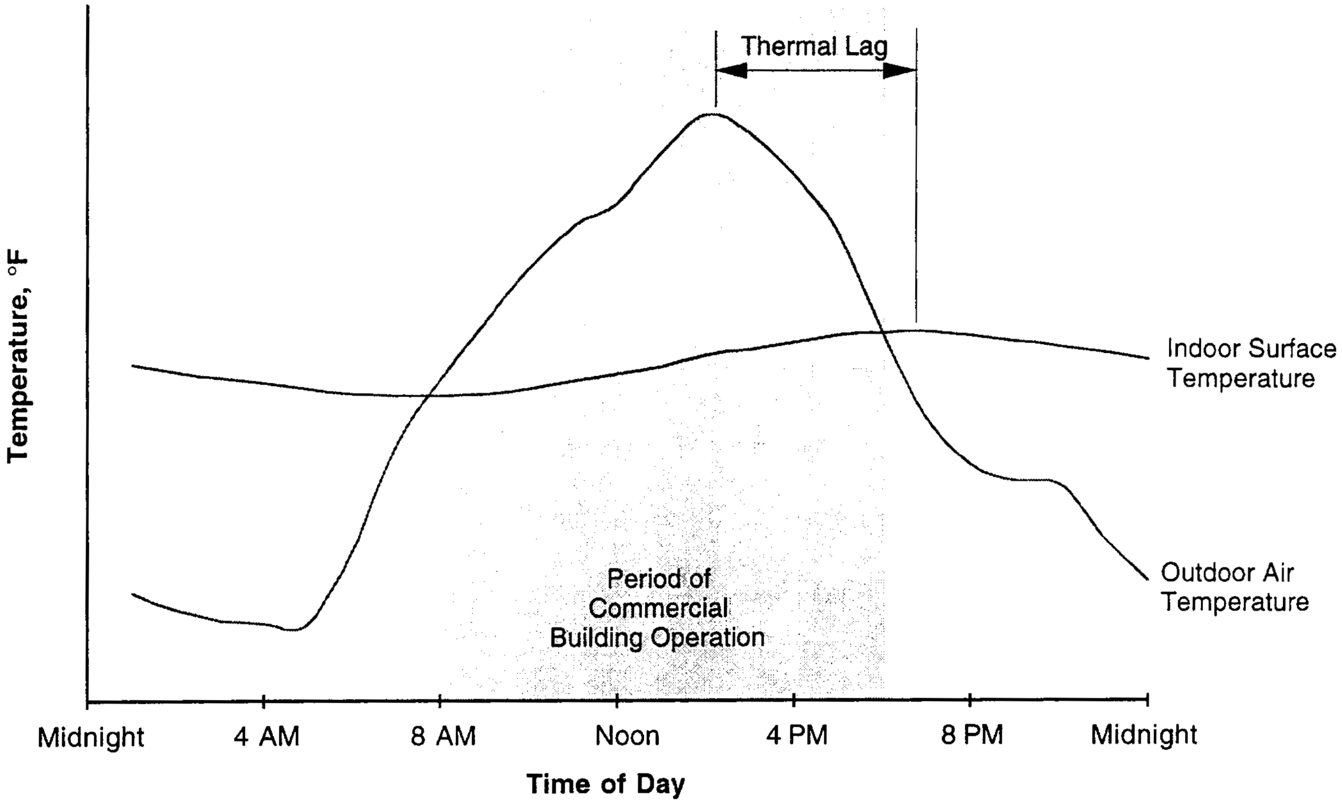

Fig. 12 Thermal Lag for 8-in. Concrete Wall

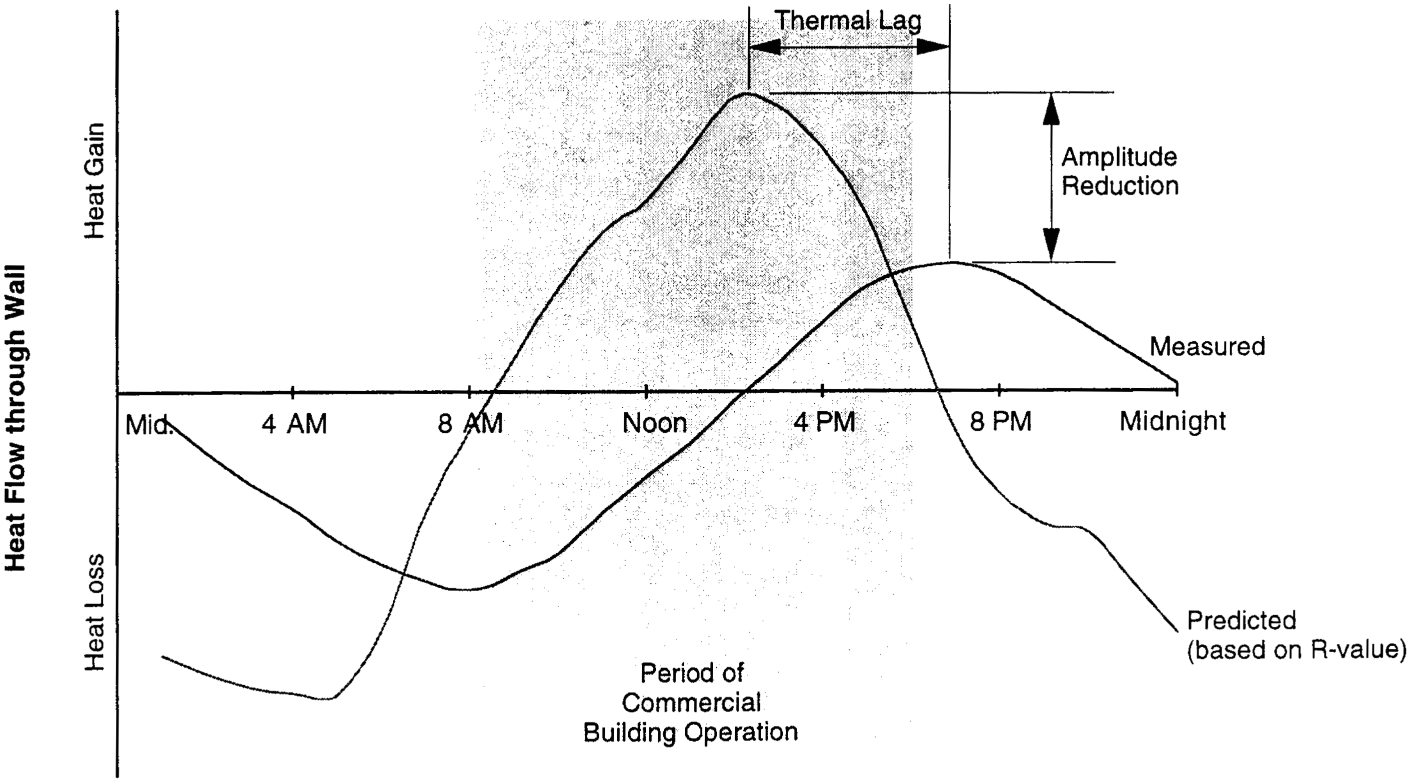

Fig. 13 Thermal Lag and Amplitude Reduction for 8-in. Concrete Wall

Using Orlando, Florida in August as an example, when the maximum outdoor temperature including the effects of the sun is 110°F at 5 PM, the inside of the mass wall experiences a maximum temperature at 7 or 8 PM when the outdoor air temperature has dropped to the 90's. The inside of a frame wall in August experiences a maximum temperature at 5 or 6 PM when the outdoor air temperature including the effects of the sun is still in the 100's. In April, when the maximum outdoor temperature including the effects of the sun is 100°F at 4 PM, the inside of the mass wall experiences a maximum temperature at 7 or 8 PM when the outdoor air temperature has dropped to the high 70's or low 80's. The inside of a frame wall in April experiences a maximum temperature at 5 or 6 PM when the outdoor air temperature including the effects of the sun is still in the 90's.

These examples show the effect of shift in peak load. During the more moderate spring and fall months, air-conditioning loads can be further reduced by shifting to night time ventilation (opening the windows) in the evening when the mass walls are warmest.

Moderated Peak Loads

Since thermal mass also moderates peak loads, steady-state calculations using only R-values overestimate the amplitude of the peak load for mass walls. Figure 13 shows heat flow predicted using R-values and measured through a concrete wall. The amplitude reduction shows the reduction in peak loads due to mass. For mass walls in warm climates the peak loads can be overestimated by 100% using R-value calculations. Smaller capacity cooling equipment can often be used for homes with mass walls.

Energy Savings

The energy savings from mass walls are most pronounced when the outdoor temperatures fluctuate above and below the indoor temperature each day. During these conditions heat flow reversals occur within the wall that significantly reduce cooling loads. This occurs most days in Orlando based on daily high and low temperatures, averaged monthly. In July and August, the average daily temperatures range from a low of 73°F to a high of 108°F (including solar effects) in July and August when thermostats are generally set at 75 to 78°F. In April, the average daily temperatures range from a low of 60°F to a high of 101°F (including solar effects). In Orlando, the energy savings due to heat flow reversals occur during the entire cooling season but are most significant during the spring and fall.

The energy savings due to heat flow reversals are also pronounced for the winter temperatures in Orlando. Indoor temperatures fluctuate above and below the indoor temperatures for most winter days. In January, the average daily temperature range from a low of 49°F to a high of 89°F (including solar effects) when thermostats are generally set in the low 70's.

Cold Climates

In cold climates heat flow reversals within mass walls occur in the spring, summer, and fall when temperatures including the effects of the sun fluctuate above and below the indoor temperature. During these times heating and cooling load calculations using R-values overestimate loads. Also, further energy savings are realized when nighttime ventilation is used to cool buildings in the evenings when the mass wall is warmest.

Thermal mass moderates and shifts peak loads in all climates. Heating and cooling equipment runs at a more constant pace in homes with mass walls.

Equipment Design Loads

The above discussion is for a mass wall with 5-½-in. of normal weight concrete. A complete analysis of building energy requirements must include considerations of the entire building envelope (windows, roof, and slab), the building orientation, and building operation. An hour by hour simulation program, such as DOE2(6) or BLAST(7), that takes into account the heat capacity or thermal storage effects of the concrete walls can be used to predict energy use and size heating, ventilating, and air-conditioning (HVAC) equipment.

Framing Effects in Wood Frame and ICF Walls

Thermal resistance values of wood frame walls installed in houses are less than the rated value of the insulation. For instance, an R-11 fiberglass batt in a wood frame cavity with 1/2-in. plywood on the exterior and 1/2-in. gypsum wall board on the interior will have an R-value of 13.6 hr·ft·^{2}F/Btu at the center of the wall cavity with the insulation. If standard 2x4 wood framing is taken into account, the "clear" wall R-value is 10.6. A "whole" wall R-value includes structural connections in walls such as corners, the wall/roof connection, the wall/floor connection, window headers, window sills, window jambs, door headers, door sills, and door jambs. For an R-11 batt frame wall, the "whole" wall R-value is 9.6.(8)

An ICF wall does not have these reductions in R-value due to framing because the insulation on the inside and outside are continuous throughout the wall and at corners. Minimal framing is required for windows and doors. An ORNL publication(8) actually predicts "whole" wall R-values 3% higher than the "clear" wall value for ICF walls.

Convection Effects in Frame and ICF Walls

In cold climates, thermal resistance values in wood frame walls are less than the predicted value if the batts do not fill the entire cavity, creating air spaces. This type of defect occurs where faced batts are recessed deliberately into the cavity so that they can be stapled against the side of the stud rather than the edge of the stud where the gypsum board is attached, or where insulation is depressed behind electrical boxes. In cold regions, convection occurs within these air spaces that degrades the effectiveness of batt insulation. A 1993 study at the National Research Council of Canada(9) showed that full height ¾-in. vertical gaps in all four corners of a frame wall cavity causes a reduction in R-value that depends on the density of the batt and temperature. At cold side temperatures of 23°F, the insulation lost 5 to 15% of its R-value, depending on the density of the insulation. At -31°F, the insulation lost 30 to 40% of its R-value. There was no reduction in R-value when batts completely filled the cavity.

The insulation in an ICF wall is not affected by convection in air spaces. The insulation is an integral part of the wall necessary to hold the concrete in place during construction. Once the wall is filled with concrete, there are no air spaces for convection currents.

The ICF wall combines insulation, thermal mass, and air-tightness to provide an energy efficient wall for all climates.

3. HEAT TRANSMISSION COEFFICIENTS OF ICF WALLS

The energy savings of construction materials is generally marketed using thermal resistance (R-value), but the standard and code use thermal transmittance (U-factor).

DEFINITION OF THERMAL RESISTANCE (R-VALUE)

Thermal resistance (R-value) is defined as the reciprocal of the time rate of heat flow through a unit area induced by a unit temperature difference between two defined surfaces of material or construction under steady-state conditions. This is equal to the temperature difference divided by the steady-state heat flow through a unit area of a material or construction. For a homogeneous material, thermal resistance is equal to a material's thickness divided by thermal conductivity.

For a wall constructed of layers of material perpendicular to the heat flow, such as an ICF panel wall with a uniform cavity thickness and no metal ties, the total thermal resistance (R_T) of the wall is the sum of the resistances of the layers that make up the wall as shown in Fig. 14. This includes the insulation, concrete, inside finish such as gypsum wallboard, outside finish such as vinyl siding, and interior and exterior air films. An air film resistance is the thermal resistance between the material surface and the air.

DEFINITION OF THERMAL TRANSMITTANCE (U-FACTOR)

Thermal transmittance (U-factor) is defined as the heat transmission in unit time through unit area of a material or construction and the boundary air films, induced by unit temperature difference between steady-state environments on each side(10). Thermal transmittance is the reciprocal of the total thermal resistance. Higher thermal resistance (R-value) and lower thermal transmittance (U-factor) provide more energy efficiency.

INSULATION R-VALUES

The thermal resistance of the insulation layers in ICF walls depends on their thickness, material, and density. Thermal conductivities and thermal resistances per inch of insulations used in ICF walls are provided in Table 1. Expanded polystyrene (EPS) is molded beads fused together. Extruded expanded polystyrene (XPS) has a smooth skin surface. Thermal conductivity (k) is defined as the time rate of steady-state heat flow through a unit area of a homogeneous material induced by a unit temperature gradient in a direction perpendicular to that unit area. This property is for a unit thickness of the homogeneous material.

XPS has a higher thermal resistance per inch than EPS, but is more expensive. Some ICF manufacturers use EPS, some use XPS, and some offer both. Some manufacturers use polyurethane foam.

R_T-VALUES AND U-FACTORS FOR ICF WALLS

Cross-sectional dimensions, R_T, and U of ICF systems are presented in Table 2. Properties are listed according to brand name and manufacturer. The thickness of the insulation, concrete, and total wall are provided for ICF walls with insulation of uniform thickness (flat panel, flat plank, and flat block walls as shown in Figs. 5, 8, and 9). The nominal insulation

$$R_T = R_o + R_1 + R_2 + R_3 + R_4 + R_5 + R_i$$

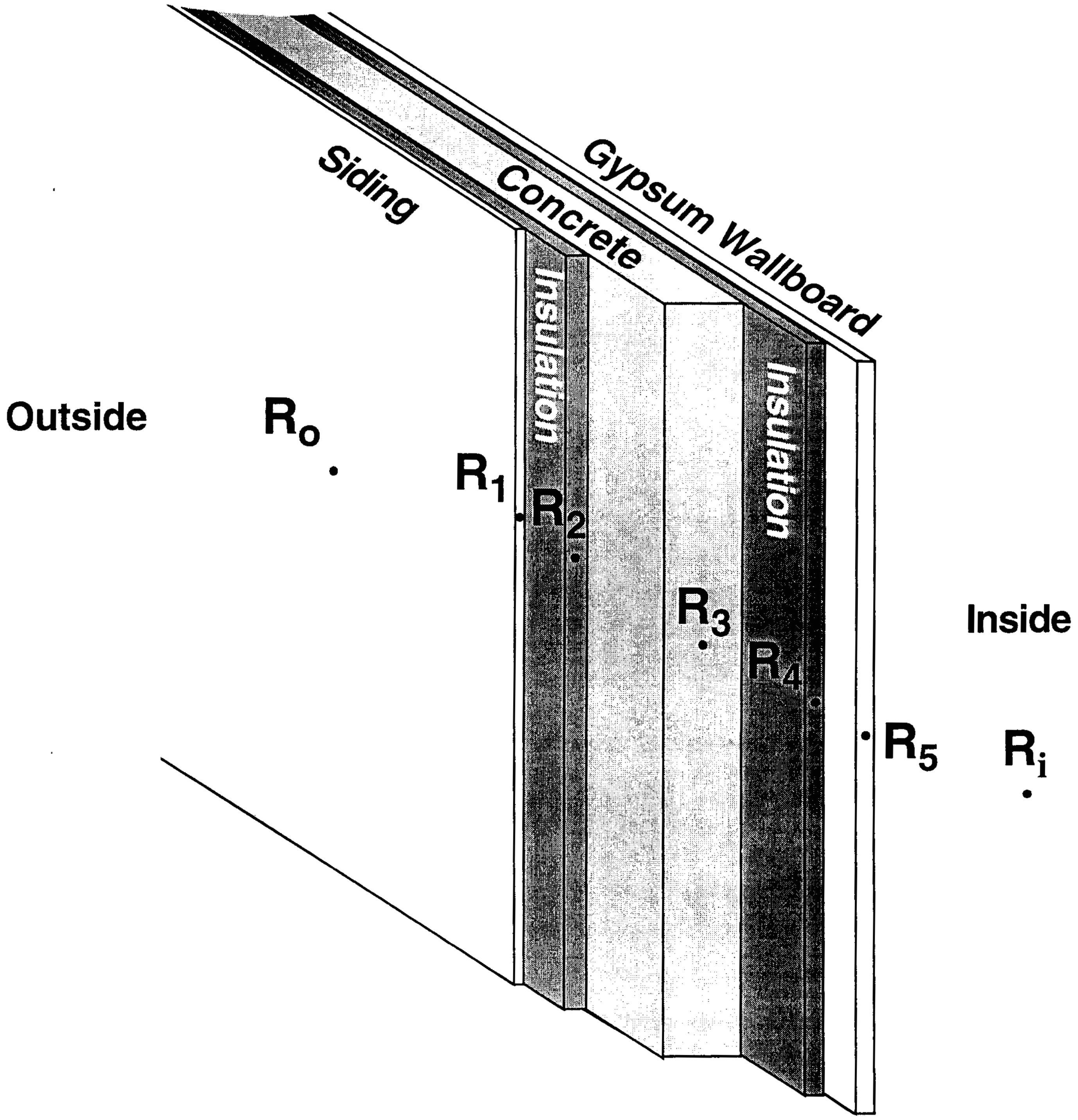

Fig. 14 Example of Total Thermal Resistance (R_T)

TABLE 1 - THERMAL PROPERTIES OF BOARD INSULATION(11)

Insulation	Density, lb/ft3	Thermal Conductivity k, $\frac{\text{Btu·in}}{\text{h·ft}^2\text{·°F}}$	Thermal Resistance R Per Inch Thickness $(1/k)$, $\frac{\text{°F·ft}^2\text{·h}}{\text{Btu·in}}$
Expanded polystyrene, molded beads (EPS)	1.00	0.26	3.85
	1.25	0.25	4.00
	1.50	0.24	4.17
	1.75	0.24	4.17
	2.00	0.23	4.35
Expanded polystyrene, extruded (smooth skin surface) (XPS)	1.8-3.5	0.20	5.00
Polyurethane foam	1.5-2.5	0.16-0.18	6.25-5.56

and concrete thickness are provided, if available, and the total wall thickness is provided for ICF walls with nonuniform insulation thicknesses (grid panel, post-and-beam panel, grid block, and post-and-beam block walls as shown in Figs. 6, 7, 10, and 11).

R_T-values and U-factors are listed for the ICF walls with no interior or exterior finishes, only an interior finish, and an interior *and* exterior finish. The portion labeled "No Finishes" is the R_T - values and U-factors for the ICF walls with concrete and air films. Values in the table assume the thermal conductivity of normal weight concrete is 16 Btu·in./hr·ft^2·°F. All R_T -values and U-factors were calculated by CTL.

The portion labeled "Interior Finish, ½-in. Gyp. Board" is for ICF walls with ½-in. gypsum wall board interior finish and no exterior finish. The ½-in. gypsum wallboard is required by many local building codes to meet the requirement for a 15-minute fire resistance protection over plastic foam. Calculations assume an R-value of 0.45 hr·ft^2·°F/Btu for the gypsum wallboard. The "½-in. Gyp. Board" values can also be used for stucco as an exterior finish since the R-value of stucco is small.The portion labeled "Interior and Exterior Finish, Gyp. Board & Siding" is for ICF walls with ½-in. gypsum wall board and either wood, vinyl, or aluminum siding. Calculations assume an R-value of 0.6 hr·ft^2·°F/Btu for siding.

Values in the table may be modified for interior or exterior finishes with higher R-values. If a siding with a higher R-value is used, the additional rating of the siding above 0.6 may be added to the R-value of the system. If an interior finish with a higher R-value is used, the additional rating of the interior finish above 0.45 may be added to the R-value of the system. The U-factor is the inverse of the modified R_T -value.

TABLE 2 - THERMAL TRANSMITTANCE (U) AND TOTAL THERMAL RESISTANCE (R_T) OF ICF WALLS*

Insulating Concrete Form System		Company Literature						No Finishes		*Interior Finish* 1/2-in. Gyp. Board		*Interior and Exterior Finish* Gyp. Board & Siding	
		Thickness, in.			Insulation								
Brand Name	Manufacturer	Insulation	Concrete	Total Wall	Type	Density, pcf	Conductivity**	R_T-Value**	U-Factor**	R_T-Value**	U-Factor**	R_T-Value**	U-Factor**
BLUE MAXX	AAB Building Systems	4-3/4	6-1/2	11-1/4	EPS	1.5	0.24	21.0	0.048	21.5	0.047	22.1	0.045
		4-3/4	8	12-3/4	EPS	1.5	0.24	21.1	0.047	21.6	0.046	22.2	0.045
Diamond Snap Form	AFM Corp.	4	4	8	EPS	2	0.23	18.5	0.054	18.9	0.053	19.5	0.051
		4	6	10	EPS	2	0.23	18.6	0.054	19.1	0.052	19.7	0.051
		4	8	12	EPS	2	0.23	18.7	0.053	19.2	0.052	19.8	0.051
		4	10	14	EPS	2	0.23	18.9	0.053	19.3	0.052	19.9	0.050
Feather Lite	Feather Lite, Inc.	Varies	5.25	8	Foam†	2	0.17	21.8	0.046	22.3	0.045	22.9	0.044
Fold-Form	Lite Form, Inc.	4	4	8	EPS	2	0.23	18.5	0.054	18.9	0.053	19.5	0.051
		4	6	10	EPS	2	0.23	18.6	0.054	19.1	0.052	19.7	0.051
		4	8	12	EPS	2	0.23	18.7	0.053	19.2	0.052	19.8	0.051
GreenBlock	GREENBLOCK WorldWide Corp.	4-1/2	5-3/4	9-7/8	EPS	1.5	0.24	18.3	0.055	18.8	0.053	19.4	0.052
Ice Block	Foam Block	Varies	6 nom.	9-1/4	EPS	1.5	0.24	12.2	0.082	12.7	0.079	13.3	0.075
		Varies	8 nom.	11	EPS	1.5	0.24	12.5	0.080	13.0	0.077	13.6	0.074
Lite Form	Lite Form, Inc.	4	4	8	XPS	2	0.20	21.1	0.047	21.6	0.046	22.2	0.045
		4	6	10	XPS	2	0.20	21.2	0.047	21.7	0.046	22.3	0.045
		4	8	12	XPS	2	0.20	21.4	0.047	21.8	0.046	22.4	0.045
		4	10	14	XPS	2	0.20	21.5	0.047	21.9	0.046	22.5	0.044
		4	12	16	XPS	2	0.20	21.6	0.046	22.1	0.045	22.7	0.044
Polysteel Form	American Polysteel Forms	4.8" avg	4.45" avg	9-1/4	EPS	1.5	0.24	12.2	0.082	12.7	0.079	13.3	0.075
		5.0" avg	6" avg	11	EPS	1.5	0.24	12.5	0.080	13.0	0.077	13.6	0.074

* All R_T -values and U-factors were calculated by CTL. Detailed complex calculations are required for systems with nonuniform insulation thicknesses or systems with metal ties that penetrate the insulation layers. In these cases, the hot box test method (ASTM C236 or C976) is preferred since curved shapes in multiple dimensions make analysis complex and results subject to assumptions.

** Units for *conductivity* are Btu·in./h·ft^2·°F, units for *R-value* are h·ft^2·°F/Btu, and units for *U-value* are Btu/h·ft^2·°F.

† Polyurethane Foam

TABLE 2 (CONTINUED) - THERMAL TRANSMITTANCE (U) AND TOTAL THERMAL RESISTANCE (R_T) OF ICF WALLS*

Insulating Concrete Form System		Company Literature						No Finishes		Interior Finish 1/2-in. Gyp. Board		Interior and Exterior Finish Gyp. Board & Siding	
		Thickness, in.			Insulation								
Brand Name	Distributor	Insulation	Concrete	Total Wall	Type	Density, pcf	Conductivity*	R_T-Value**	U-Factor**	R_T-Value**	U-Factor**	R_T-Value**	U-Factor**
Quad-Lock	Quad Lock Building Systems	4-1/2	3-5/8	8-1/8	EPS	2	0.23	20.6	0.048	21.1	0.047	21.7	0.046
		4-1/2	5-5/8	10-1/8	EPS	2	0.23	20.8	0.048	21.2	0.047	21.8	0.046
		4-1/2	7-5/8	12-1/8	EPS	2	0.23	20.9	0.048	21.3	0.047	21.9	0.046
		4-1/2	9-5/8	14-1/8	EPS	2	0.23	21.0	0.048	21.5	0.047	22.1	0.045
R-FORMS	R-Forms	4	4	8	XPS	1.8	0.20	21.1	0.047	21.6	0.046	22.2	0.045
		4	6	10	XPS	1.8	0.20	21.2	0.047	21.7	0.046	22.3	0.045
		4	8	12	XPS	1.8	0.20	21.4	0.047	21.8	0.046	22.4	0.045
		4	10	14	XPS	1.8	0.20	21.5	0.047	21.9	0.046	22.5	0.044
Reddi-Form	Reddi-Form	Varies	Varies	9-5/8	EPS	1.8	0.24	19.2	0.052	19.6	0.051	20.2	0.050
ThermoFormed	Thermoformed Block Corp.	Varies	5	8	EPS	≥1.0	0.26	16.0	0.063	16.5	0.061	17.1	0.059
Therm-O-Wall	Therm-O-Wall	Varies	6	9-1/4	EPS	1.5 - 2	0.24	15.1	0.066	15.6	0.064	16.2	0.062
		Varies	8	11	EPS	1.5 - 2	0.24	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

* All R_T -values and U-factors were calculated by CTL. Detailed complex calculations are required for systems with nonuniform insulation thicknesses or systems with metal ties that penetrate the insulation layers. In these cases, the hot box test method (ASTM C236 or C976) is preferred since curved shapes in multiple dimensions make analysis complex and results subject to assumptions.

** Units for *conductivity* are Btu·in./h·ft²·°F, units for *R-value* are h·ft²·°F/Btu, and units for *U-value* are Btu/h·ft²·°F.

† Polyurethane Foam

Systems with a thermal resistance greater than 17.5 hr·ft^2·°F/Btu exceed single and multifamily residential building requirements in virtually all areas of the continental United States (except for some extremely cold, sparsely populated portions of Idaho, Montana, North Dakota, and Minnesota), without considering the beneficial effects of thermal mass. Most values are also higher than the R-value fiberglass batt insulation (R-11, 13, or 15) provides in standard 4-in. frame wall construction.

EXAMPLE CALCULATION OF R_T AND U FOR ICF WALLS WITH UNIFORM INSULATION THICKNESSES

For a wall constructed of layers of material perpendicular to the heat flow, the total thermal resistance (R_T) of the wall is the sum of the resistances of the layers that make up the wall. This method is applicable to ICF walls with a uniform cavity thickness and no metal ties, such as flat panel, flat plank, and flat block walls. Thermal transmittance (U) is the inverse of the total thermal resistance (R_T).

Example 1:

Problem:: Determine the total thermal resistance (R_T) of a flat plank ICF wall with 2 in. of expanded polystyrene insulation (EPS) on each side and a 6-in. concrete core. The inside surface is ½-in. gypsum wallboard and the outside surface is wood siding. The EPS has a 1 pcf density.

Solution: Using Table 1, the thermal conductivity of the 1 pcf EPS is 0.26 Btu·in./hr·ft^2·°F. The thermal conductivity of normal weight concrete is assumed to be 16 Btu·in./hr·ft^2·°F. The resistance of a material is the thickness divided by the thermal conductivity. Calculations are shown in Table 3. The total thermal resistance (R_T) is 17.7 hr·ft^2·°F/Btu and the thermal transmittance (U) is 0.057 Btu/hr·ft^2·°F.

THERMAL CONDUCTANCE (C-FACTOR) FOR ICF WALLS

Thermal conductance (C-factor) is defined as the time rate of steady state heat flow through a unit area of a material or construction induced by a unit temperature difference between the body surfaces. C-factor is similar to U-factor but does not include the thermal transmittance of air films on the indoor and outdoor surfaces. C-factors are used in the standard and code to show compliance for below grade walls.

For a wall constructed of layers of material perpendicular to the heat flow, such as an ICF panel wall with a uniform cavity thickness and no metal ties, the thermal conductance (C) is the inverse of the sum of the resistances of the layers that comprise the wall, excluding air films.

Thermal conductance factors of ICF walls are presented in Table 4. The portion labeled "No Finishes" lists the R-values and C-factors for the plain ICF walls. The portion labeled "Interior Finish, ½-in. Gyp. Board" lists values for ICF walls with an interior finish of ½-in. gypsum wall board and no exterior finish. All other assumptions are the same as those used to develop Table 2.

VALUES FOR NONUNIFORM INSULATION THICKNESSES

Detailed complex calculations are required for systems with nonuniform insulation thicknesses or systems with metal ties that penetrate the insulation layers. In these cases, the higher conducting concrete and steel cause thermal bridges that increase heat loss. Area

TABLE 3 - EXAMPLE 1, CALCULATION OF RT AND U FOR ICF WALL WITH UNIFORM INSULATION THICKNESS

Component	R Thermal Resistance, hr·ft2·°F/Btu
1. Outside air film	0.17*
2. Wood siding	0.60
3. 2-in. expanded polystyrene (EPS) insulation, 1 pcf density (2/0.26)	7.69
4. 6-in. normal weight concrete (6/16)	0.38
5. 2-in. expanded polystyrene (EPS) insulation	7.69
6. 1/2-in. gypsum wallboard	0.45
7. Inside air film	0.68*
RT (sum)	17.7
U** (1/RT)	0.057

*Ref. 11, Chapter 24.

**Units for thermal transmittance are Btu/hr·ft2·°F.

TABLE 4 - THERMAL CONDUCTANCE (C) OF ICF WALLS*

Insulating Concrete Form System		Company Literature						No Finishes		Interior Finish 1/2-in. Gyp. Board	
		Thickness, in.			Insulation						
Brand Name	***Manufacturer***	**Insulation**	**Concrete**	**Total Wall**	**Type**	**Density, pcf**	**Conductivity****	**R_T-Value****	**C-Factor****	**R_T-Value****	**C-Factor****
BLUE MAXX	AAB Building Systems	4-3/4	6-1/2	11-1/4	EPS	1.5	0.24	20.2	0.050	20.6	0.048
		4-3/4	8	12-3/4	EPS	1.5	0.24	20.3	0.049	20.7	0.048
Diamond Snap Form	AFM Corp.	4	4	8	EPS	2	0.23	17.6	0.057	18.1	0.055
		4	6	10	EPS	2	0.23	17.8	0.056	18.2	0.055
		4	8	12	EPS	2	0.23	17.9	0.056	18.3	0.055
		4	10	14	EPS	2	0.23	18.0	0.056	18.5	0.054
Feather Lite	Feather Lite, Inc.	Varies	5.25	8	Foam†	2	0.17	21.0	0.048	21.4	0.047
Fold-Form	Lite Form, Inc.	4	4	8	EPS	2	0.23	17.6	0.057	18.1	0.055
		4	6	10	EPS	2	0.23	17.8	0.056	18.2	0.055
		4	8	12	EPS	2	0.23	17.9	0.056	18.3	0.055
GreenBlock	GREENBLOCK WorldWide Corp.	4-1/2	5-3/4	9-7/8	EPS	1.5	0.24	17.5	0.057	17.9	0.056
Ice Block	Foam Block	Varies	6 nom.	9-1/4	EPS	1.5	0.24	11.4	0.088	11.8	0.085
		Varies	8 nom.	11	EPS	1.5	0.24	11.7	0.086	12.1	0.083
Lite Form	Lite Form, Inc.	4	4	8	XPS	2	0.20	20.3	0.049	20.7	0.048
		4	6	10	XPS	2	0.20	20.4	0.049	20.8	0.048
		4	8	12	XPS	2	0.20	20.5	0.049	21.0	0.048
		4	10	14	XPS	2	0.20	20.6	0.048	21.1	0.047
		4	12	16	XPS	2	0.20	20.8	0.048	21.2	0.047

* All R_T -values and C-factors were calculated by CTL. Detailed complex calculations are required for systems with nonuniform insulation thicknesses or systems with metal ties that penetrate the insulation layers. In these cases, the hot box test method (ASTM C236 or C976) is preferred since curved shapes in multiple dimensions make analysis complex and results subject to assumptions.

** Units for *conductivity* are Btu·in./h·ft^2·°F, units for *R-value* are h·ft^2·°F/Btu, and units for *C-factor* are Btu/h·ft^2·°F.

† Polyurethane Foam

TABLE 4 (CONTINUED) - THERMAL CONDUCTANCE (C) OF ICF WALLS*

Insulating Concrete Form System		Company Literature						No Finishes		Interior Finish 1/2-in. Gyp. Board	
		Thickness, in.			Insulation						
Brand Name	Manufacturer	Insulation	Concrete	Total Wall	Type	Density, pcf	Conductivity**	R_T-Value**	C-Factor**	R_T-Value**	C-Factor**
Polysteel Form	American Polysteel Forms	4.8" avg	4.45" avg	9-1/4	EPS	1.5	0.24	11.4	0.088	11.8	0.085
		5.0" avg	6" avg	11	EPS	1.5	0.24	11.7	0.086	12.1	0.083
Quad-Lock	Quad Lock Building Systems	4-1/2	3-5/8	8-1/8	EPS	2	0.23	19.8	0.051	20.2	0.049
		4-1/2	5-5/8	10-1/8	EPS	2	0.23	19.9	0.050	20.4	0.049
		4-1/2	7-5/8	12-1/8	EPS	2	0.23	20.0	0.050	20.5	0.049
		4-1/2	9-5/8	14-1/8	EPS	2	0.23	20.2	0.050	20.6	0.049
R-FORMS	R-Forms	4	4	8	XPS	1.8	0.2	20.3	0.049	20.7	0.048
		4	6	10	XPS	1.8	0.2	20.4	0.049	20.8	0.048
		4	8	12	XPS	1.8	0.2	20.5	0.049	21.0	0.048
		4	10	14	XPS	1.8	0.2	20.6	0.048	21.1	0.047
Reddi-Form	Reddi-Form	Varies	Varies	9-5/8	EPS	1.8	0.24	18.3	0.055	18.8	0.053
ThermoFormed	Thermoformed Block Corp.	Varies	5	8	EPS	≥1.0	0.26	15.2	0.066	15.6	0.064
Therm-O-Wall	Therm-O-Wall	Varies	6	9-1/4	EPS	1.5 – 2	0.24	14.3	0.070	14.7	0.068
		Varies	8	11	EPS	1.5 – 2	0.24	N.A.	N.A.	N.A.	N.A.

* All R_T -values and C-factors were calculated by CTL. Detailed complex calculations are required for systems with nonuniform insulation thicknesses or systems with metal ties that penetrate the insulation layers. *In these cases, the hot box test method* (ASTM C236 or C976) is preferred since curved shapes in multiple dimensions make analysis complex and results subject to assumptions.

** Units for *conductivity* are Btu·in./h·ft^2·°F, units for *R-value* are h·ft^2·°F/Btu, and units for *C-factor* are Btu/h·ft^2·°F.

† Polyurethane Foam

weighting the U-factors of materials in the wall cross-sections (the parallel path method) underestimates the effects of these thermal bridges in most cases. To accurately determine the R-value or U-factor of the wall cross section, one of the following must be used:

(1.) Two or three dimensional finite difference or finite element computer model

(2.) Isothermal planes calculation method

(3.) Zone calculation method

(4.) Hot box test (ASTM C 236(12) or C 976)(13) on a typical ICF wall section

The hot box test method is preferred since many of the ICF systems have curved shapes in multiple dimensions that make analysis complex and results subject to assumptions. The hot box test report should include wall dimensions and insulation properties such as type, density and thermal conductivity provided by the manufacturer.

The isothermal planes calculation method, provided in Appendix A, is generally applicable to complex insulation shapes. The zone calculation method, provided in Appendix B, is generally applicable to systems with metal ties.

To determine overall thermal resistance (R_T), R-values of standard finishes such as gypsum wallboard and siding materials can be added to R-values of ICF systems determined from calculations or tests.

4. CHOICE OF COMPLIANCE PATHS

Three methods, or paths, are available to show compliance with the building envelope portion of the ASHRAE 90.2 code(2) or standard(1). The standard uses nonmandatory language (using verbs such as "should" and "may") and provides some guidelines. The code is written mandatory language (using the verb "shall). Differences between the code and standard are indicated in this document, although in most cases the two are equivalent.

PRESCRIPTIVE

The simplest method is the prescriptive path. Using this method, the prescriptive criteria for each component, such as a door or window, are compared to those proposed.

ENVELOPE TRADE-OFF

The envelope trade-off path is used if an individual component does not meet the standard or code requirement, or if the window and skylight area is greater than 125 sq. ft (standard version) or 18% of the floor area of all conditioned spaces (code version). The envelope trade-off cannot be used for a window and skylight criteria greater than 32% of the floor area.

This method is also useful to assess compliance when some envelope components fail to meet prescriptive requirements while others pass. Those components that exceed requirements are allowed to make up for deficiencies in those that fail when certain conditions are met. For example, if walls have more insulation than required, as many ICF systems do, this method can be used to lessen the insulation required in the ceiling.

ANNUAL ENERGY COST

The annual energy cost method is used to assess compliance when the prescriptive and envelope trade-off paths do not show compliance. Using the annual energy cost method, the calculated energy cost of a proposed building is compared to the calculated energy cost of a building that meets the prescriptive requirements. The proposed building meets the requirements of the standard or code if its annual energy cost is less than that of a budget building meeting prescriptive requirements.

5. PRESCRIPTIVE PATH

Using this prescriptive path, the prescriptive criteria for each component, such as a door or window, are compared to the properties of proposed components. The building passes if the properties for each component of the proposed building meet or exceed the prescriptive criteria for each component. Other mandatory requirements for the building must also be met (See Section 8 of this manual.)

Follow these steps to determine compliance with the prescriptive path:

Step 1 Determine the window and skylight (fenestration) area. The fenestration area must be less than 125 sq ft (standard version) or 18% of the floor area of all conditioned spaces (code version) to use this path.

Step 2 Determine the building type:

- single family, ducts within conditioned space
- single family, ducts outside conditioned space
- multifamily structures

Step 3 Determine type of construction for each component. For instance determine whether the above grade walls are mass with interior insulation (ICF walls) or wood frame.

Step 4 Determine properties of proposed components.

Step 5 Determine criteria for each of the proposed components (Step 3) based on climate.

Step 6 Compare properties of the proposed components (Step 4) to criteria (Step 5).

Data determined from the six steps may be entered on "Table C1 — Worksheet to Determine Compliance with Prescriptive Requirements of ASHRAE 90.2" in Appendix C.

STEP 1 — WINDOW AND SKYLIGHT AREA

The window and skylight area must be less than 125 sq ft (standard version) or 18% of the floor area (code version) to use the prescriptive path. First, determine the total square footage of windows plus skylights (fenestration). For the standard version, if the total is greater than 125 sq ft, the envelope trade-off method must be used. For the code version also determine the total square feet of floor area. This includes floors of all habitable conditioned spaces, including conditioned basements, attics, and associated partition walls, closets and stairwells. Divide the fenestration area by the floor area. If the total is greater than 18%, the envelope trade-off method must be used.

STEP 2 — BUILDING TYPE

The standard and code provide separate criteria for single family and multifamily dwellings.

Single Family

Single family is defined here as a single-family home, a duplex, or a townhouse. A townhouse is "a living unit in which one or more walls are partition, lot line or common walls, but not containing common floor or ceiling combinations."

For the single-family category, the standard and code provide more stringent envelope requirements for cases where ducts are located outside the conditioned space. The conditioned space is the heated or cooled space. The components that separate the conditioned space from the outdoor environment define the building envelope as shown in Fig. 15. Note that the ceiling rather than the roof is part of the building envelope if the ceiling is insulated. If insulation was between the roof rafters, then the roof would be part of the building envelope. Generally, the components that comprise the building envelope must meet the criteria specified in the standard or code.

These buildings meet the criteria for **Ducts Within Conditioned Space**:

(1.) Buildings that do not have air distribution systems for either heating or cooling. Such systems include hydronic systems, electric radiant panels, electric baseboard heat, and through-the-wall or window units.

(2.) Buildings with air distribution systems that have eight or less feet of the supply or return ducts, or both, located outside the conditioned space. The central equipment can be located outside the conditioned space such as in a garage or carport.

(3.) Buildings with a high efficiency heating system to make up for the deficiency of ducts located outside the conditioned space. This procedure is described in Appendix D.

These buildings are considered to have **Ducts Outside Conditioned Space**

(1.) Buildings with air distribution systems that have eight or more feet of the supply or return ducts, or both, located outside the conditioned space. Outside the conditioned space includes outdoors, crawl spaces, or in an unconditioned environment such as a garage or unheated basement.

(2.) Buildings with ducts within a slab.

Multi-Family

Multi-family is defined as a building three stories or fewer above grade containing three or more living units, other than townhomes. Generally, the standard covers congregate residences with complete facilities including kitchens. This includes apartments, condominiums, dormitories, rooming houses, sorority and fraternity houses. The standard does not include hotels, motels, nursing homes, hospitals, barracks, and jails. Housing with more than three stories above grade are high-rise residential and are covered by ASHRAE/IESNA 90.1-1989 "Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings." (14) Multi-family housing criteria are not dependent on duct location.

STEP 3 — TYPE OF COMPONENT

The standard and code provide criteria for each type of component or class of construction. Use Tables Nos. 5, 6, and 7 to determine which classes of construction apply to the proposed building. Table No. 5 applies to single family dwellings, Table No. 6 applies to multi-family dwellings using the standard, and Table No. 7 applies to multi-family dwellings using the code. Each type of component in the proposed building may be listed in the worksheet (Table C1).

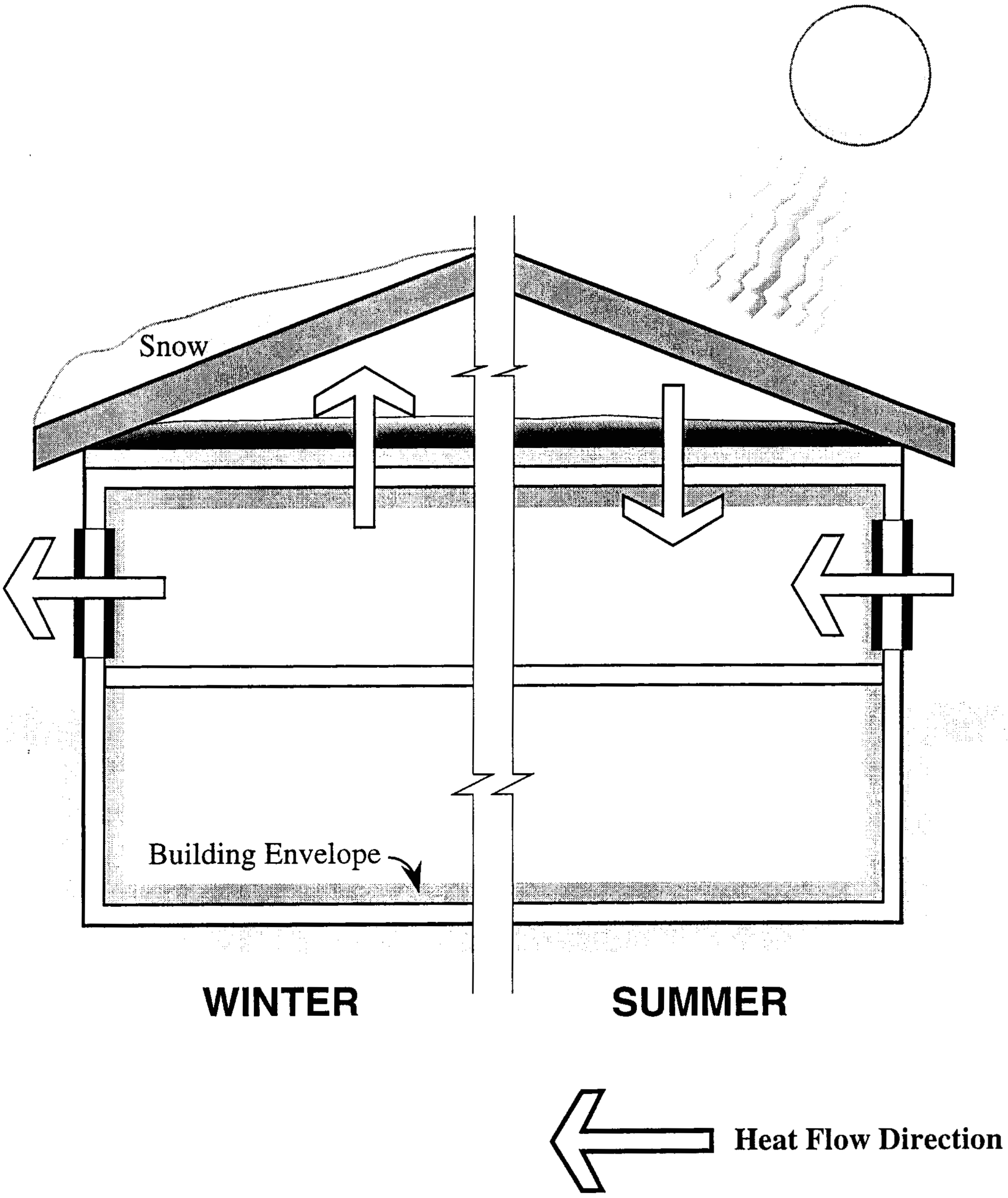

Fig. 15 Building Envelope

TABLE 5 - TYPE OF COMPONENT (CLASS OF CONSTRUCTION) AND CRITERIA FIG. NOS. FOR SINGLE FAMILY DWELLINGS

Component	90.2 Fig. No. for Criteria*
Walls	
Above grade	
Concrete, masonry, or log with interior insulation (**ICF Walls**)	5
Concrete, masonry, or log with exterior or integral insulation	4
Wood or metal frame and band joists	3
Adjacent to unconditioned space	
Concrete or masonry (**ICF Walls**)	7
Wood and metal frame	6
Below grade basement	
Exterior or integral insulation	10
Interior insulation (**ICF Walls**)	11
Crawl space	13
Ceilings	
With attics	1
Without attics	2
Floors	
Over exterior ambient conditions	
Frame	8
Over unconditioned space	
Frame	9
Slab-on-grade	
Unheated	12
Heated	12 + R2
Fenestration	15, 16†
Doors	
Non-wood	14
Wood	U≤0.40 up to 10,000 HDD; then U≤0.19

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* In the standard, these numbers are Chapter 5 figure numbers, i.e., 1 is Fig. 5-1. In the code, these are Appendix B figure numbers, i.e., 1 is Fig. B-1. The suffix "A" in the figure number in the code and standard are for buildings with ducts located within the conditioned space. The suffix "B" in the figure number in the code and standard are for buildings with ducts located outside the conditioned space.

† In the code, the suffixes "C" and "D" for Figs. B-15 and B-16 are criteria for buildings with fenestration greater than 125 sq ft but less than 18% of the floor area.

TABLE 6 - TYPE OF COMPONENT (CLASS OF CONSTRUCTION) AND STANDARD CRITERIA FIG. NOS. FOR MULTI-FAMILY DWELLINGS

Component	90.2 Fig. No. for Criteria*
Walls	
Above grade	
Concrete, masonry, or log with interior insulation (**ICF Walls**)	23
Concrete, masonry, or log with exterior or integral insulation	22
Wood frame and band joists	20
Metal frame	21
Adjacent to unconditioned space	
Concrete or masonry (**ICF Walls**)	26
Wood frame	24
Metal frame	25
Below grade basement	
Exterior or integral insulation	30
Interior insulation (**ICF Walls**)	31
Crawl space	33
Ceilings	
With attics	18
Without attics	19
Floors	
Over exterior ambient conditions	
Concrete	29
Frame	27
Over unconditioned space	
Frame	28
Slab-on-grade	
Unheated	32
Heated	32 + R2
Fenestration	35, 36
Doors	
Non-wood	34
Wood	U≤0.40 up to 10,000 HDD; then U≤0.19

* Numbers are Chapter 5 figure numbers, i.e., 23 is Fig. 5-23.

TABLE 7 - TYPE OF COMPONENT (CLASS OF CONSTRUCTION) AND CODE CRITERIA FIG. NOS. FOR MULTI-FAMILY DWELLINGS

Component	90.2 Fig. No. for Criteria*
Walls	
Above grade	
Concrete, masonry, or log with interior insulation (**ICF Walls**)	22
Concrete, masonry, or log with exterior or integral insulation	21
Wood frame and band joists	19
Metal frame	20
Adjacent to unconditioned space	
Concrete or masonry (**ICF Walls**)	25
Wood frame	23
Metal frame	24
Below grade basement	
Exterior or integral insulation	29
Interior insulation (**ICF Walls**)	30
Crawl space	32
Ceilings	
With attics	17
Without attics	18
Floors	
Over exterior ambient conditions	
Concrete	28
Frame	26
Over unconditioned space	
Frame	27
Slab-on-grade	
Unheated	31
Heated	31 + R2
Fenestration	34, 35†
Doors	
Non-wood	33
Wood	$U \leq 0.40$ up to 10,000 HDD; then $U \leq 0.19$

* Numbers are Appendix B figure numbers, i.e., 22 is Fig. B-22.

† The suffix "A" for Figs. B-34 and B-35 are criteria for buildings with fenestration less than 125 sq ft . The suffix "B" for Figs. B-34 and B-35 are criteria for buildings with fenestration greater than 125 sq ft but less than 18% of the floor area.

Walls

Above grade ICF walls are classified as "above grade concrete, masonry, or log walls with interior insulation" To qualify as exterior insulation position, the mass must be exposed (coupled) to the room air and the entire mass must be on the interior of the insulation layer. To qualify as integral insulation, the mass must be thermally coupled to the room air and either the mass and insulation has to be well mixed, as in wood logs, or substantial amounts of mass must be located on the exterior and interior, as in concrete blocks with insulated cores. ICF walls meet neither of these and therefore are classified as interior insulation.

Below grade ICF walls are classified as "below grade basement walls with interior insulation." A wall is below grade if more than 50% of the wall area for that story is below grade.

"Walls adjacent to unconditioned spaces" separate conditioned (heated or cooled) spaces from unconditioned spaces. Examples include walls separating living spaces from garages, mechanical rooms, and stairwells. ICF walls are classified as "concrete or masonry walls adjacent to unconditioned spaces."

All crawl space walls must meet the same criteria regardless of construction.

Fenestration and Doors

All skylights, windows, glass doors, and glass portions of doors are classified as fenestration. Greenhouses or solariums do not need to meet the fenestration requirements if the envelope component (usually a wall) separating the the greenhouse from the conditioned space meets the insulation requirements. Doors are classified as wood or non-wood.

STEP 4 — PROPERTIES OF PROPOSED COMPONENTS

Properties of the components defined in Step 3 need to be determined so they can be compared to criteria. Properties of the proposed components may be entered on the worksheet (Table C1) in the row corresponding to each component, under the column labeled "Proposed."

U-factors for wood and steel frame walls, ceilings, and floors must account for thermal bridges through framing members and other anomalies. For example, a wall with R-13 cavity insulation between framing members does not have an R-value of 13 because of the extra heat loss through wood framing members. Heat losses through steel framing members are greater than through wood framing because of the higher conductance of steel.

Walls

Determine the U-factors for above-grade IFC walls using the values in Table 2 of Section 3 of this manual. C-factors for below grade walls and crawl spaces can be found in Table 4 in the same section. For systems not in Tables 2 or 4, calculate values according to methods in Section 3.

Typical U-factors for wood frame and metal frame walls are presented in Appendix E, Tables E1 and E2, respectively. The first column specifies the depth of the wood or steel framing member. The second column provides the rated R-value of the insulation between the framing members in the wall cavity. The R-values across the top of the table are the rated R-value of the insulation sheathing continuously spanning the wall outside the cavity. U-factors listed in the table are for the total wall assembly.

Ceilings

U-factors for wood and metal framed ceilings must also account for thermal bridges through framing members and other anomalies. Typical U-factors for wood-framed ceilings with attics are presented in Table E3. These values assume a 4-in. deep wood member as the lower cord of a roof truss or ceiling joist. The standard framing values assume 5% of the insulation is tapered at the ceiling perimeter. The advanced framing values assume the insulation has a full and even depth extending to the outside edge of exterior walls. Typical U-factors for attics with metal joists are presented in Table E4.

Typical U-factors for ceilings with no attics are provided in the ASHRAE 90.2 User's Manual(4).

Floors

Typical U-factors for intermediate concrete floors with continuous insulation are presented in Table E5. These values assume the insulation is continuous and uninterrupted by framing. They also include standard air film resistances and carpet over a rubber pad with an R-value of 1.23 hr·ft^2·°F/Btu. The base R-value for this concrete floor with no insulation is 0.50 hr·ft^2·°F/Btu.

Typical U-factors for wood frame floors are presented in Table E6. The first column specifies the depth of the wood or framing member. The second column provides the rated R-value of the insulation between the framing members in the floor cavity. The R-values across the top of the table are the rated R-value of the insulation sheathing continuously spanning the floor outside the cavity. U-factors listed in the table are for the total floor assembly. These values include standard air film resistances, carpet over a rubber pad with an R-value of 1.23 hr·ft^2·°F/Btu, and a ¾-in. wood subfloor with an R-value of 0.94 hr·ft^2·°F/Btu.

Insulation requirements for slab-on-grade floors are dependent on the climate and not the U-factor of the floor. Therefore, U-factors of slab-on-grade floors do not need to be determined. Criteria are specified in terms of an R-value and length of added perimeter insulation starting at the top surface of the slab. The insulation can be any combination of vertical or horizontal insulation as long as it is continuous.

Fenestration

U-factors for vertical fenestration (windows) are provided in Table E7. Values are provided for single glazing for all frame types, and double and triple glazing depending on the material used to construct the frame. The glazing indicates the numbers of panes of glass in the window separated by an air space. For example, double glazing indicates the window is manufactured with two panes of glass separated by an air space. Values are also dependent on whether the glass is clear or tinted. These values may be conservative; U-factors for individual products are generally available from manufacturers and can be used in these analyses for compliance. Manufacturers should also be consulted for skylight U-factors. Typical values for skylights are also listed in the ASHRAE 90.2 User's Manual (4).

The standard and code require shading coefficients of either 0.7 or 0.5 to meet the solar heat gain requirement. Since all windows are assumed to have window treatments such as draperies, blinds, or sheers, all windows meet the 0.7 requirement. Single pane glass with a high performance tint or double pane glass with a tint or low-emissivity (low e) coating meet the 0.5 requirement(4). Shading coefficients are also available from window manufacturers.

Doors

Doors separating conditioned from unconditioned spaces, including doors to garages, must meet the criteria for doors.

Wood doors are required to have a U-factor less than 0.4 Btu/hr·ft^2·°F for all climates except very cold climates (more than 10,000 heating degree days, base 65°F). Manufacturers should be consulted for wood door U-factors. Generally, solid wood, insulated wood, or wood panel doors with ½-in. or greater panels have a U-factor less than 0.4 Btu/hr·ft^2·°F. Hollow wood doors and panel doors with thinner panels generally have a U-factor greater than 0.4 Btu/hr·ft^2·°F and do not comply. For very cold climates an insulated wood door is required.(4)

Non-wood doors are required to have a U-factor of 0.19 Btu/hr·ft^2·°F except in very mild climates. To meet this requirement, a steel door generally needs to have a polyurethane core and a thermal break(4). Manufacturers should be consulted for steel and other non-wood door U-factors.

STEP 5 — DETERMINE CRITERIA FOR COMPONENTS BASED ON CLIMATE

Criteria for each of the components in the proposed building must be determined. Criteria are based on the location of the proposed building. The climate parameters used are heating degree days base 65 (HDD65) and cooling degree hours base 74 (CDH74).

Use Chapter 9 of the standard and Appendix A of the code and select an appropriate location. Climate data are listed by state for the United States and by province for Canada. The HDD65 and CDH74 may be entered on the worksheet (Table C1).

For climates with less than 10,000 HDD65, use the figures in Chapter 5 of the standard and Appendix B of the code. Tables 5 (single family, standard and code), 6 (multi-family, standard), and 7 (multi-family, code) of this manual indicate which figures correspond to each building component. To use the figures, enter the HDD65 along the horizontal axis and the CDH74 along the vertical axis. The value printed in the area between lines is the criteria. For values close to lines such that it is difficult to determine criteria, use Section 5.3.11 of the standard for single family homes, 5.5.11 of the standard for multi-family homes, or Appendix B of the code.

Criteria may be entered on the worksheet (Table C1) in the row corresponding to each component, under the column "Criteria."

For climates with more than 10,000 HDD65, use Table 5-2 in the standard and Table 404 in the code for single family homes, and Table 5-5 in the standard and Table 407 in the code for multi-family homes.

STEP 6 — COMPARE PROPOSED AND CRITERIA TO DETERMINE COMPLIANCE

The properties of the proposed components, determined in Step 4, are compared to criteria for those components, determined in Step 5. The U, C, and SC factors of the proposed components must be less than the criteria. The R-value of the proposed slab-on-grade insulation must be more than the criteria. If all components comply, the building complies. If any one of the components does not comply, the building does not comply under the prescriptive method. If this is the case, the building can be reevaluated using the envelope trade-off method.

The ICF wall with a U-factor of 0.057 used in the examples meets the prescriptive criteria in climates with up to approximately 10,000 HDD for walls in single family homes with ducts within the conditioned space and multi-family homes, as shown in Figs. 5-5-A (single family) and 5-23 (multi-family) of the standard.

PRESCRIPTIVE COMPLIANCE EXAMPLE

Example 2:

Problem: Determine if an 1800 sq ft ranch house meets the prescriptive requirements of the standard and code. The house is constructed of ICF walls with a U-factor of 0.057 as described in Example No. 1 (Section 3 of this manual). The house, located in St. Louis, has slab-on-grade construction, 300 sq ft of double glazed windows in vinyl frames, two solid wood doors, and a wood frame attic with R-30 insulation above the ceiling. Air conditioning and heating ducts are entirely within the conditioned space. The amount of slab-on-grade insulation is not specified. Determine the amount of slab-on-grade perimeter insulation required to meet prescriptive requirements.

Solution: The prescriptive worksheet, Table C1 in Appendix C, is used to show compliance. Table 8 is a completed worksheet with values for Example 2. Since the requirements for fenestration area are exceeded for the standard but not for the code, the prescriptive path can be used to show compliance with the code but not the standard.

Components relevant for the example home are listed in the table within Table 8. The U-factor for the ICF walls is 0.057 and listed under "Proposed." The U-factor for an R-30 ceiling with wood joists is 0.034 from Table E3. For windows, either default U-factors or the manufacturer's label may be used. The default U-factor for double glazed windows with vinyl frames is 0.60 from Table E7. The default shading coefficient value of 0.70 is assumed. The solid wood door is assumed to have a U-factor of 0.4.

Chapter 9 of the standard and Appendix A of the code show St. Louis has 4948 HDD65 and 17,843 CDH74. Criteria tables in the code are used to determine values listed under "Criteria" in the table within Table 8. Table 5 of this document lists applicable criteria table numbers (Tables B-5A, B-1A, B-12A, and B-15C of the code.) Since U, C, and SC factors of the components in the proposed home are less than the criteria, the home complies with the prescriptive path of the code.

The code requires two feet of R5 insulation along the perimeter of the slab-on-grade floor. This can be accomplished using a footing in combination with ICF walls as shown in Fig. 16.

TABLE 8 — PRESCRIPTIVE COMPLIANCE EXAMPLE USING WORKSHEET/TABLE C1

Building Name: ***1800 sq ft ranch***
Prepared by: ***M. G. Van Geem***
Date: ***June 26, 1997***

STEP 1: WINDOW AND SKYLIGHT AREA

Determine fenestration (window and skylight) area in sq. ft ***300*** (A)
For standard version, is this less than 125 sq. ft? ***No***
If yes, proceed.
If no you cannot use prescriptive path; use envelope tradeoff method
For code version
Determine total sq. ft of all floors ***1800*** (B)
Determine per cent fenestration area by dividing A by B and multiplying by 100 ***17%***
Is this equal to or less than 18%? ***Yes***
If yes, proceed
If no you cannot use prescriptive path; use envelope tradeoff method

STEP 2: BUILDING TYPE

Check appropriate building type
Single family (single family home, duplex, or townhouse) ***SFH***
Ducts within conditioned space:
8 ft or less of ducts outside conditioned space X
High efficiency heating system (See appendix C) ______
Ducts outside conditioned space:
More than 8 ft of ducts outside conditioned space ______
Ducts within a slab ______
Multi family (less than 3 stories, 3 or more units, not a townhouse) ______

STEP 3: TYPE OF COMPONENT (CLASS OF CONSTRUCTION)

Use selections in Tables 5, 6, and 7 to list types of components that apply.

	Type of Component	Proposed	Criteria	Comply: Yes or No?
Above-Grade Wall	***Interior Insulation***	U= ***0.057***	U≤ ***0.080***	***Yes***
	ICF Walls			
Below-Grade Wall		C= ***N.A.***	C≤ ***N.A.***	
Ceiling	***Wood Frame***	U= ***0.034***	U≤ ***0.036***	***Yes***
	Attic			
Intermediate Floor		U= ***N.A.***	U≤ ***N.A.***	
Slab-on-Grade Floor	***Slab-on-Grade***	R= ***Not Given***	R≥ ***R-5, 2 ft***	***USE R-5, 2 ft***
Fenestration	***Double Glazed***	U= ***0.60***	U≤ ***0.87***	***Yes***
	Windows	SC=***0.7***	SC≤***0.7***	***Yes***
Door	***Solid Wood***	U= ***0.4***	U≤ ***0.40***	***Yes***

STEP 4: PROPERTIES OF PROPOSED COMPONENTS

Determine the following properties of the proposed components and insert them in the above table:
For above grade walls, ceilings, intermediate floors, and doors, list U-factor.
For below grade walls (basement and crawl space walls), list C-factor.
For slab-on-grade floors, list R-value and length of additional insulation.
For fenestration, list U-factor and shading coefficient.

STEP 5: CRITERIA BASED ON CLIMATE

Determine criteria for each of the proposed components (Step 3) based on climate.
Use Chap. 9 of standard or App. A of code to determine HDD65 and CDH74 for appropriate location.
Location of home: ***St. Louis, MO.***
HDD65 ***4948***
CDH74 ***17,843***
Determine criteria using figures and tables in Chap. 5 of the standard or Chap. 4 and App. B of the code.
Insert these in the above table.

STEP 6: COMPARE PROPOSED PROPERTIES TO CRITERIA TO DETERMINE COMPLIANCE

Compare properties of the proposed components (Step 4) to criteria (Step 5).
U, C, and SC of proposed components must be less than or equal to criteria.
R of proposed components must be more than or equal to criteria.
If all components comply, the building complies; if not, try the envelope trade-off method.

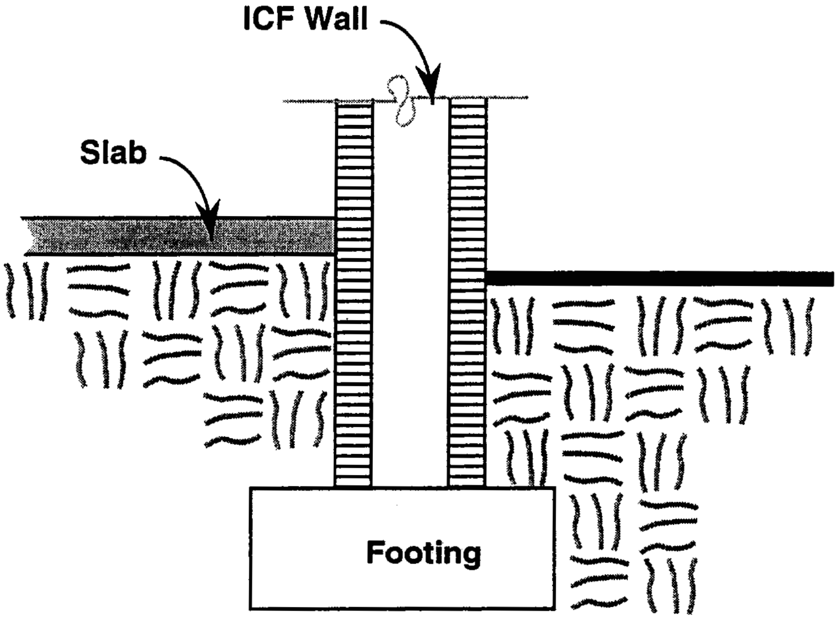

Fig. 16 IFC Wall Used to Meet Perimeter Insulation Requirements.

6. ENVELOPE TRADE-OFF PATH

The envelope trade-off path is more complicated than the prescriptive path but nevertheless is a straightforward method of assessing compliance when the prescriptive path does not show compliance. The envelope trade-off method uses values determined in the prescriptive path; so the steps outlined for the prescriptive path are always the first step in using the envelope trade-off path.

The envelope trade-off path is used if an individual component does not meet the standard or code requirement, or if the window and skylight area is greater than 125 sq. ft (standard version) or 18% of the floor area (code version). The envelope trade-off cannot be used for a window and skylight criteria greater than 32% of the floor area.

This method is also useful to show compliance when some envelope components fail to meet prescriptive requirements while others pass. Those components that exceed requirements are allowed to make up for deficiencies in those that fail when certain conditions are met. For example, if walls have more insulation than required, as many ICF systems do, this method can be used to reduce the amount of insulation required in the ceiling. However, prudence should be used when considering less insulation than the prescriptive requirements. Insulation levels in the code and standard are generally economically justified. Generally, the cost of the insulation is justifiable based on its energy-savings. Not using enough insulation for any given component may increase heat losses through that component in a disproportionate manner.

Forms ET-1, ET-2, and ET-3 in ASHRAE User's Manual(4) are reprinted in Appendix C and can be used to show compliance with the envelope trade-off method. The following steps are similar to those in the manual:

Step 1 Determine prescriptive criteria following the procedure in Section 5 of this manual.

Step 2 Determine the area of the building components.

Step 3 Calculate the climate factors for components used in the home.

Step 4 Determine the difference in load between the mandatory requirements and the proposed building for the opaque elements.

Step 5 Determine the difference in load between the mandatory requirements and the proposed building for the fenestration elements.

Step 6 Calculate the total load change and determine compliance.

Calculations are repetitive and ideally suited for a computer spreadsheet.

Other mandatory requirements for the building must also be met (See Section 8 of this manual.)

STEP 1 — DETERMINE PRESCRIPTIVE CRITERIA

Determine prescriptive criteria following the procedure in Section 5 of this manual. Data may be entered into Table C1 - Worksheet to Determine Compliance with Prescriptive Requirements of ASHRAE 90.2" in Appendix C. Components, proposed properties, and criteria may then be listed on Form ET-2, the opaque envelope trade-off worksheet. Components are listed under "Construction Class," the proposed properties are listed under "Up" and the prescriptive criteria are listed under "Um." For slab-on-grade perimeter insulation, the U-factor for the proposed and criteria columns are the inverse of 1 plus the R-value of the added insulation.

STEP 2 — AREA OF BUILDING COMPONENTS

The area of each component or class of construction listed in Step 1 is required for calculations. All components have associated areas except slab-on-grade insulation which is specified in linear feet of perimeter insulation. Associated areas or linear feet may be entered in Form ET-2.

STEP 3 — CALCULATE CLIMATE FACTORS

Climate factors are required to calculate the change in load between the mandatory requirements and those in the proposed building. Climate factors are required only for those components in the proposed building, although they may be calculated for all possible components and saved for later use.

Climate factors are dependent on the location of the proposed building. The climate parameters used are heating degree days base 65°F (HDD65) and cooling degree hours base 74°F (CDH74). These values were determined for the prescriptive criteria and should be listed on the completed Worksheet C1. HDD65 and CDH74 are also listed in Chapter 9 of the standard and Appendix A of the code. These values should be inserted in every row of the appropriate column in Form ET-1.

Complete calculations in rows of Form ET-1 to determine the climate factor for all components in the proposed home. Insert climate factors in the appropriate rows of Form ET-2.

STEP 4 — LOAD DIFFERENCE FOR OPAQUE ELEMENTS

The load difference between the mandatory requirements and the proposed properties of components are calculated using Form ET-2. Necessary values were determined in Steps 1, 2, and 3. Complete calculations in rows of Form ET-2 to determine the load change for all opaque components in the proposed home. Sum the load changes for the components to determine the load change for the opaque envelope.

If the proposed fenestration met the prescriptive requirements and the sum of the load changes for the opaque envelope is positive, the proposed building meets the envelope trade-off requirements. If the proposed fenestration does not meet prescriptive requirements, Steps 5 and 6 must be performed.

STEP 5 — LOAD DIFFERENCE FOR FENESTRATION

Form ET-3 follows the procedure for calculating the load difference between the mandatory requirements and the proposed properties for fenestration. Use fenestration areas, climate factors from Form ET-1, and properties of the proposed fenestration and criteria from Table C1 to complete Form ET-3.

STEP 6 — TOTAL LOAD CHANGE

Sum the total load change from the opaque elements from Form ET-2 and the fenestration from Form ET-3. The proposed home meets the envelope trade-off requirements if the total sum is positive. Negative values for individual components indicate components that do not comply with prescriptive requirements; positive values indicate prescriptive compliance for opaque components.

If the envelope trade-off approach does not show compliance, the annual energy cost method is a more comprehensive and rigorous analysis method that may show compliance.

ENVELOPE TRADE-OFF COMPLIANCE EXAMPLES

Example 3 (Fenestration):

Problem: Use the home in Example 2 and determine if the home meets the requirements of the standard. This home has a total window area exceeding 125 sq ft and does not meet the prescriptive requirements of the standard. The home has a total window area less than 18% of the floor area and meets the prescriptive requirements of the code.

Solution: Table 9 shows completed Forms ET-1, ET-2, and ET-3 for this example. The opaque element descriptions, proposed values, and criteria from Table 8 (Worksheet C1) are entered on Form ET-2 under construction class, "Up", and "Um." For slab-on-grade insulation, "Um" and "Up" the are inverse of the sum of the added insulation R-value plus 1.0. The component areas are then determined and entered on Form ET-2. The house is assumed to be 42.5 ft square with 8 ft high walls. The foundation perimeter is 170 ft. Each door is 17 sq ft. Form ET-1 is completed using the HDD65 and CDH74 for St. Louis. Climate factors are transferred from Form ET-1 to Form ET-2 for the applicable components and the load change is calculated. Fenestration descriptions, proposed values, and criteria from Table 8 (Worksheet C1) are transferred on to Form ET-3. Window areas are also entered and the load change (LC) is calculated. Since the load changes on Forms ET-2 and ET-3 are both positive, the total is positive and the building meets the envelope trade-off requirements.

Example 4 (Ceiling Insulation):

Problem: Use the home in Example 2 and determine if less insulation can be used for the ceiling.

Solution: For this example, the extra energy efficiency in the walls is traded to reduce the ceiling insulation. Table 10 is completed Worksheet ET-2 for this example. The opaque element descriptions, proposed values, and criteria from Table 8 (Worksheet C1) are entered on Form ET-2 under construction class, "Up", and "Um." "Up" for the ceiling is left blank and will be determined. For slab-on-grade insulation, the "Um" and "Up" are inverse of the sum of the added insulation R-value plus 1.0. The component areas are then determined and entered on Form ET-2. The house is assumed to be 42.5 ft square with 8 ft high walls. The foundation perimeter is 170 ft. Each door is 17 sq ft. Form ET-1 from Table 9 (Example 3) is applicable to this example and all houses in St. Louis. Climate factors are transferred from From ET-1 to Form ET-2 for the applicable components and the load change is calculated. The load change for the slab-on-grade floor and doors is zero.

For the total load change to equal 0, the ceiling load change must be -2,768,000 or greater. The "Up" is determined by solving the equation in the ceiling row. "Up", the U-factor of the ceiling, equals 0.045. A ceiling with a U-factor less than or equal to 0.045 meets the envelope trade-off requirements. Using the envelope trade-off method, the allowable thermal transmittance (U-factor) for the ceiling can be increased from 0.036 to 0.045 Btu/hr·ft^2·°F, and the allowable total thermal resistance (R_T-value) of the ceiling can be reduced from 27.7 to 22.2 hr·ft^2·°F/Btu. (R_T is the inverse of U.) The U-factor of the ceiling may be further increased by using Form ET-3 to trade-off the extra energy-efficiency in the windows for ceiling insulation.

Envelope Trade-off - Climate Factor Worksheet ET-1

Project Name: ***Table 9 - Example 3, St. Louis climate factors***

Fill in this table once for your climate.
The climate factors calculated here are used in the trade-off calculation worksheets ET-2 (opaque env.) and ET-3 (windows and skylights).

Opaque Construction Class		HLF		HDD65		CLF		CDH74			Climate Factor, CF	Units
Ceiling with attic	(	26.0	x	***4948***	) + (	2.0	x	***17,843***	)	=	***164,334***	ft^2
Ceiling without attic	(	23.0	x	***4948***	) + (	1.7	x	***17,843***	)	=	***144,137***	ft^2
Frame walls	(	21.0	x	***4948***	) + (	1.0	x	***17,843***	)	=	***121,751***	ft^2
Mass walls with ext. or integral insulation	(	21.0	x	***4948***	) + (	0.82	x	***17,843***	)	=	***118,539***	ft^2
Mass walls with interior insulation	(	21.0	x	***4948***	) + (	0.79	x	***17,843***	)	=	***118,004***	ft^2
Wall adjacent to unconditioned space	(	5.4	x	***4948***	) + (	0.4	x	***17,843***	)	=	***33,856***	ft^2
Doors	(	21.0	x	***4948***	) + (	1.0	x	***17,843***	)	=	***121,751***	ft^3
Floor over exterior ambient conditions	(	21.0	x	***4948***	) + (	1.0	x	***17,843***	)	=	***121,751***	ft^2
Ceiling with attic	(	5.4	x	***4948***	) + (	0.4	x	***17,843***	)	=	***33,856***	ft^2
Slab-on-grade: 2 ft	(	3.5	x	***4948***	) + (	0.3	x	***17,843***	)	=	***22,671***	ft
Slab-on-grade: 4 ft	(	4.5	x	***4948***	) + (	0.3	x	***17,843***	)	=	***27,619***	ft
Bsmnt wall (mass): deep, top half insul.	(	26.0	x	***4948***	) + (	0.4	x	***17,843***	)	=	***135,785***	ft
Ceiling with attic	(	36.0	x	***4948***	) + (	0.6	x	***17,843***	)	=	***188,834***	ft
Bsmnt wall (mass): shallow; entire wall ins	(	56.0	x	***4948***	) + (	1.4	x	***17,843***	)	=	***302,068***	ft
Bsmnt wall (wood): deep	(	51.0	x	***4948***	) + (	1.8	x	***17,843***	)	=	***284,465***	ft
Bsmnt wall (wood): shallow	(	88.0	x	***4948***	) + (	3.6	x	***17,843***	)	=	***499,659***	ft
Crawl space wall: concrete & masonry	(	23.5	x	***4948***	) + (	1.0	x	***17,843***	)	=	***134,121***	ft
Crawl space wall: wood	(	32.0	x	***4948***	) + (	1.9	x	***17,843***	)	=	***192,238***	ft

Window & Skylight Climate Factors				HDD65				CDH74				CF	
Window U-value base	(	20	x	***4948***	) + (	0.24	x	***17,843***	) +	-2,440	=	***100,802***	CF1
Window U-value proposed	(	-20	x	***4948***	) + (	-0.24	x	***17,843***	) +	2,440	=	***-100,802***	CF2
Window SC base	(	-9.775	x	***4948***	) + (	1.3	x	***17,843***	) +	14,850	=	***-10,321***	CF3
Window SC-north	(	4.8	x	***4948***	) + (	-0.8	x	***17,843***	) +	-10,500	=	***-1,024***	CF4
Window SC-east	(	9.8	x	***4948***	) + (	-1.6	x	***17,843***	) +	-15,100	=	***4,842***	CF5
Window SC-south	(	15.9	x	***4948***	) + (	-1.3	x	***17,843***	) +	-11,600	=	***43,877***	CF6
Window SC-west	(	8.6	x	***4948***	) + (	-1.5	x	***17,843***	) +	-22,200	=	***-6,412***	CF7
Skylight-north-A	(	-0.145	x	***4948***	) + (	0.056	x	***17,843***	) +	672	=	***954***	CF8
Skylight-north-B	(	16.6	x	***4948***	) + (	-5.9	x	***17,843***	) +	-70,300	=	***-93,437***	CF9
Skylight-east-A	(	-0.106	x	***4948***	) + (	0.048	x	***17,843***	) +	579	=	***911***	CF10
Skylight-east-B	(	21.1	x	***4948***	) + (	-6.4	x	***17,843***	) +	-73,900	=	***-83,692***	CF11
Skylight-south-A	(	-0.047	x	***4948***	) + (	0.052	x	***17,843***	) +	694	=	***1,389***	CF12
Skylight-south-B	(	23.9	x	***4948***	) + (	-6.9	x	***17,843***	) +	-82,900	=	***-87,760***	CF13
Skylight-west-A	(	-0.117	x	***4948***	) + (	0.049	x	***17,843***	) +	579	=	***874***	CF14
Skylight-west-B	(	20.3	x	***4948***	) + (	-6.4	x	***17,843***	) +	-77,100	=	***-90,851***	CF15

Definitions

HDD65 = Heating Degree Days, base 65°F. From Tables 9-1 or 9-2 of the Standard.
CDH74 = Cooling Degree Hours, base 74°F. From Tables 9-1 or 9-2 of the Standard.
CF = Climate Factor, used in envelope tradeoff worksheet calculations.

Envelope Trade-off - Opaque Envelope Load Change Worksheet ET-2

Project Name: *Table 9 - Example 3*

Construction Class		Um		Up		Size (ft or ft2)		Climate Factor		Load Change
	(		-		) X		X		=	
ceiling, wood frame attic	(	*0.036*	-	*0.034*	) X	*1800*	X	*164,334*	=	*591,602*
2 solid wood doors	(	*0.40*	-	*0.40*	) X	*38*	X	*121,751*	=	*0*
slab on grade	(	*0.17*	-	*0.17*	) X	*170*	X	*22,671*	=	*0*
above grade ICF walls	(	*0.08*	-	*0.057*	) X	*1020*	X	*118,004*	=	*2,768,374*
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	

Total Load Change for Opaque Envelope, LC_{opq} = *3,359,976*

(Enter LC_{opq}, along with LC_{fen}, on the compliance summary form)

Definitions

Construction Class = type of opaque envelope contruction, from ENV-CRIT, Envelope Criteria Summary Sheet.
U_m = Prescriptive U-factor, C-factor or R-value requirement for the construction (see ENV-CRIT, the Env. Criteria Summary Sht.) (Btu/h-ft2-°F)
U_p = Actual U-factor, C-factor or R-value for the proposed construction. (Btu/h-ft2-°F)
Size = Area (ft2) or length (ft) of the component.
Climate Factor = Value that depends on HDD65 and CDH74 for your location. Calculated on Climate Factor Worksheet, ET-1.
LC = Load Change (Btu).

Envelope Trade-off - Window Load Change Worksheet ET-3

Project Name: *Table 9 - Example 3*

WINDOWS

North-Facing	Area		Up		CF2		SC		CF4			LC
Double Glazed Vinyl Frames	*75*	x [	*0.6*	x	*-100,802*	+	*0.7*	x	*-1,024*	]	=	*-4,589,850*
		x [		x		+		x		]	=	
		x [		x		+		x		]	=	
East-Facing									CF5			
Double Glazed Vinyl Frames	*75*	x [	*0.6*	x	*-100,802*	+	*0.7*	x	*4,842*	]	=	*-4,281,920*
		x [		x		+		x		]	=	
		x [		x		+		x		]	=	
South-Facing									CF6			
Double Glazed Vinyl Frames	*75*	x [	*0.6*	x	*-100,802*	+	*0.7*	x	*43,877*	]	=	*-2,232,546*
		x [		x		+		x		]	=	
		x [		x		+		x		]	=	
West-Facing									CF7			
Double Glazed Vinyl Frames	*75*	x [	*0.6*	x	*-100,802*	+	*0.7*	x	*-6,412*	]	=	*-4,872,719*
		x [		x		+		x		]	=	
		x [		x		+		x		]	=	

Window Area, A_{win} *300*

SKYLIGHTS

North-Facing	Area		Up		CF2		SC		CF9		Tilt°		CF8			LC
None		x [		x		+		x (		+		x		)]	=	*0*
East-Facing									CF11				CF10			
None		x [		x		+		x (		+		x		)]	=	*0*
South-Facing									CF13				CF12			
None		x [		x		+		x (		+		x		)]	=	*0*
West-Facing									CF15				CF14			
None		x [		x		+		x (		+		x		)]	=	*0*

Skylight Area, A_{sky} *0*

BASE CASE FENESTRATION

A_{win}		A_{sky}		A_{tot}	A_{floor}				$A_{18\%}$
300	+	*0*	=	*300*	*1800*	x	0.18	=	*324*

A_m		U_m		CF1		SC_m		CF3			LC_{base}
300	x [	*0.87*	x	*100,802*	+	*0.7*	x	*-10,321*	]	=	*24,141,996*

A_m = smaller of (A_{tot}) or ($A_{18\%}$)

U_m = U-factor criteria for windows, from the Envelope Criteria Summary Sheet, ENV-CRIT.

SC_m = shading coefficient criteria for windows, also from ENV-CRIT.

WALL & CEILING AREA CORRECTION FACTORS (calculate only if $A_{tot} > A_{18\%}$, otherwise LC_{corr} = 0)

(A_{tot}-A_m)		A_{win}/A_{tot}		U_{wall}		CF_{wall}		A_{sky}/A_{tot}		$U_{ceiling}$		$CF_{ceiling}$			LC_{corr}
0	x [		x		x		+		x		x		]	=	*0*

U_{wall} & $U_{ceiling}$ = average U-factors for actual opaque wall and ceiling as entered in form ET-2.

CF_{wall} & $CF_{ceiling}$ = Climate Factors for the opaque wall and ceiling, from ET-1.

TOTAL LOAD CHANGE FOR FENESTRATION, LC_{fen}

(Enter LC_{fen}, along with LC_{opq}, on the compliance summary form)

LC_{fen} (sum of above) *8,164,960*

Envelope Trade-off - Opaque Envelope Load Change Worksheet ET-2

Project Name: *Table 10 - Example 4*

Construction Class		Um		Up		Size (ft or ft2)		Climate Factor		Load Change
	(		-		) X		X		=	
ceiling, wood frame attic	(	*0.036*	-	*0.045*	) X	*1800*	X	*164,334*	=	*-2,662,211*
2 solid wood doors	(	*0.40*	-	*0.40*	) X	*38*	X	*121,751*	=	*0*
slab on grade	(	*0.17*	-	*0.17*	) X	*170*	X	*22,671*	=	*0*
above grade ICF walls	(	*0.08*	-	*0.057*	) X	*1020*	X	*118,004*	=	*2,768,374*
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	

Total Load Change for Opaque Envelope, LC_{opq} = *106,163*

(Enter LC_{opq}, along with LC_{fen}, on the compliance summary form)

Definitions

Construction Class = type of opaque envelope contruction, from ENV-CRIT, Envelope Criteria Summary Sheet.
U_m = Prescriptive U-factor, C-factor or R-value requirement for the construction (see ENV-CRIT, the Env. Criteria Summary Sht.) (Btu/h-ft2-°F)
U_p = Actual U-factor, C-factor or R-value for the proposed construction. (Btu/h-ft2-°F)
Size = Area (ft2) or length (ft) of the component.
Climate Factor = Value that depends on HDD65 and CDH74 for your location. Calculated on Climate Factor Worksheet, ET-1.
LC = Load Change (Btu).

Example 5 (Slab-on-Grade Perimeter Insulation):

Problem: Use the home in Example 2 and determine if perimeter slab-on-grade insulation is required.

Solution: Table 11 is completed Form ET-2 for this example. The opaque element descriptions, proposed values, and criteria from Table 8 (Worksheet C1) are entered on Form ET-2 under construction class, "Up", and "Um." For slab-on-grade insulation, "Um" is the inverse of the sum of the added insulation R-value plus 1.0. "Up" for no added insulation is 1.0. The component areas are then determined and entered on Form ET-2. The house is assumed to be 42.5 ft square with 8 ft high walls. The foundation perimeter is 170 ft. Each door is 17 sq ft. Form ET-1 from Table 9 (Example 3) is applicable to this example and all houses in St. Louis. Climate factors are transferred from Form ET-1 to Form ET-2 for the applicable components and the load change is calculated. Since the total load change is positive, the building without added slab-on-grade perimeter insulation meets the envelope trade-off requirements.

Envelope Trade-off - Opaque Envelope Load Change Worksheet ET-2

Project Name: *Table 11 - Example 5*

Construction Class	Um	Up	Size (ft or ft2)	Climate Factor	Load Change
	(-	) x	x	=	
ceiling, wood frame attic	(*0.036* -	*0.034*) x	*1800* x	*164,334* =	*591,602*
2 solid wood doors	(*0.40* -	*0.40*) x	*38* x	*121,751* =	*0*
slab on grade (perimeter)	(*0.17* -	*1*) x	*170* x	*22,671* =	*-3,198,878*
above grade ICF walls	(*0.08* -	*0.057*) x	*1020* x	*118,004* =	*2,768,374*
	(-	) x	x	=	
	(-	) x	x	=	
	(-	) x	x	=	
	(-	) x	x	=	
	(-	) x	x	=	
	(-	) x	x	=	
	(-	) x	x	=	
	(-	) x	x	=	
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	(-	) x	x	=	
	(-	) x	x	=	
	(-	) x	x	=	
	(-	) x	x	=	
	(-	) x	x	=	
	(-	) x	x	=	
	(-	) x	x	=	
	(-	) x	x	=	

Total Load Change for Opaque Envelope, LC$_{opq}$ = *161,098*

(Enter LC$_{opq}$, along with LC$_{fen}$, on the compliance summary form)

Definitions

Construction Class = type of opaque envelope contruction, from ENV-CRIT, Envelope Criteria Summary Sheet.

U_m = Prescriptive U-factor, C-factor or R-value requirement for the construction (see ENV-CRIT, the Env. Criteria Summary Sht.) (Btu/h-ft2-°F)

U_p = Actual U-factor, C-factor or R-value for the proposed construction. (Btu/h-ft2-°F)

Size = Area (ft2) or length (ft) of the component.

Climate Factor = Value that depends on HDD65 and CDH74 for your location. Calculated on Climate Factor Worksheet, ET-1.

LC = Load Change (Btu).

7. ANNUAL ENERGY COST

The annual energy cost method is used to assess compliance when the prescriptive and envelope trade-off paths do not show compliance. This method requires considerable more effort than the prescriptive and envelope trade-off paths. Use of an energy load computer program or complex hand calculations are required. Using the annual energy cost method, the calculated energy cost of a proposed building is compared to the calculated energy cost of a building that meets the prescriptive requirements. A proposed building meets the requirements of the standard or code if its annual energy cost is less than that of a budget building meeting prescriptive requirements.

The annual energy cost method allows for the most flexibility in design and is well suited for incorporating passive solar design and innovative techniques.

Chapter 8 of the standard and Chapter 700 of the code provide guidelines and rules for determining the energy cost of the proposed and budget buildings. The 90.2 User's Manual also provides practical information on this method.(4)

8. ADDITIONAL MANDATORY REQUIREMENTS

The code and standard have additional requirements that must be met for compliance. The heating and cooling equipment and service water heating requirements are described in the ASHRAE 90.2 User's Manual(4). A separate manual is available for sizing heating and cooling equipment in homes with ICF systems(15).

The code and standard have air leakage, moisture prevention, and ventilation requirements that must be met regardless of the compliance method used.

AIR LEAKAGE

The air leakage requirements are intended to reduce the energy losses associated with uncontrolled air leakage. To comply with the code or standard, the home must meet one of the following:

- *ANSI/ASHRAE 119-1988 (RA1994), Air Leakage Performance for Detached Single-Family Residential Buildings* (16). The ASHRAE 119 method requires a building pressurization test for compliance.

- The following requirements:

  (1.) Windows and doors are required to meet minimum air leakage requirements listed in Sections 5.6.1, 5.6.2, and 5.6.3 in the standard and Section 408.1 in the code. These are manufacturer's requirements. The purchaser should request windows and doors that meet ASHRAE 90.2 requirements.

  (2.) Access hatches must be well-sealed using weatherstripping and must have a latch or other positive means of closure. Access hatches are openings between conditioned and unconditioned spaces other than doors described in (1.). If an access hatch penetrates an insulated envelope assembly, they must have the same level of insulation as the assembly. If not, the standard allows for a calculation to take into account the increased U-factor of the access hatch. The proposed section U-factor (i.e., the ceiling or wall) is adjusted to be the area weighted average of the U-factors of the access hatch and the remainder of the assembly.

  (3.) Joints that potentially allow for unwanted air infiltration must be appropriately caulked or sealed with weatherstripping, gasketing, or other material. These joints include those:

    (a). Around window and door frames

    (b.) Between above-grade walls and foundations or basements

    (c.) Between above-grade walls and roofs

    (d.) Between separate wall panels

    (e.) Between conditioned and unconditioned spaces

    (f.) At edges of crawl spaces with insulated walls

    - (g.) Around utility or service openings
    - (h.) At edges of below grade unheated spaces with HVAC equipment

(4.) Joints between dissimilar materials, such as between wood and concrete, must allow for differential expansion and contraction so a permanent seal is maintained.

AIR INFILTRATION RETARDERS

The standard recommends but does not require air infiltration retarders (housewrap). The code has no requirement for these products. Generally, ICF systems with solid concrete throughout their height and width like "flat" and "waffle" grid systems would not benefit from the addition of an air infiltration retarder.

If used, air retarders located on the outside of the insulation layer should be continuous and sealed against air leakage. To prevent moisture build-up within components, the air retarders should have a water vapor permeance of 5.0 perm or more, and greater than other layers in the component (i.e.wall).

VAPOR RETARDERS

Vapor retarders are generally used in cold climates to avoid condensation within building components. The standard and code require vapor retarders in walls and ceilings except in humid climates. Vapor retarders must be durable to resist tearing or other failure under normal construction practices. They are generally installed on the inside or conditioned side of the component. Continuous insulation materials often have facers that serve as vapor retarders. Vapor retarding paints are also available. A vapor retarder is defined as a material with a permeance of less than 1.0 perm.

Vapor retarders are discouraged in hot and humid climates. Hot and humid climates are generally located within 200 miles of the Gulf Coast or 100 miles of the Atlantic coast south of central North Carolina, and are defined as meeting one of the following conditions(11):

(1.) 67°F or higher wet-bulb outdoor ambient temperature for 3500 or more hours during the warmest six consecutive months of the year

(2.) 73°F or higher wet-bulb outdoor ambient temperature for 1750 or more hours during the warmest six consecutive months of the year

If vapor retarders are used in these regions, they should be placed on the exterior side of insulation to prevent moisture ingress from the outdoors.

MOISTURE BARRIERS

Moisture barriers are required beneath heated slabs and over exposed soils in crawl spaces. For crawl spaces, the moisture barrier must have at least a 6 mil thickness and extend 1.0 ft up the walls. Joints in the moisture barrier material must overlap by at least 1.0 ft and be taped or held in place with durable materials.

ATTIC AND CRAWL SPACE VENTILATION

The code requires attics and crawl spaces be ventilated as required by local building codes.

Attic The standard requires a ventilation opening area of at least 1.0 sq ft for each 150 sq ft of attic floor area for ceilings with no vapor retarder. For ceilings with a vapor retarder, the standard requires a ventilation opening area of at least 1.0 sq ft for each 300 sq ft of attic floor area.

Crawl Space The standard requires a ventilation opening area of at least 1.0 sq ft for each 1500 sq ft of crawl space floor area. At least four vent openings are required, with at least one within 3 ft of each corner and as high on the wall as possible. If crawl space walls are insulated, the vents must be operable.

9. REFERENCES

1. *ASHRAE Standard for Energy-Efficient Design of New Low-Rise Residential Buildings,* ASHRAE 90.2 - 1993, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, 1993.

2. *Energy Code for New Low-Rise Residential Buildings*, Codification of *ASHRAE 90.2 - 1993*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, 1995.

3. Van Geem, Martha G., *Guidelines for Using the CABO Model Energy Code with Insulating Concrete Forms,* Portland Cement Association, Skokie, IL, 1997.

4. *90.2 User's Manual*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, 1996.

5. Vanderwerf, Pieter A., and Munsell, W. Keith, *Insulating Concrete Forms Construction Manual*, McGraw-Hill, 1995.

6. DOE2, Lawrence Berkeley Laboratory, University of California.

7. BLAST, Construction Engineering Research Laboratory, P.O. Box 4005, Champaign, IL.

8. J. E. Christian and J. Kosny, "Thermal Performance and Wall Ratings," *ASHRAE Journal,* March 1996, ASHRAE, Atlanta.

9. Brown, W. C., Bomberg, M. T., and Ullett, J. M., "Measured Thermal Resistance of Frame Walls with Defects in the Installation of Mineral Fibre Insulation," *Journal of Thermal Insulation and Building Envelopes*, April 1993.

10. ASTM C 168-90, "Standard Terminology Relating to Thermal Insulating Materials," Volume 4, *Annual Book of ASTM Standards*, American Society for Testing and Materials, West Conshohocken, PA, 1996.

11. *1997 ASHRAE Handbook — Fundamentals,* American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, 1997.

12. ASTM C 236, "Standard Test Method for Steady-State Thermal Performance of Building Assemblies by Means of a Guarded Hot Box," *Annual Book of ASTM Standards*, American Society for Testing and Materials, West Conshohocken, PA, 1996.

13. ASTM C 976, "Standard Test Method for Thermal Performance of Building Assemblies by Means of a Calibrated Hot Box," *Annual Book of ASTM Standards*, American Society for Testing and Materials, West Conshohocken, PA, 1996.

14. *Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings*, ASHRAE/IESNA 90.1-1989, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, 1989.

15. Van Geem, Martha G., Gajda, John W., and Wilcox, Bruce A., *Sizing Air-Conditioning and Heating Equipment for Residential Buildings with ICF Walls*, Portland Cement Association, Skokie, IL, 1997.

16. *Air Leakage Performance for Detached Single-Family Residential Buildings,* ANSI/ASHRAE 119-1988 (RA1994), American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, 1988.

17. Hogan, John, "Approach for Opaque Envelope U-factors for ASHRAE 90.1-1989R," *1995 ASHRAE Transactions*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, 1995.

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APPENDIX A — ISOTHERMAL PLANES METHOD FOR CALCULATING HEAT TRANSMISSION COEFFICIENTS OF ICF WALLS

The isothermal planes method is most useful for calculating the thermal transmittance (U-factor) and thermal resistance (R-value) of ICF systems with nonuniform insulation thicknesses.

For the ICF system in Fig. A1, the total thermal resistance is calculated as follows(11):

$$R_T = R_i + R_f + (a_w/R_w + a_c/R_c)^{-1} + R_o \qquad \text{(Eq. A1)}$$

where:

R_T = Total thermal resistance, hr·ft^{2}·°F/Btu
R_i = Thermal resistance of inside surface film (still air), usually 0.68 hr·ft^{2}·°F/Btu
R_f = Thermal resistance of continuous insulation board on inside and outside face
R_w = Thermal resistance of insulation board acting as web between face boards
R_c = Thermal resistance of concrete core
R_o = Thermal resistance of outside surface film (15 mph wind), usually 0.17 hr·ft^{2}·°F/Btu
a_c = Fraction of area transverse to heat flow represented by concrete core
a_w = Fraction of area transverse to heat flow represented by insulation board as web

The U-factor is the inverse of the total thermal resistance.

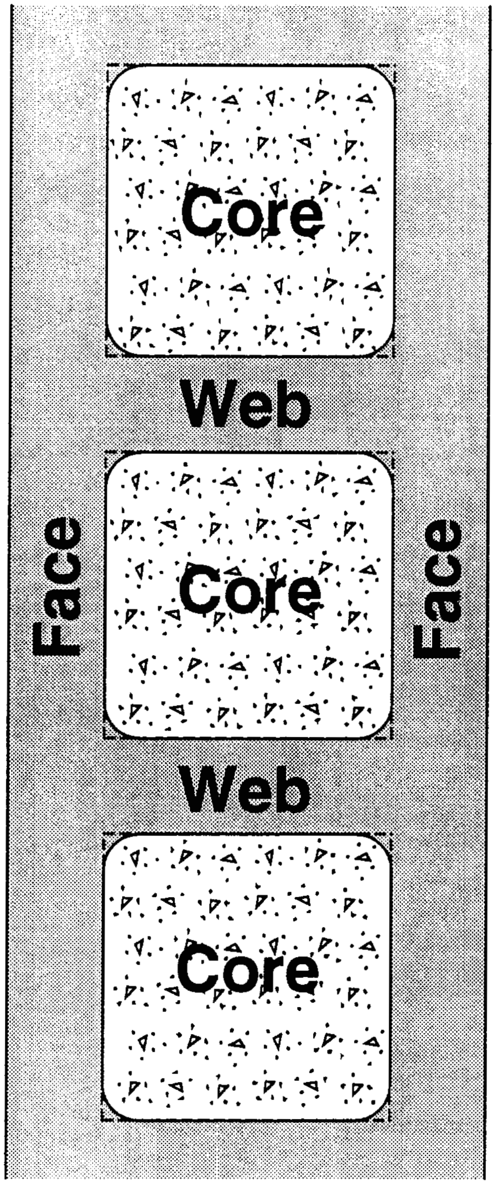
Insulation shapes in ICF systems are generally curved in multiple dimensions and therefore do not easily lend themselves to simplified one or two dimensional calculations such as the isothermal planes method. The following example indicates the types of assumptions required for many ICF systems.

Example No. A1:

Problem: Determine the R-value and U-factor of the ICF post and beam system shown in Fig. A2. Assume the thermal conductivities of the expanded polystyrene insulation (EPS) and concrete, respectively, are 0.23 and 16 Btu·in./hr·ft^{2}·°F.

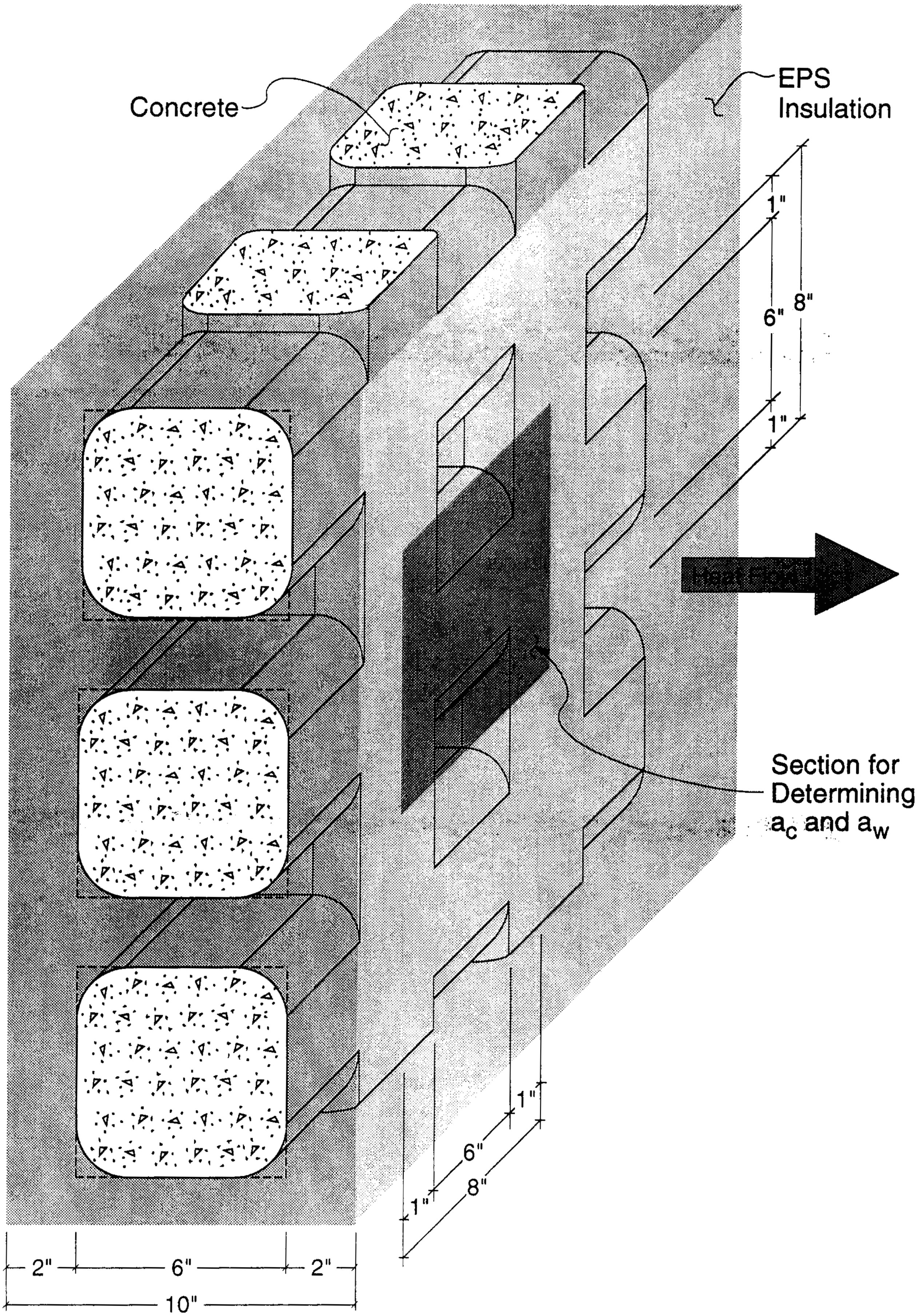
Solution: Thermal resistance for a homogeneous material is equal to its thickness divided by thermal conductivity. Assume the cores are square in cross-section, with the dimension equal to the maximum concrete thickness. (Assuming an average concrete thickness will underestimate the effects of thermal bridging.)

R_i = 0.68 hr·ft^{2}·°F/Btu
R_f = 2 x (2 in. / (0.23 Btu·in./hr·ft^{2}·°F)) = 17.4 hr·ft^{2}·°F/Btu
R_w = 6 in. / (0.23 Btu·in./hr·ft^{2}·°F) = 26.1 hr·ft^{2}·°F/Btu
R_c = 6 in. / (16 Btu·in./hr·ft^{2}·°F) = 0.375 hr·ft^{2}·°F/Btu
R_o = 0.17 hr·ft^{2}·°F/Btu



Plan

Fig. A1 - Plan View of ICF System



Isometric

Fig. A2 - ICF System Used in Example for Isothermal Planes Calculation Method

Beam Column

a_c = (2 in. / 8 in.)(6 in. / 8 in.) + (6 in. / 8 in.)(8 in. / 8 in.) = 0.94
a_w = (2 in. / 8 in.)(2 in. / 8 in.) = 0.06
$a_c + a_w = 1$

$R_T = R_i + R_f + (a_w/R_w + a_c/R_c)^{-1} + R_o$
$R_T = 0.68 + 17.4 + (0.06/26.1 + 0.94/0.375)^{-1} + 0.17 = 18.7$ hr·ft²·°F/Btu

$U = 1 / R_T$
$U = 1 / 18.65 = 0.054$ Btu/hr·ft²·°F

The isothermal planes method is conservative and the dimensional assumptions made in the example are conservative. A hot box test would probably provide a slightly higher R-value.

APPENDIX B — ZONE METHOD FOR CALCULATING HEAT TRANSMISSION COEFFICIENTS OF ICF WALLS

The zone method$^{(11)}$ is most useful for calculating the thermal transmittance (U-factor) and thermal resistance (R-value) of ICF systems with metal spanning the concrete core. The method essentially limits the extent of the isothermal plane in the isothermal planes method, and will be explained by example.

Example No. B1:

Problem: Determine the R-value and U-factor of the ICF system shown in Fig. B1. Assume the thermal conductivities of the expanded polystyrene insulation (EPS), concrete, and steel, respectively, are 0.23, 16, and 315 Btu·in./hr·ft^2·°F.

Solution: First determine the thermal resistance of Zone A, containing metal, using the isothermal planes method. Then determine the total thermal resistance of Zones A and B using area-weighted U-factors (parallel path method). Thermal resistance for a homogeneous material is equal to its thickness divided by thermal conductivity.

The width of influence of the metal, designated Zone A, is:

$$w = m + 2d \qquad \text{(Eq. B1)}$$

where:

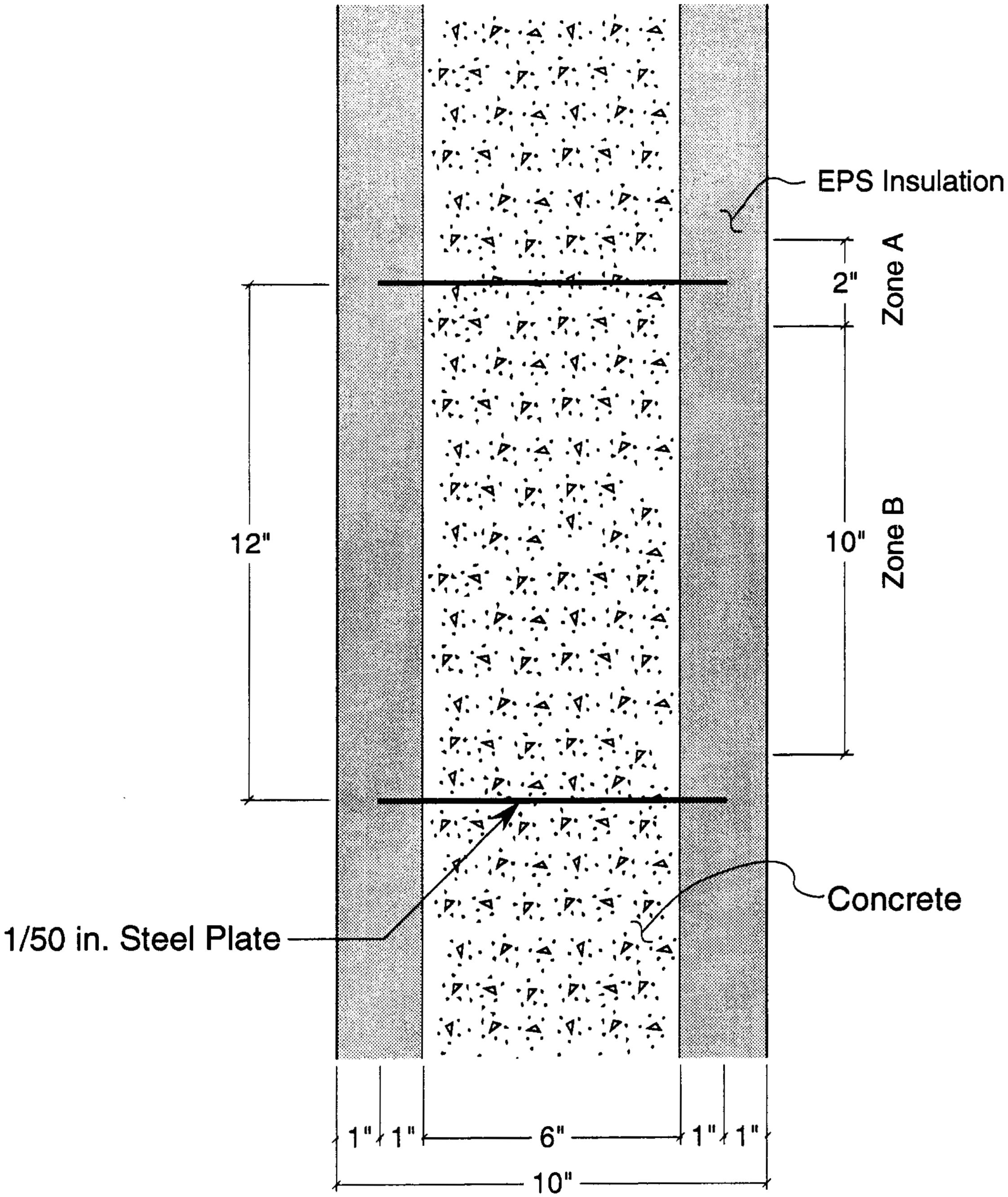
m = width or diameter of metal heat path
d = distance from panel surface to metal

For this example, $w = (0.02) + (2)(1) \approx 2$ in. Use a modified version of Eq. A1 to determine the thermal resistance of the 2-in. wide zone A.

$$R_A = R_i + R_f + (a_c/R_c + a_s/R_{s,c})^{-1} + (a_f/R_{f,s} + a_s/R_{s,f})^{-1} + R_o \qquad \text{(Eq. B2)}$$

where:

R_A = Total thermal resistance of Zone A, hr·ft^2·°F/Btu
R_i = Thermal resistance of inside surface film (still air), usually 0.68 hr·ft^2·°F/Btu
R_f = Thermal resistance of continuous insulation board without steel on inside and outside face
R_c = Thermal resistance of concrete
$R_{s,c}$ = Thermal resistance of steel in concrete area
$R_{f,s}$ = Thermal resistance of insulation board in steel area
$R_{s,f}$ = Thermal resistance of steel in insulation board area
R_o = Thermal resistance of outside surface film (15 mph wind), usually 0.17 hr·ft^2·°F/Btu
a_c = Fraction of area transverse to heat flow represented by concrete
a_s = Fraction of area transverse to heat flow represented by metal
a_f = Fraction of area transverse to heat flow represented by insulation board



Plan

Fig. B1 - ICF System Used in Example for Zone Calculation Method

For this example:

R_i = 0.68 hr·ft^2·°F/Btu
R_f = 4 in / (0.23 Btu·in./hr·ft^2·°F) = 17.39 hr·ft^2·°F/Btu
R_c = 6 in / (16 Btu·in./hr·ft^2·°F) = 0.375 hr·ft^2·°F/Btu
$R_{s,c}$ = 6 in / (315 Btu·in./hr·ft^2·°F) = 0.019 hr·ft^2·°F/Btu
$R_{f,s}$ = 2 in / (0.23 Btu·in./hr·ft^2·°F) = 8.70 hr·ft^2·°F/Btu
$R_{s,f}$ = 2 in / (315 Btu·in./hr·ft^2·°F) = 0.006 hr·ft^2·°F/Btu
R_o = 0.17 hr·ft^2·°F/Btu
a_c = (1.98 in. / 2.00 in.) = .99
a_s = (0.02 in. / 2.00 in.) = .01
a_f = (1.98 in. / 2.00 in.) = .99

$$\begin{aligned} R_A &= R_i + R_f + (a_c/R_c + a_s/R_{s,c})^{-1} + (a_f/R_{f,s} + a_s/R_{s,f})^{-1} + R_o \\ &= 0.68 + 8.70 + (0.99 / 0.375 + 0.01 / 0.006)^{-1} + (0.99 / 8.70 + 0.01 / 0.006)^{-1} + 0.17 \\ &= 10.34 \text{ hr·ft}^{2}\text{·°F/Btu} \end{aligned}$$

$$U_A = 1 / R_A = 0.097 \text{ Btu/hr·ft}^{2}\text{·°F}$$

The thermal resistance of Zone B is the sum of the resistances of materials in the zone.

$$\begin{aligned} R_B &= R_i + R_f + R_c + R_o \\ &= 0.68 + 17.39 + 0.375 + 0.17 \\ &= 18.62 \text{ hr·ft}^{2}\text{·°F/Btu} \\ U_B &= 1 / R_B = 0.0537 \text{ Btu/hr·ft}^{2}\text{·°F} \end{aligned}$$

The thermal transmittance is the area-weighted U-values of Zones A and B.

$$\begin{aligned} U &= (2 \text{ in.} / 12 \text{ in.})\, U_A + (10 \text{ in.} / 12 \text{ in.})\, U_B \\ &= (0.17)(0.097) + (0.83)(0.0537) \\ &= 0.0611 \text{ Btu/hr·ft}^{2}\text{·°F} \end{aligned}$$

$$R_T = 1 / U = 16.4 \text{ hr·ft}^{2}\text{·°F/Btu}$$

APPENDIX C — ENVELOPE COMPLIANCE WORKSHEETS

TABLE C1 — WORKSHEET TO DETERMINE COMPLIANCE WITH PRESCRIPTIVE REQUIREMENTS OF ASHRAE 90.2

Building Name:________________
Prepared by:_________________
Date:_______________________

STEP 1: WINDOW AND SKYLIGHT AREA

Determine fenestration (window and skylight) area in sq. ft _______ (A)

For standard version, is this less than 125 sq. ft? _______

If yes, proceed.

If no you cannot use prescriptive path; use envelope tradeoff method

For code version

Determine total sq. ft of all floors _______ (B)

Determine per cent fenestration area by dividing A by B and multiplying by 100 ______

Is this equal to or less than 18%? _______

If yes, proceed

If no you cannot use prescriptive path; use envelope tradeoff method

STEP 2: BUILDING TYPE

Check appropriate building type

Single family (single family home, duplex, or townhouse) ______

Ducts within conditioned space:

8 ft or less of ducts outside conditioned space ______

High efficiency heating system (See appendix C) ______

Ducts outside conditioned space:

More than 8 ft of ducts outside conditioned space ______

Ducts within a slab _______

Multi family (less than 3 stories, 3 or more units, not a townhouse) ______

STEP 3: TYPE OF COMPONENT (CLASS OF CONSTRUCTION)

Use selections in Tables 5, 6, and 7 to list types of components that apply.

	Type of Component	Proposed	Criteria	Comply: Yes or No?
Above-Grade Wall		U=	U≤	
Below-Grade Wall		C=	C≤	
Ceiling		U=	U≤	
Intermediate Floor		U=	U≤	
Slab-on-Grade Floor		R=	R≥	
Fenestration		U=	U≤	
		SC=	SC≤	
Door		U=	U≤	

STEP 4: PROPERTIES OF PROPOSED COMPONENTS

Determine the following properties of the proposed components and insert them in the above table:

For above grade walls, ceilings, intermediate floors, and doors, list U-factor.

For below grade walls (basement and crawl space walls), list C-factor.

For slab-on-grade floors, list R-value and length of additional insulation.

For fenestration, list U-factor and shading coefficient.

STEP 5: CRITERIA BASED ON CLIMATE

Determine criteria for each of the proposed components (Step 3) based on climate.

Use Chap. 9 of standard or App. A of code to determine HDD65 and CDH74 for appropriate location.

Location of home:_______________

HDD65 ______

CDH74 ______

Determine criteria using figures and tables in Chap. 5 of the standard or Chap. 4 and App. B of the code.

Insert these in the above table.

STEP 6: COMPARE PROPOSED PROPERTIES TO CRITERIA TO DETERMINE COMPLIANCE

Compare properties of the proposed components (Step 4) to criteria (Step 5).

U, C, and SC of proposed components must be less than or equal to criteria.

R of proposed components must be more than or equal to criteria.

If all components comply, the building complies; if not, try the envelope trade-off method.

APPENDIX D — DUCT EXCEPTION FOR HIGH EFFICIENCY EQUIPMENT

Insulation requirements for the building envelope of single-family houses are higher when distribution ducts are located outside the conditioned space than when inside the conditioned space. Section 5.3 (d) of the standard and footnote 4 of Table 403a of the code allow use of the requirements for ducts inside the conditioned space when ducts are located outside if certain high efficiency requirements are met. To use this exception for the standard, equipment efficiencies must be greater than or equal to those listed in Tables 6-5 through 6-11 divided by the applicable distribution factor in Table 8-2. For the code, equipment efficiencies must be greater than or equal to those listed in Table 504.3 divided by the applicable distribution factors in Table 708.4.5. The distribution factors for ducts depend on their location and insulation level.

For example, the minimum efficiency of a warm air gas furnace from Table 504.3 of the code (Table 6-5 of the standard) is 78% AFUE. The distribution factor for ducts with R-6 insulation in the attic of a one-story house is 0.84 (Table 708.4.5. of the code and Table 8-2 of the standard.) The furnace efficiency must be greater than 0.78/0.84 = 93% AFUE to qualify for this exception. Therefore, if the furnace efficiency is greater than or equal to 93% AFUE, and all other equipment meets similar high efficiency requirements, the envelope requirements for ducts located inside the conditioned space may be used even though the ducts are located outside the conditioned space.

APPENDIX E — TYPICAL U-FACTORS FOR WALLS, CEILINGS, FLOORS, AND FENESTRATION(17)

Table E1
Assembly U-Factors for Wood Frame Walls

FRAMING TYPE & SPACING WIDTH (Actual depth)	CAVITY INSULATION R-VALUE: Rated/ (Effective Installed)	OVERALL U-FACTOR FOR ENTIRE BASEWALL ASSEMBLY	R- 1.00	R- 2.00	R- 3.00	R- 4.00	R- 5.00	R- 6.00	R- 7.00	R- 8.00	R- 9.00	R- 10.00	R- 11.00	R- 12.00	R- 13.00	R- 14.00	R- 15.00	R- 20.00	R- 25.00	R- 30.00	R- 35.00	R- 40.00	R- 50.00	R- 60.00
WOOD																								
(3.5 in.	None (0.0)	**0.355**	0.257	0.202	0.167	0.143	0.124	0.110	0.099	0.090	0.083	0.076	0.071	0.066	0.062	0.058	0.055	0.043	0.035	0.030	0.026	0.023	0.019	0.016
depth)	R-11 (11.0)	**0.103**	0.092	0.084	0.077	0.071	0.066	0.062	0.058	0.055	0.052	0.049	0.047	0.045	0.043	0.041	0.039	0.033	0.028	0.025	0.022	0.020	0.016	0.014
	R-13 (13.0)	**0.094**	0.085	0.077	0.071	0.066	0.061	0.058	0.054	0.051	0.049	0.046	0.044	0.042	0.041	0.039	0.037	0.031	0.027	0.024	0.021	0.019	0.016	0.014
	R-15 (15.0)	**0.088**	0.079	0.072	0.067	0.062	0.058	0.054	0.051	0.049	0.046	0.044	0.042	0.040	0.039	0.037	0.036	0.030	0.026	0.023	0.021	0.019	0.016	0.014
(5.5 in.	R-19 (18.0)	**0.070**	0.065	0.060	0.056	0.053	0.050	0.047	0.045	0.043	0.041	0.039	0.038	0.036	0.035	0.034	0.033	0.028	0.024	0.022	0.020	0.018	0.015	0.013
depth)	R-21 (21.0)	**0.065**	0.060	0.056	0.052	0.049	0.047	0.044	0.042	0.040	0.039	0.037	0.036	0.034	0.033	0.032	0.031	0.027	0.023	0.021	0.019	0.017	0.015	0.013
(+ R-10	R-19 (18.0)	**0.066**	0.061	0.057	0.054	0.051	0.048	0.046	0.044	0.042	0.040	0.038	0.037	0.036	0.034	0.033	0.032	0.028	0.024	0.022	0.019	0.018	0.015	0.013
headers)	R-21 (21.0)	**0.061**	0.057	0.053	0.050	0.047	0.045	0.043	0.041	0.039	0.038	0.036	0.035	0.034	0.032	0.031	0.030	0.026	0.023	0.021	0.019	0.017	0.015	0.013
WOOD																								
(3.5 in.	None (0.0)	**0.362**	0.261	0.205	0.169	0.144	0.126	0.111	0.100	0.091	0.083	0.077	0.071	0.066	0.062	0.059	0.055	0.043	0.036	0.030	0.026	0.023	0.019	0.016
depth)	R-11 (11.0)	**0.100**	0.090	0.082	0.075	0.070	0.065	0.061	0.057	0.054	0.051	0.049	0.046	0.044	0.042	0.041	0.039	0.033	0.028	0.024	0.022	0.020	0.016	0.014
	R-13 (13.0)	**0.091**	0.082	0.075	0.069	0.064	0.060	0.057	0.053	0.051	0.048	0.046	0.044	0.042	0.040	0.038	0.037	0.031	0.027	0.024	0.021	0.019	0.016	0.014
	R-15 (15.0)	**0.085**	0.077	0.070	0.065	0.060	0.057	0.053	0.050	0.048	0.045	0.043	0.041	0.040	0.038	0.037	0.035	0.030	0.026	0.023	0.021	0.019	0.016	0.014
(5.5 in.	R-19 (18.0)	**0.068**	0.063	0.059	0.055	0.052	0.049	0.046	0.044	0.042	0.040	0.039	0.037	0.036	0.035	0.033	0.032	0.028	0.024	0.022	0.019	0.018	0.015	0.013
depth)	R-21 (21.0)	**0.063**	0.058	0.054	0.051	0.048	0.045	0.043	0.041	0.039	0.038	0.036	0.035	0.034	0.032	0.031	0.030	0.026	0.023	0.021	0.019	0.017	0.015	0.013
(+ R-10	R-19 (18.0)	**0.064**	0.060	0.056	0.053	0.050	0.047	0.045	0.043	0.041	0.039	0.038	0.036	0.035	0.034	0.033	0.032	0.027	0.024	0.021	0.019	0.018	0.015	0.013
headers)	R-21 (21.0)	**0.059**	0.055	0.052	0.049	0.046	0.044	0.042	0.040	0.038	0.037	0.035	0.034	0.033	0.032	0.031	0.030	0.026	0.023	0.020	0.019	0.017	0.014	0.013

Envelope Trade-off - Climate Factor Worksheet ET-1

Project Name:

Fill in this table once for your climate.
The climate factors calculated here are used in the trade-off calculation worksheets ET-2 (opaque env.) and ET-3 (windows and skylights).

Opaque Construction Class		HLF		HDD65		CLF		CDH74			Climate Factor, CF	Units
Ceiling with attic	(	26.0	x		) + (	2.0	x		)	=		ft^2
Ceiling without attic	(	23.0	x		) + (	1.7	x		)	=		ft^2
Frame walls	(	21.0	x		) + (	1.0	x		)	=		ft^2
Mass walls with ext. or integral insulation	(	21.0	x		) + (	0.82	x		)	=		ft^2
Mass walls with interior insulation	(	21.0	x		) + (	0.79	x		)	=		ft^2
Wall adjacent to unconditioned space	(	5.4	x		) + (	0.4	x		)	=		ft^2
Doors	(	21.0	x		) + (	1.0	x		)	=		ft^3
Floor over exterior ambient conditions	(	21.0	x		) + (	1.0	x		)	=		ft^2
Floor over unconditioned space	(	5.4	x		) + (	0.4	x		)	=		ft^2
Slab-on-grade: 2 ft	(	3.5	x		) + (	0.3	x		)	=		ft
Slab-on-grade: 4 ft	(	4.5	x		) + (	0.3	x		)	=		ft
Bsmnt wall (mass): deep, top half insul.	(	26.0	x		) + (	0.4	x		)	=		ft
Bsmnt wall (mass): deep, entire wall insul.	(	36.0	x		) + (	0.6	x		)	=		ft
Bsmnt wall (mass): shallow; entire wall ins	(	56.0	x		) + (	1.4	x		)	=		ft
Bsmnt wall (wood): deep	(	51.0	x		) + (	1.8	x		)	=		ft
Bsmnt wall (wood): shallow	(	88.0	x		) + (	3.6	x		)	=		ft
Crawl space wall: concrete & masonry	(	23.5	x		) + (	1.0	x		)	=		ft
Crawl space wall: wood	(	32.0	x		) + (	1.9	x		)	=		ft

Window & Skylight Climate Factors				HDD65				CDH74				CF	
Window U-value base	(	20	x		) + (	0.24	x		) +	-2,440	=		CF1
Window U-value proposed	(	-20	x		) + (	-0.24	x		) +	2,440	=		CF2
Window SC base	(	-9.775	x		) + (	1.3	x		) +	14,850	=		CF3
Window SC-north	(	4.8	x		) + (	-0.8	x		) +	-10,500	=		CF4
Window SC-east	(	9.8	x		) + (	-1.6	x		) +	-15,100	=		CF5
Window SC-south	(	15.9	x		) + (	-1.3	x		) +	-11,600	=		CF6
Window SC-west	(	8.6	x		) + (	-1.5	x		) +	-22,200	=		CF7
Skylight-north-A	(	-0.145	x		) + (	0.056	x		) +	672	=		CF8
Skylight-north-B	(	16.6	x		) + (	-5.9	x		) +	-70,300	=		CF9
Skylight-east-A	(	-0.106	x		) + (	0.048	x		) +	579	=		CF10
Skylight-east-B	(	21.1	x		) + (	-6.4	x		) +	-73,900	=		CF11
Skylight-south-A	(	-0.047	x		) + (	0.052	x		) +	694	=		CF12
Skylight-south-B	(	23.9	x		) + (	-6.9	x		) +	-82,900	=		CF13
Skylight-west-A	(	-0.117	x		) + (	0.049	x		) +	579	=		CF14
Skylight-west-B	(	20.3	x		) + (	-6.4	x		) +	-77,100	=		CF15

Definitions

HDD65 = Heating Degree Days, base 65°F. From Tables 9-1 or 9-2 of the Standard.
CDH74 = Cooling Degree Hours, base 74°F. From Tables 9-1 or 9-2 of the Standard.
CF = Climate Factor, used in envelope tradeoff worksheet calculations.

Envelope Trade-off - Opaque Envelope Load Change Worksheet ET-2

Project Name

Construction Class		Um		Up		Size (ft or ft2)		Climate Factor		Load Change
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	
	(		-		) X		X		=	

Total Load Change for Opaque Envelope, LC_{opq} =

(Enter LC_{opq}, along with LC_{fen}, on the compliance summary form)

Definitions

Construction Class = type of opaque envelope contruction, from ENV-CRIT, Envelope Criteria Summary Sheet.
U_m = Prescriptive U-factor, C-factor or R-value requirement for the construction (see ENV-CRIT, the Env. *Criteria Summary Sht.*) (Btu/h-ft2-°F)
U_p = Actual U-factor, C-factor or R-value for the proposed construction. (Btu/h-ft2-°F)
Size = Area (ft2) or length (ft) of the component.
Climate Factor = Value that depends on HDD65 and CDH74 for your location. Calculated on Climate Factor Worksheet, ET-1.
LC = Load Change (Btu).

Envelope Trade-off - Window Load Change Worksheet ET-3

Project Name:

WINDOWS

North-Facing	Area		Up		CF2		SC		CF4		LC
		× [		×		+		×		] =	
		× [		×		+		×		] =	
		× [		×		+		×		] =	
East-Facing									CF5		
		× [		×		+		×		] =	
		× [		×		+		×		] =	
		× [		×		+		×		] =	
South-Facing									CF6		
		× [		×		+		×		] =	
		× [		×		+		×		] =	
		× [		×		+		×		] =	
West-Facing									CF7		
		× [		×		+		×		] =	
		× [		×		+		×		] =	
		× [		×		+		×		] =	

Window Area, A_{win} ☐

SKYLIGHTS

North-Facing	Area		Up		CF2		SC		CF9		Tilt°		CF8		LC
		× [		×		+		× (		+		×		)] =	
East-Facing									CF11				CF10		
		× [		×		+		× (		+		×		)] =	
South-Facing									CF13				CF12		
		× [		×		+		× (		+		×		)] =	
West-Facing									CF15				CF14		
		× [		×		+		× (		+		×		)] =	

Skylight Area, A_{sky} ☐

BASE CASE FENESTRATION

A_{win}		A_{sky}		A_{tot}	A_{floor}				$A_{18\%}$
	+		=			x	0.18	=	

A_m		U_m		CF1		SC_m		CF3		LC_{base}
	x [		x		+		x		] =	

A_m = smaller of (A_{tot}) or ($A_{18\%}$)

U_m = U-factor criteria for windows, from the Envelope Criteria Summary Sheet, ENV-CRIT.

SC_m = shading coefficient criteria for windows, also from ENV-CRIT.

WALL & CEILING AREA CORRECTION FACTORS (calculate only if $A_{tot} > A_{18\%}$, otherwise $LC_{corr} = 0$)

(A_{tot}-A_m)		A_{win}/A_{tot}		U_{wall}		CF_{wall}		A_{sky}/A_{tot}		$U_{ceiling}$		$CF_{ceiling}$		LC_{corr}
	x [		x		x		+		x		x		] =	

U_{wall} & $U_{ceiling}$ = average U-factors for actual opaque wall and ceiling as entered in form ET-2.

CF_{wall} & $CF_{ceiling}$ = Climate Factors for the opaque wall and ceiling, from ET-1.

TOTAL LOAD CHANGE FOR FENESTRATION, LC_{fen}

(Enter LC_{fen}, along with LC_{opq}, on the compliance summary form)

LC_{fen} (sum of above) ☐