PORTLAND CEMENT ASSOCIATION

5420 Old Orchard Road
Skokie, Illinois 60077-1083
VOICE 847.966.6200 FAX 847.966.8389
INTERNET www.portcement.org

RESEARCH & DEVELOPMENT INFORMATION

PCA R&D Serial No. 2150

Guidelines for Using the CABO Model Energy Code with Insulating Concrete Forms

by Martha G. Van Geem

Guidelines for Using the CABO Model Energy Code 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 the Model Energy Code.(1)** The manual describes three methods of complying with the standard and thermal properties of ICF walls needed to show compliance. A separate manual(2) is available for showing compliance with ASHRAE Standard 90.2-1993, *Energy-Efficient Design of New Low-Rise Residential Buildings*,(3) and its codified version.(4)

The code pertains to all one and two family residences regardless of height and multi-family residences with three or less stories above grade. Generally, the code covers congregate residences with complete facilities including kitchens. This includes apartments, condominiums, rooming houses, rectories, monasteries, convents, boarding houses, and sorority and fraternity houses. The code does not include hotels, motels, dormitories, nursing homes, hospitals, barracks, and jails. The MEC requires these buildings to comply with the codified version of ASHRAE/IESNA 90.1-1989, *Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings*(5). This manual does not cover non-residential buildings.

The MEC 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 MEC does not cover lighting requirements. This manual focuses on the the requirements for walls. A draft commentary(6) for the Model Energy Code is also available.

* Principal Engineer, Construction Technology Laboratories, Inc., 5420 Old Orchard Road, Skokie, IL 60077. Telephone: 847-965-7500

** Numbers in parentheses refer to references.

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(7). 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.

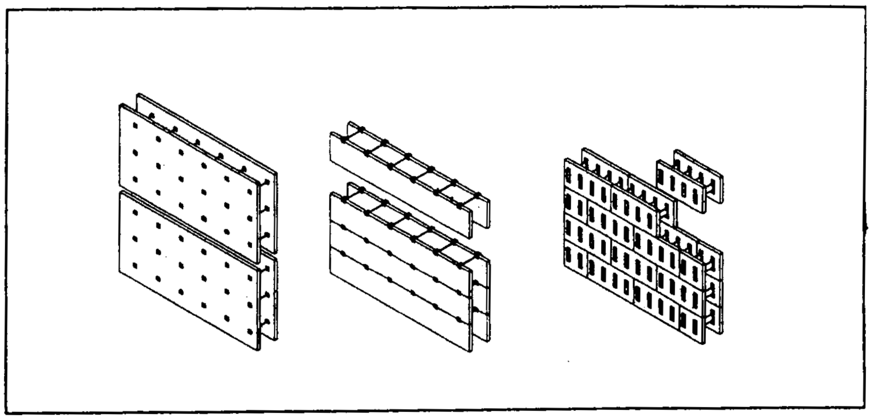


Fig. 1 Panel, Plank, and Block Systems

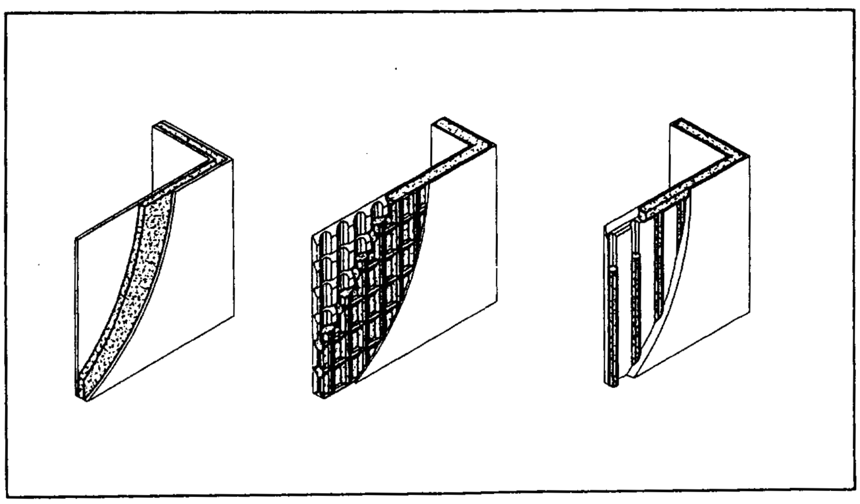


Fig. 2 Flat, Grid, and Post-and-Beam Systems

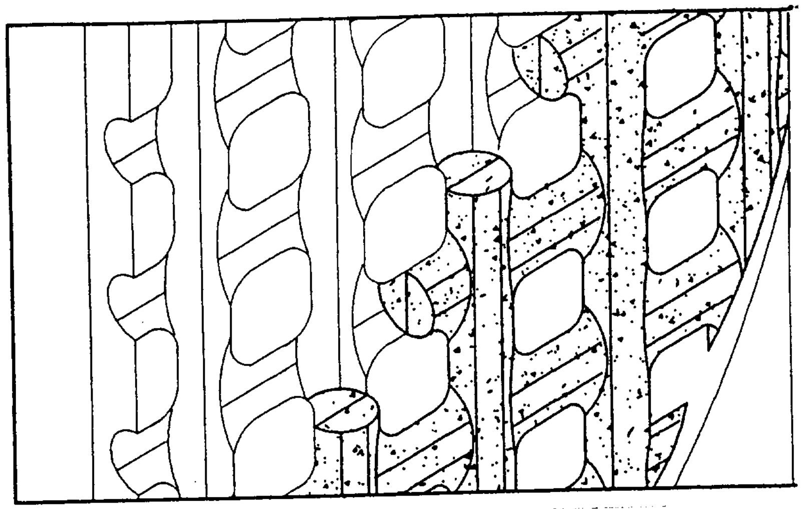


Fig. 3 Cutaway View of a "Screen" Grid System

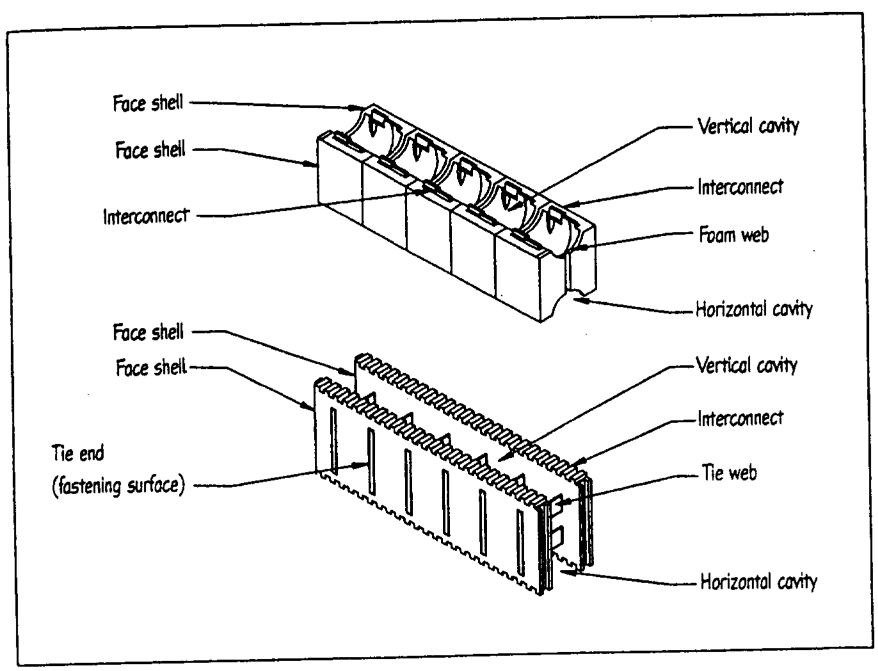


Fig. 4 Parts of ICF Units

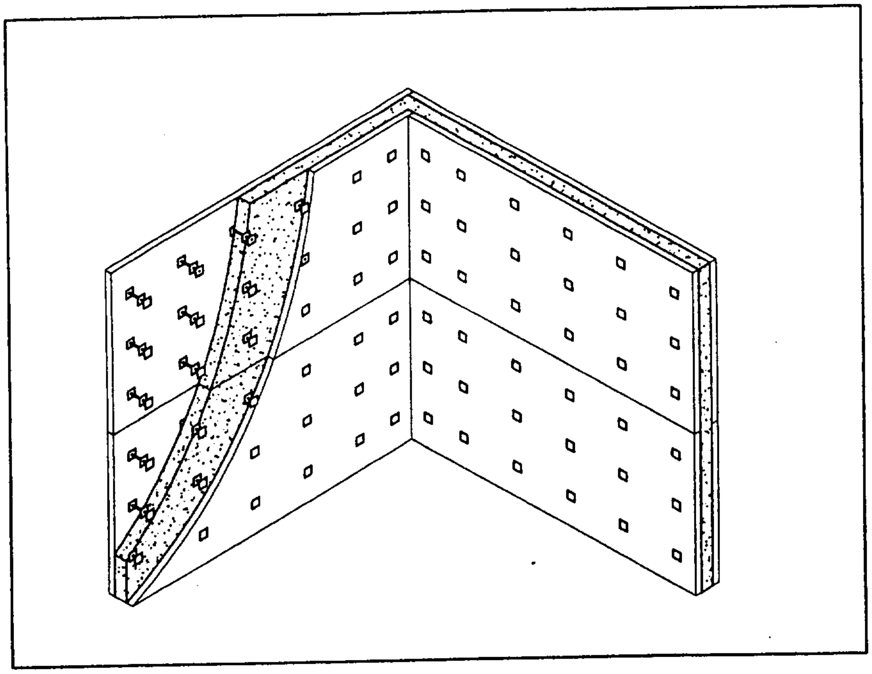


Fig. 5 Cutaway View of a Wall Created with a Flat Panel System

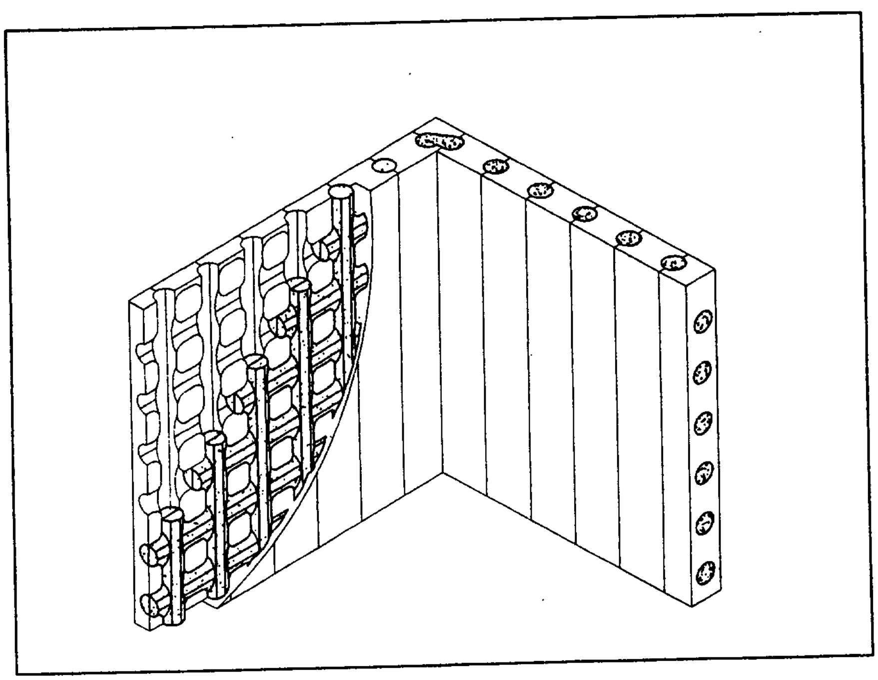


Fig. 6 Cutaway View of a Wall Created with a "Screen" Grid Panel System

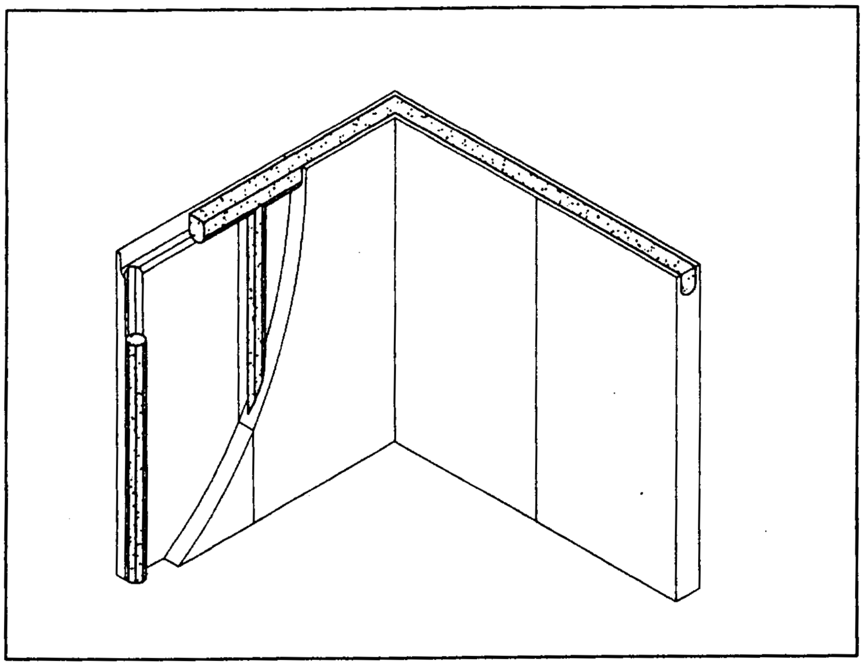


Fig. 7 Cutaway View of a Wall Created with a Post-and-Beam Panel System

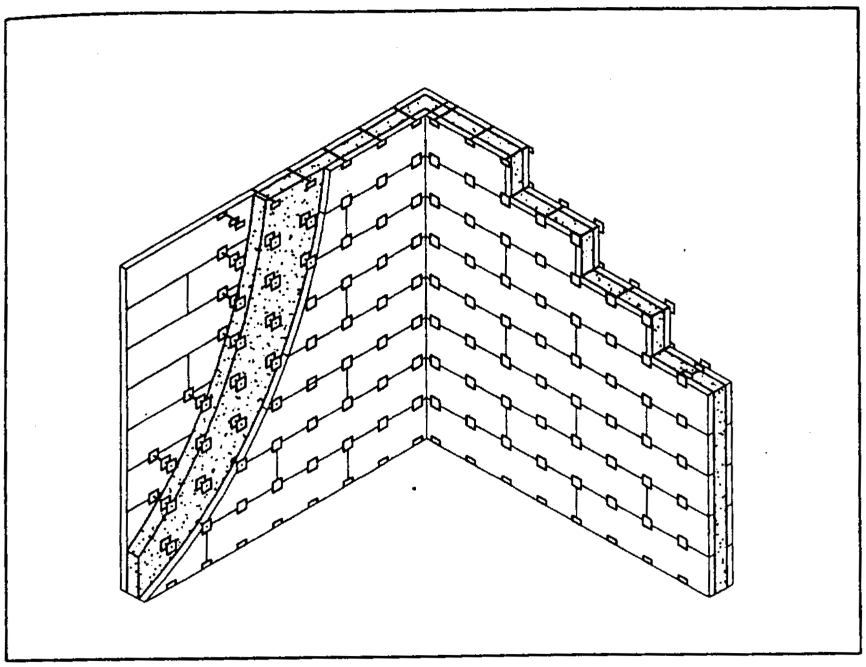


Fig. 8 Cutaway View of a Wall Created with a Flat Plank System

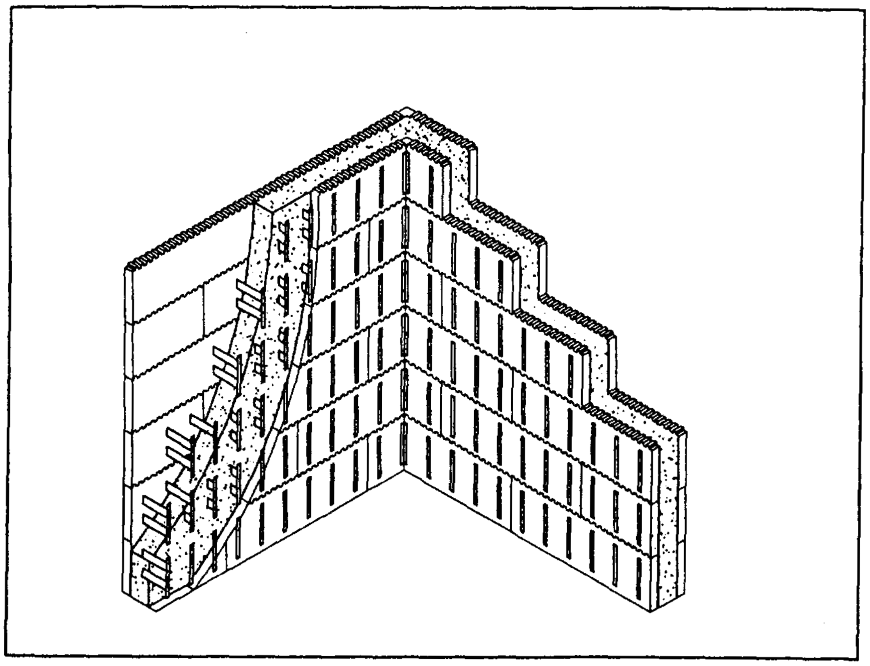


Fig. 9 Cutaway View of a Wall Created with a Flat Block System

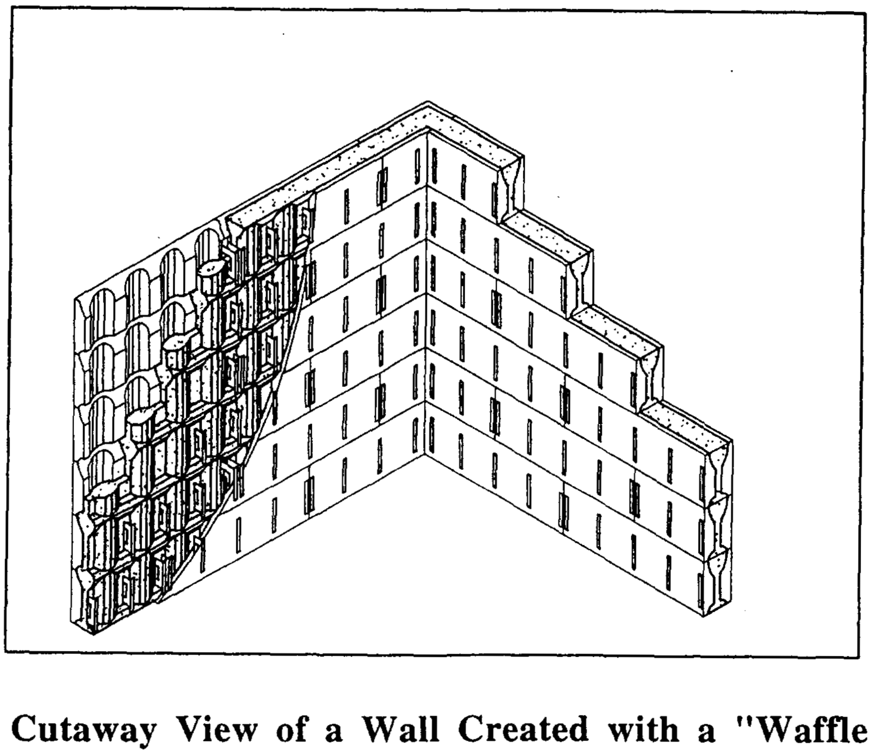


Fig. 10 Cutaway View of a Wall Created with a "Waffle" Grid Block System

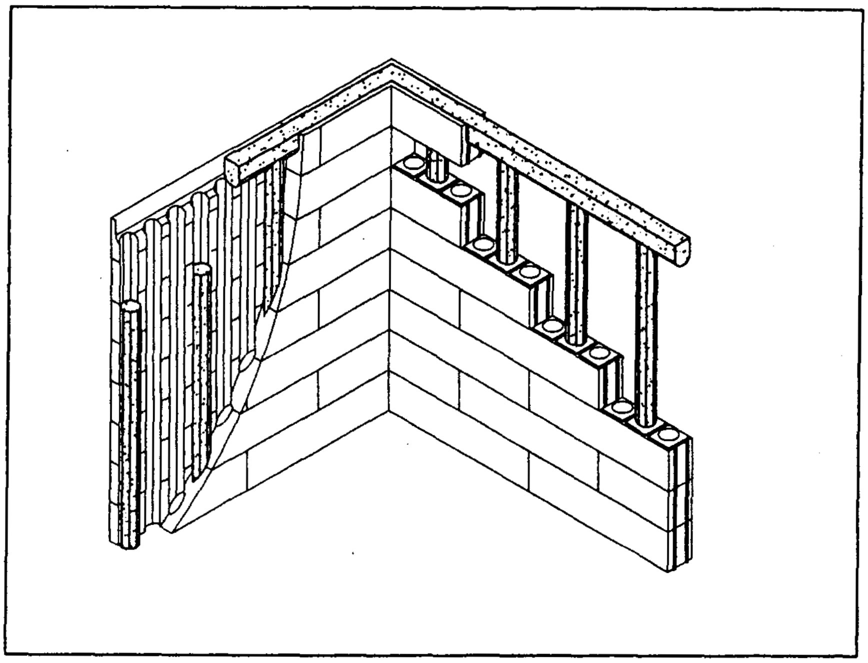


Fig. 11 Cutaway View of a Wall Created with a Post-and-Beam Block System

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 fluctuations, and holds it for much longer periods of time than less massive materials. This energy storage delays and reduces heat transfer through a building component with thermal mass, 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 predictor of energy use 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.

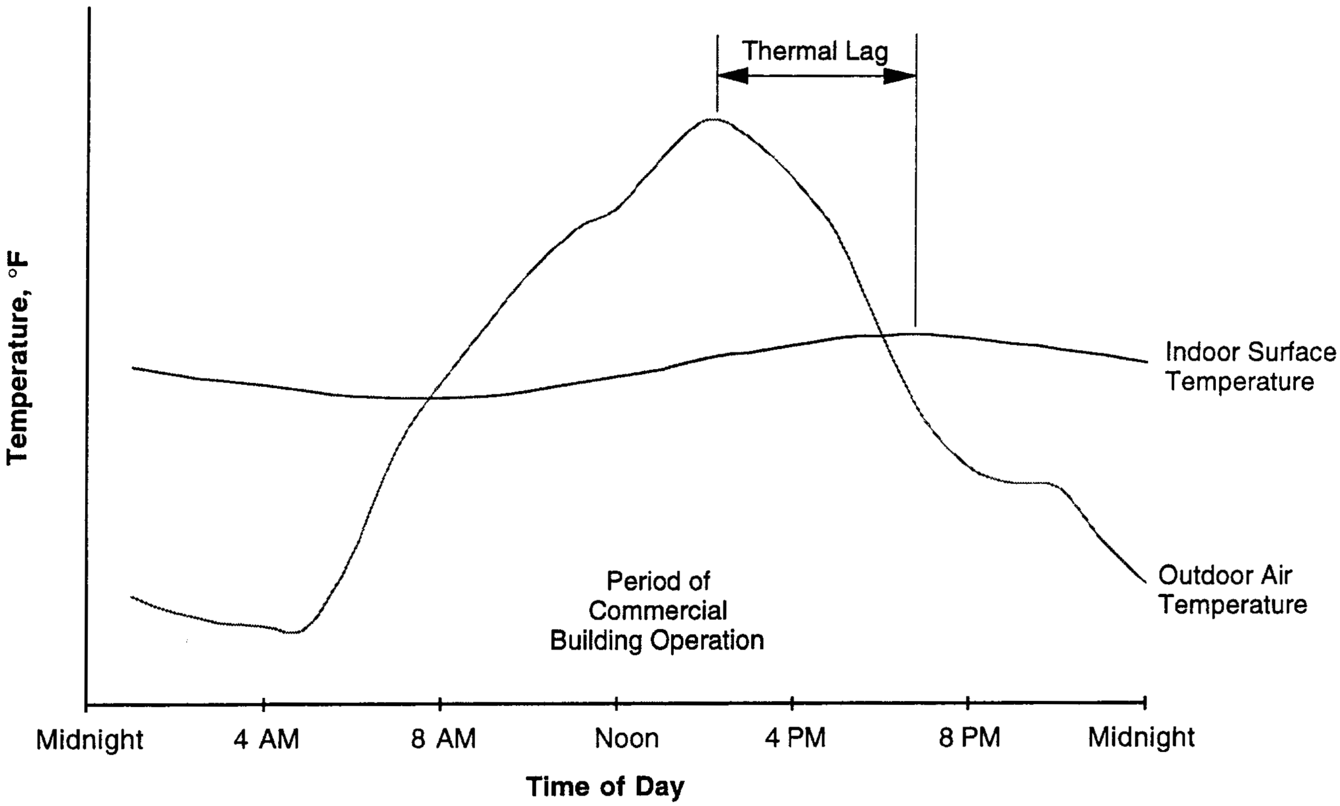


Fig. 12 Thermal Lag for 8-in. Concrete Wall

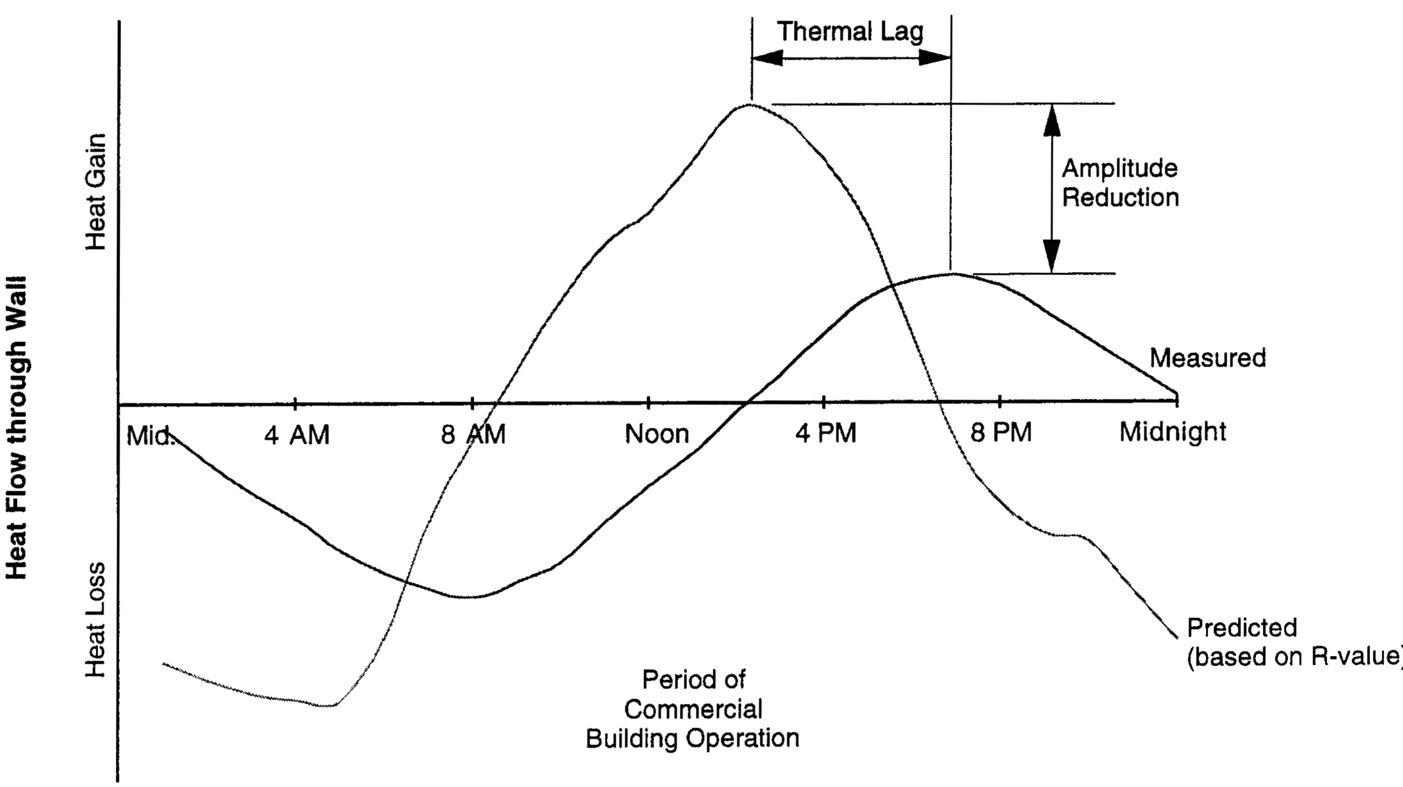


Fig. 13 Thermal Lag and Amplitude Reduction for 8-in. Concrete Wall

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.

Warm Climates

Heat flow reversals in walls occur 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 of energy savings for hot and cold climates 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[8] or BLAST[9], 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.[10]

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[10] 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[11] 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. THERMAL PROPERTIES OF ICF WALLS

The energy savings of construction materials is generally marketed using thermal resistance (R-value), but the MEC uses thermal transmittance (U-factor) to determine compliance. U-factor requirements are higher (less stringent) for mass walls with a heat capacity of at least 6.0 Btu/ft^{2}·°F.

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 at the surface of the wall and the air.

DEFINITION OF THERMAL TRANSMITTANCE (U-FACTOR)

Thermal transmittance (U-factor) is defined by ASTM(12) 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. The MEC(1) defines thermal transmittance as:

> The coefficient of heat transmission (air to air). It is the time rate of heat flow per unit area and unit temperature difference between the warm side and the cold side air films (Btu/(h·ft^{2}·°F)) [W/(m^{2}·k)]. The *U*-value applies to combinations of different materials used in series along the heat flow path, single materials that comprise a building section, cavity air spaces and surface air films on both sides of a building element.

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 homogeneous material.

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

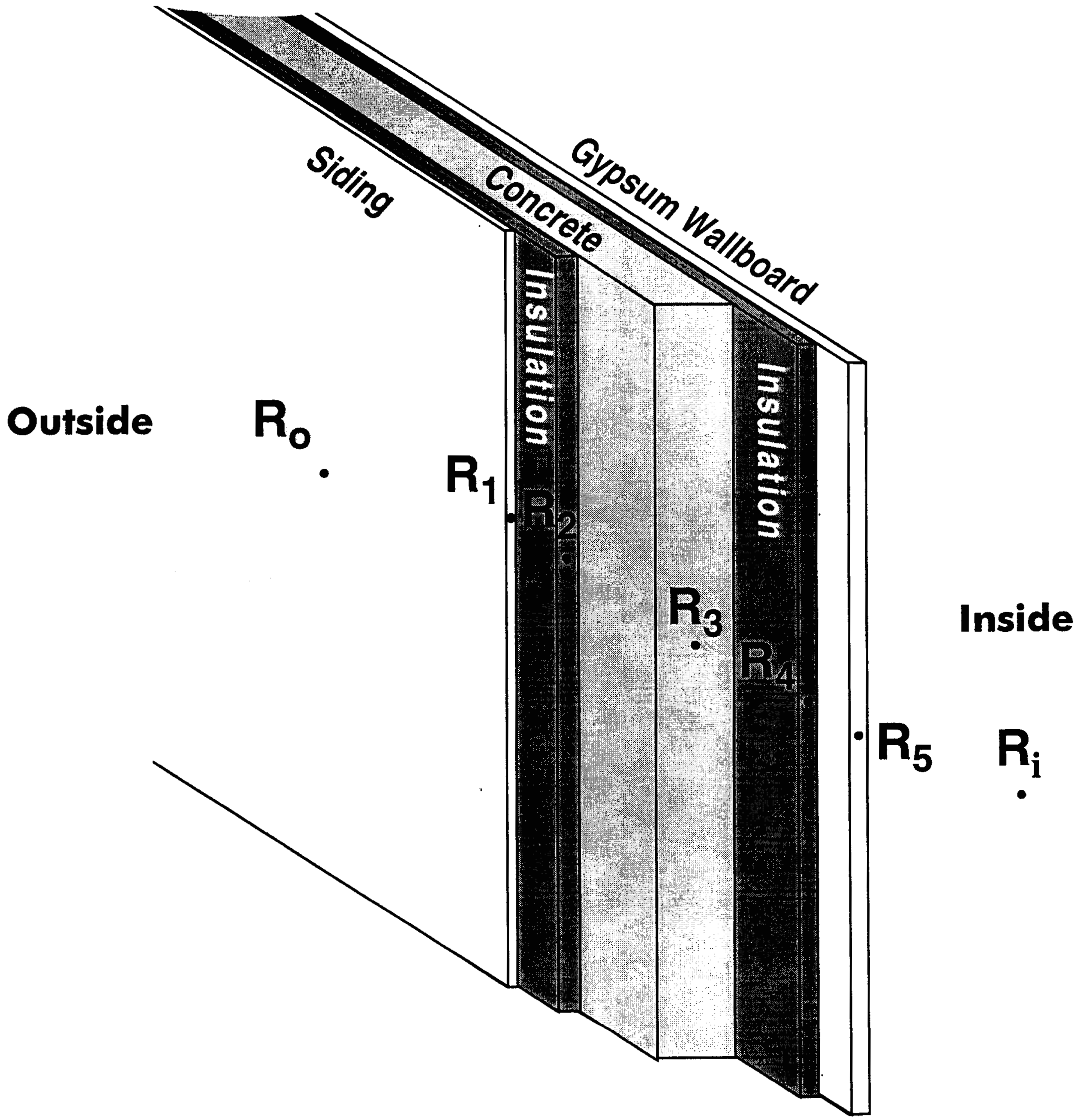


Fig. 14 Example of Total Thermal Resistance (R_T)

TABLE 1 - THERMAL PROPERTIES OF BOARD INSULATION[13]

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

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 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.

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

Insulating Concrete Form System		Company Literature: Thickness, in.			Company Literature: Insulation			No Finishes		Interior Finish 1/2-in. Gyp. Board		Interior and Exterior Finish Gyp. Board & Siding	
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·ft²·°F, units for *R-value* are h·ft²·°F/Btu, and units for *U-value* are Btu/h·ft²·°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·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

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·ft²·°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.

Systems with a thermal resistance greater than 17.5 hr·ft²·°F/Btu exceed the R-value fiberglass batt insulation (R-11, 13, 15 or 19) provides in standard frame wall construction, without considering the beneficial effects of thermal mass.

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·ft²·°F. The thermal conductivity of normal weight concrete is assumed to be 16 Btu·in./hr·ft²·°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·ft²·°F/Btu and the thermal transmittance (U) is 0.057 Btu/hr·ft²·°F.

R_T AND U 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 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[14] or C 976)[15] on a typical ICF wall section

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

Component	R Thermal Resistance, hr·ft^2·°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*
R_T (sum)	17.7
U** ($1/R_T$)	0.057

*Ref. 13, Chapter 24.

**Units for thermal transmittance are Btu/hr·ft^2·°F.

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.

DEFINITION OF HEAT CAPACITY

Heat capacity (HC) is defined as the amount of heat necessary to raise the temperature of a given mass one degree. Heat capacity of a wall is calculated from weight and specific heat of the materials within the wall. For a wall constructed of a single material, the heat capacity is the wall unit weight (lbs per sq ft) times the specific heat (Btu/lb·°F). The unit weight of a material is its density (pcf) times thickness (ft). For a wall with more than one material, the heat capacity is the sum of the heat capacities for each material in the wall:

$$HC = \sum \text{density} \times \text{thickness} \times \text{specific heat} \qquad \text{(Eq. 1)}$$

where:

HC	=	Heat capacity of the wall, $Btu/ft^2 \cdot °F$
Density	=	Density of material, pcf
Thickness	=	Average thickness of material in wall, ft
Specific Heat	=	Specific heat of material in wall, equal to 0.2 Btu/lb·°F for most concrete

HEAT CAPACITY OF ICF WALLS

Table 4 presents heat capacities of ICF walls. Values were calculated by CTL assuming the walls had no interior or exterior finishes, which is a conservative assumption. The MEC thermal mass provisions may be used when the heat capacity of a wall is greater than or equal to 6 $Btu/ft^2 \cdot °F$. An average thickness of 2-½ in. of normal-weight concrete meets this requirement. All walls listed in Table 4 (and all typical ICF walls) have a heat capacity greater than 6 $Btu/ft^2 \cdot °F$ and therefore can use the thermal mass provisions of the MEC. These provisions are not dependent on actual heat capacity as long as it is 6 $Btu/ft^2 \cdot °F$ or greater.

TABLE 4 - HEAT CAPACITY (HC) OF ICF WALLS†

Insulating Concrete Form System		Total Wall Thickness, in.	Heat Capacity,* Btu/ft^2·°F
Brand Name	Distributor		
BLUE MAXX	AAB Building Systems	11-1/4 12-3/4	16 20
Diamond Snap Form	AFM Corp.	8 10 12 14	10 15 20 25
Feather Lite	Feather Lite, Inc.	8	9
Fold-Form	Lite Form, Inc.	8 10 12	10 15 20
GreenBlock	Grreenblock WorldWide Corp.	9-7/8	14
Ice Block	Foam Block	9-1/4 11	12 15
Lite Form	Lite Form, Inc.	8 10 12 14 16	10 15 20 25 30
Polysteel Form	American Polysteel Forms	9-1/4 11	11 15
Quad-Lock	Quad Lock Building Systems	8-1/8 10-1/8 12-1/8 14-1/8	9 14 19 24
R-FORMS	R-Forms	8 10 12 14	10 15 20 25
Reddi-Form	Reddi-Form	9-5/8	10
ThermoFormed	Thermoformed Block Corp.	8	8
Therm-O-Wall	Therm-O-Wall	9-1/4 11	11 15

† A heat capacity of 6 is required to use the thermal mass provisions in the MEC. An average concrete thickness of 2-1/2-in. meets this requirement.

* Not including exterior or interior finishes.

4. CHOICE OF COMPLIANCE PATHS

Three methods, or paths, are available to show compliance with the MEC. These are the Component Performance Approach, Chapter 5 of the MEC; Acceptable Practice, Chapter 6 of the MEC; and Systems Analysis and Design Utilizing Renewable Energy Resources, Chapter 4 of the MEC. Chapters 4 and 5 of the MEC allow the use of provisions which take advantage of thermal mass in walls of residences.

The insulation requirements of the MEC are more stringent for colder climates.

COMPONENT PERFORMANCE APPROACH

The Component Performance Approach, Chapter 5, is the simplest method with thermal mass provisions. Using this method, less insulation is required for mass walls than for lightweight frame walls. This method requires the calculation of an overall thermal transmittance value, U_o, for the exterior walls. This value is the sum of the area-weighted average thermal transmittances of the opaque walls, U_w, the windows including glazing in doors, U_g, and the doors, U_d. For components other than walls such as floors and ceilings, prescriptive criteria for each component are compared to the properties of proposed components.

This method allows an envelope trade-off path. This allows 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.

ACCEPTABLE PRACTICE

The Acceptable Practice, Chapter 6, is the simplest method to assess compliance with the MEC but is based solely on U-factors and does not allow ICF walls to take advantage of thermal mass. However, since many ICF walls have a relatively low U-factor, many may comply with this method even though their mass effects have not been considered. The Acceptable Practice method emphasizes, but does not require, the use of precalculated U-factors listed in appendices of the MEC. PCA has submitted U-factors for ICF walls for use with the Acceptable Practice method to the MEC Revision Committee. The committee tentatively approved these U-factors at a public hearing in April 1997. If no negative comments are received, the U-factors will stand approved as submitted.

A residential building must have a gross floor area, including basements, less than 5000 sq ft to use the Acceptable Practice method. Walls, floors, and ceilings must meet specific prescriptive requirements for this method; no trade-off procedure is allowed.

SYSTEMS ANALYSIS AND DESIGN UTILIZING RENEWABLE ENERGY RESOURCES

The method in Chapter 4, Systems Analysis and Design Utilizing Renewable Energy Resources, is used to assess compliance when the Component Performance Approach and the Acceptable Practice methods do not show compliance. Using this method, the calculated energy cost of a proposed building is compared to the calculated energy cost of a budget building that meets the requirements of the Component Performance Approach, Chapter 5. The proposed building meets the requirements of the MEC if its annual energy cost is less than or equal to that of a budget building meeting the requirements of Chapter 5.

5. COMPONENT PERFORMANCE APPROACH

Using the Component Performance Approach, Chapter 5 of the MEC, the prescriptive criteria for each component is compared to the U-factor or R-value of the proposed component. Components with prescriptive criteria include walls, roof/ceilings, slabs-on-grade (unheated and heated), floor over unheated spaces, crawl space walls, and basement walls. 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.)

This method requires the calculation of an overall thermal transmittance value, U_o, for the exterior walls. This value is the area-weighted average of the thermal transmittances of the above-grade opaque walls, U_w; the windows including glazing in doors, U_g; and the doors, U_d.

This method also allows an envelope trade-off path. The trade-off path allows compliance when some envelope components fail to meet prescriptive requirements while others pass.

Generally, the components that comprise the building envelope must meet the criteria specified in the MEC. The components that separate the conditioned (heated and / or cooled) space from the outdoor environment define the building envelope as shown in Fig. 15. Note the ceiling rather than the roof is part of the building envelope if the ceiling is insulated. If insulation is between the roof rafters, then the roof becomes be part of the building envelope.

Follow these steps to determine compliance with the Component Performance Approach:

Step 1 Determine whether the building is one and two family (Type A-1) or multifamily (Type A-2).

Step 2 Determine areas of the opaque portions of above-grade walls, windows, and doors, including the area of windows in the doors. If the building has skylights, determine the ceiling and skylight area.

Step 3 Determine the U-factor of the above-grade walls, windows, and doors in the proposed building.

Step 4 Determine climate factor (heating degree days base 65°F) based on location.

Step 5 Determine the wall U_o required by the MEC.

Step 6 Determine the opaque wall U_w required by the MEC.

Step 7 Determine U-factor of the proposed roof/ceilings, floor over unheated spaces, crawl space walls, and basement walls; and R-value of the proposed slabs-on-grade, where applicable.

Step 8 Determine MEC criteria for each of the proposed components from Step 7 based on climate.

Step 9 Compare properties of the proposed components (Steps 3 and 7) to criteria (Steps 5 and 8). If building passes, stop. If building does not pass, consider trying the trade-off procedure in Step 10.

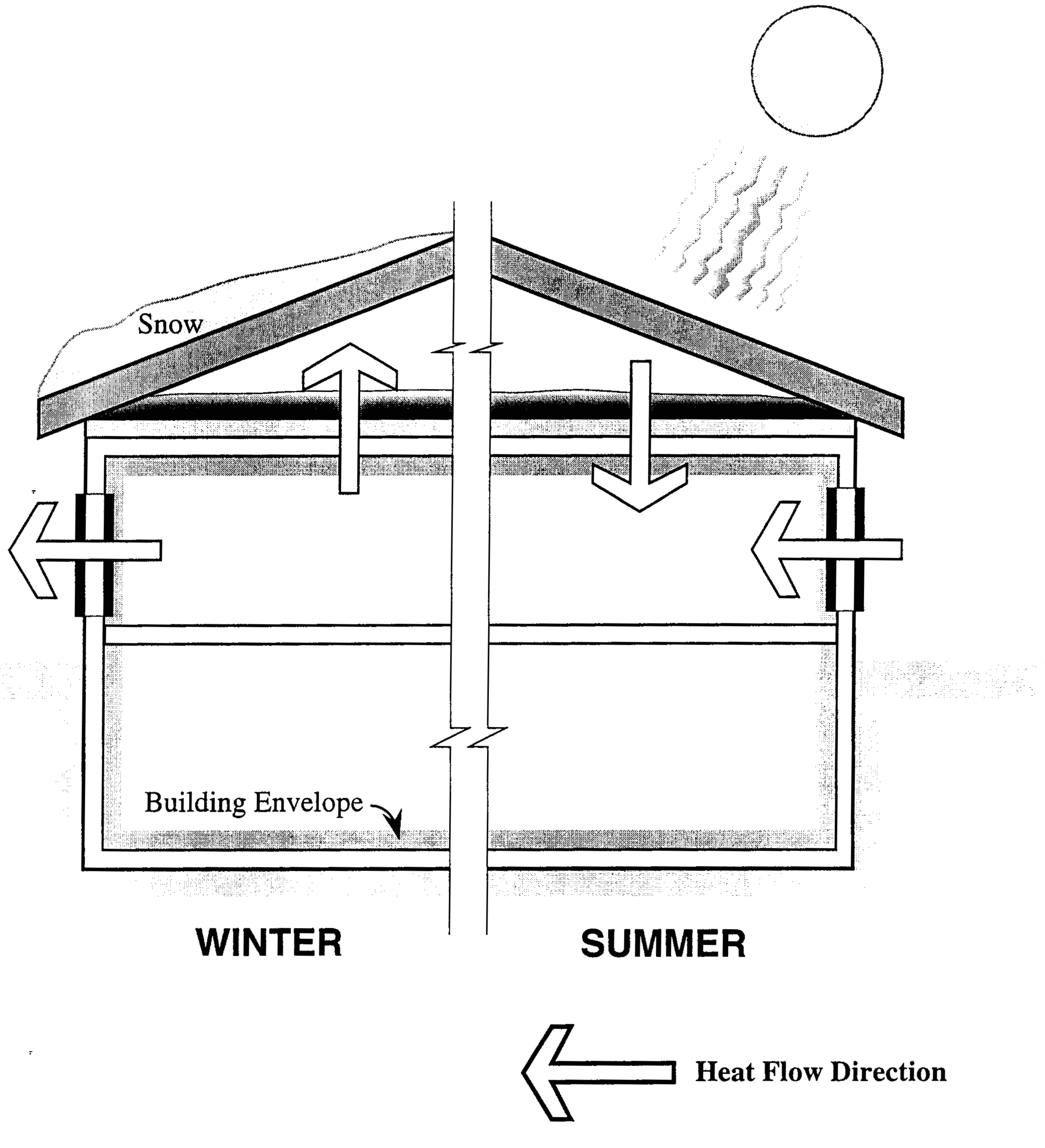


Fig. 15 Building Envelope

Step 10 If the building does not comply using Steps 1 through 9, the trade-off procedure may be used to assess compliance. This step requires calculation of the UA of the proposed building and criteria.

Data determined from the first nine steps may be entered on "Worksheet C1 — Worksheet to Determine Compliance with the Component Performance Approach (Chapter 5) of the MEC" in Appendix C. Data using the trade-off procedure, Step 10, may be entered on "Worksheet C2 — Worksheet to Determine Compliance with the Trade-Off Option of the Component Performance Approach (Section 502.1.1) of the MEC" in Appendix C.

STEP 1 — BUILDING TYPE

The MEC provides separate wall U_0 criteria for "Type A-1" and "Type A-2" dwellings.

"Type A-1" is defined as "detached one and two family dwellings," and includes single family residences and duplexes regardless of height.

"Type A-2" is considered multi-family and is defined as "all other residential buildings, three stories or less in height." Generally, the MEC covers congregate residences with complete facilities including kitchens. This includes apartments, condominiums, rooming houses, rectories, monasteries, convents, boarding houses, and sorority and fraternity houses. The code does not include hotels, motels, dormitories, nursing homes, hospitals, barracks, and jails.

Multifamily 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)

STEP 2 — WALL, WINDOW, DOOR, AND SKYLIGHT AREA

To determine the wall U_0, the areas of the above-grade opaque walls, windows, and doors are required. The area of the opaque portion of the above-grade walls is generally the total area of the exterior walls less the nominal or rough opening areas of the windows and doors. The door area includes the opaque portion of all doors, and includes exterior basement doors if the basement is conditioned and floors above the basement are uninsulated. The window area includes all non-opaque glazing such as sliding glass doors and window panes in doors. For conditioned basements below uninsulated floors, the glazing in exterior basement windows and doors is included in this window area. The window area includes the surface area of the entire window assembly including the glass, sash, and other framing elements. For bay windows and other glazing that is not flat, the window area includes the entire window and framing area, not just the rough opening. Areas may be entered on Worksheet C1.

Note that the U_0 calculation **does not** include basement walls. The MEC has separate requirements for exterior walls in conditioned basements below uninsulated floors. These provisions are covered in Step 7 of this section. A wall is considered below grade (basement) if more than 50% of the wall area for that story is below grade. If less than 50% of the wall is below grade, the entire wall is classified as above grade.

For buildings with skylights, the ceiling and skylight areas are required to determine the roof/ceiling U_0. The skylight area includes the curbing and other framing elements. For skylights that are not flat, the skylight area includes the entire glazing and framing surface area, not just the rough opening. The ceiling/roof area is the nominal area covered by insulation. For insulation between framing above a ceiling, this is the horizontal surface area of the ceiling. For a cathedral ceiling, the appropriate area is actual area of the sloped ceiling.

STEP 3 — U-FACTOR OF ABOVE-GRADE WALLS, WINDOWS, AND DOORS

The U-factor of the above-grade opaque walls, windows, and doors in the proposed building are required to determine the wall U_o. U-factors of the proposed components determined in the following subsections may be entered on Worksheet C1 in the row corresponding to each component, under the column labeled "U-factor U_p."

Walls

U-factors for wood and steel frame walls 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 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. The MEC provides correction factors for steel framing.

ICF Walls. The U-factors for above-grade ICF walls are provided in Table 2 of Section 3 of this manual. For systems not in Table 2, calculate values according to methods in Section 3. The U-factor may also be determined using Fig. 16. This figure is a portion of Proposed Change No. 35-97 submitted by PCA to the MEC Revision Committee. The committee tentatively approved these values at a meeting in April 1997.

Frame Walls. The MEC provides U-factors for specific insulated wood and metal frame walls in Appendix Table 602.2.1a, "Wall Assemblies." Values for cavity insulation are for insulation placed between wood or metal studs. Values for sheathing are for insulation continuously spanning the wall and uninterrupted by wood or metal studs.

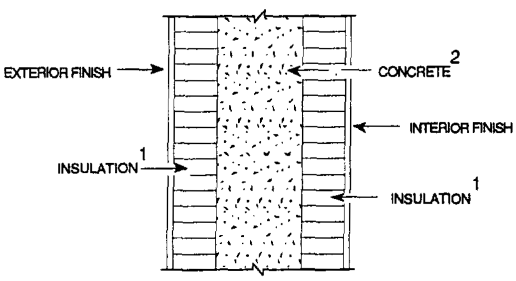
Typical U-factors for additional wood frame and metal frame walls are presented in Appendix D, Tables D1 and D2, respectively. The first column specifies the depth of the wood or steel framing member. The second column provides the rated R-value of the insulation between the framing members in the wall 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. The MEC provides specific procedures in Section 502.2.1 for calculating the Uw of a metal frame wall. The MEC procedure may provide different results than values presented in Table D2.

Other Concrete and Masonry Walls. The MEC provides U-factors for specific concrete block, clay brick, and concrete walls in Appendix Tables 602.2.1b and c, also denoted "Wall Assemblies."

Fenestration

The simplest procedure for determining window and skylight U-factors is to use MEC Table 102.3a, "U-Value Default Table for Windows, Glazed Doors, and Skylights." This table provides values depending on the frame material and whether the window is single or double glazed. The glazing indicates the numbers of panes of glass in the window separated by an air space. For example, double glazing indicates the window has two panes of glass separated by an air space. A single glazed window with a storm window qualifies as double glazed. The values in MEC Table 102.3a may be conservative.

WALL DETAIL[3]	R-VALUE OF INSULATION	U_W	R_O
INSULATING CONCRETE FORM SYSTEM (ICF)	12	0.07	13.55
	15	0.06	16.55
	16	0.06	17.55
	17	0.05	18.55
	20	0.05	21.55
	22	0.04	23.55



1. The R value listed is the sum of values for the exterior and interior insulation layers.
2. The manufacturer shall be consulted for the Uw and Ro values if the insulated concrete form system (ICF) uses metal form ties to connect the interior and exterior insulation layers.
3. These values shall be permitted to be used for concrete masonry wall assemblies with exterior and interior insulation layers.

This figure is a portion of Proposed Change No. 35-97 to the MEC submitted by PCA.
These values have been tentatively approved at a meeting in April 1997.

Fig. 16 Heat Transmission Values for ICF Exterior Walls in the MEC

It is also acceptable to use values provided by window and skylight manufacturers provided these are determined in accordance with National Fenestration Rating Council (NFRC) 100-91, "Procedure for Determining Fenestration Product Thermal Properties," by an accredited, independent laboratory, and labeled and certified by the manufacturer. A product directory of glazing U-factors listed according to manufacturer and model number is available from NFRC (1300 Spring Street, Suite 120, Silver Spring, MD, 20910.)

Doors

The simplest procedure for determining door U-factors is to use MEC Table 102.3b, "U-Value Default Table for Nonglazed Doors." These values may be conservative; door manufacturers may also be consulted.

STEP 4 — CLIMATE FACTOR

The MEC criteria are based on the location of the proposed building. The climate parameters used are heating degree days base 65 °F (HDD65). The HDD65 for a particular location may be obtained from "NOAA Annual Degree Days to Selected Bases Derived from the 1961-1990 Normals," or other references acceptable to the building official. Chapter 9 of Reference 3 and Appendix A of Reference 4 list HDD65 by state for the United States and by province for Canada. The HDD65 may be entered on Worksheet C1.

STEP 5 — WALL U_o REQUIRED BY THE MEC

The Wall U_o required by the MEC for a given climate and building type is determined using MEC Chapter 8, Fig. 1, "U_o Walls - Group R Buildings - Heating." To use the figure, enter the HDD65 along the horizontal axis and move vertically up to the appropriate curve (A-1 for one and two family, and A-2 for multifamily.) Then move left to read the required U_o in Btu/hr·ft^2·°F. The exact U_o may also be calculated using the formulas in the upper right corner of Figure 1. Formulas are provided based on the building type and heating degree days.

Buildings in locations with low heating requirements, defined as less than 500 HDD65, have separate requirements than those in MEC Fig. 1. These are presented in footnote 5 of MEC Table 502.2.1a. If the building is heated only and not cooled, the MEC provides no limit on the wall U_o required. If the building will be mechanically cooled, the maximum required wall U_o is 0.30 Btu/hr·ft^2·°F for Type A-1 (one and two family) and 0.38 Btu/hr·ft^2·°F for Type A-2 (multifamily.)

Criteria may be entered on Worksheet C1 as part of Step 5.

STEP 6 — OPAQUE WALL U_W REQUIRED BY THE MEC

The opaque wall U_w required by the MEC is determined using the U_o required by the MEC from Step 5; the opaque wall area, A_w; the total wall area, A_o; and the sum of the UA of the doors and windows calculated in Steps 2 and 3.

$$U_w\,(\text{reqd}) = \frac{U_o(\text{reqd}) \times A_o - \Sigma(U_{di} \times A_{di}) - \Sigma(U_{gi} \times A_{gi})}{A_w} \qquad \text{(Eq. 2)}$$

$$= \frac{U_o(\text{reqd}) \times A_o - (U_{d1} \times A_{d1}) - (U_{d2} \times A_{d2}) - (U_{g1} \times A_{g1}) - (U_{g2} \times A_{g2})}{A_w}$$

where:

U_w(reqd)	=	Thermal transmittance of opaque wall required by MEC, Btu/hr·ft^2·°F
U_o(reqd)	=	Thermal transmittance of wall required by MEC, Btu/hr·ft^2·°F
U_{di}	=	Thermal transmittance of the ith door, Btu/hr·ft^2·°F
U_{gi}	=	Thermal transmittance of the ith window, Btu/hr·ft^2·°F
A_o	=	Area of the exterior wall, ft^2
A_{di}	=	Area of the *i*th door, ft^2
A_{gi}	=	Area of the *i*th window, ft^2
A_w	=	Area of the opaque wall, ft^2

This calculation and the resulting above-grade U_w may be shown on Worksheet C1.

Thermal Mass Provision

Thermal mass provisions are then applied to above-grade wall U_w. The MEC thermal mass provisions may be used when the heat capacity of a wall is greater than or equal to 6 Btu/ft^2·°F. Most ICF walls have a heat capacity greater than 6 Btu/ft^2·°F (see Table 5 in Section 3) and therefore can use the thermal mass provisions. These provisions are not dependent on actual heat capacity as long as it is 6 Btu/ft^2·°F or greater. If the heat capacity of a particular wall is not listed in Table 5, it can be calculated using procedures in Section 3. An average thickness of 2-½ in. of normal-weight concrete meets this requirement.

Thermal mass provisions are provided for walls with insulation interior of the wall mass, insulation exterior of the wall mass, and integral insulation. Above grade ICF walls are classified as "insulation placed on the interior of the wall mass." 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.

The thermal transmittance required for a mass wall, denoted U_w(reqd,mass), is determined using MEC Table 502.1.2b, "Required U_w for Wall with a Heat Capacity Equal to or Exceeding 6 Btu/ft^2·°F with Insulation Placed on the Interior of the Wall Mass." First determine the appropriate column based on the U_w(reqd). The U_w(reqd,mass) is at the intersection of the column that lists the U_w(reqd) in the first row, and the row with the appropriate HDD65 for the location. This value may be entered on the worksheet (Table C1).

STEP 7 — THERMAL PROPERTIES OF OTHER PROPOSED COMPONENTS

Properties of the building envelope components other than walls must also be determined so they may be compared to criteria. Required properties are thermal transmittance (U) of the proposed roof/ceilings, floors over unheated spaces, crawl space walls, and basement walls; and thermal resistance (R-value) of the proposed slabs-on-grade, where applicable. U-factors 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-factor U_P."

Roof / Ceilings

U-factors for wood and steel frame roof/ceilings must account for thermal bridges through framing members and other anomalies. For example, a ceiling with R-13 cavity insulation between framing members does not have an R-value of 13 because of the 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.

The MEC provides U-factors for specific roof/ceiling assemblies in Appendix Table 602.2.2, "Roof/Ceiling Assemblies."

Typical U-factors for other wood-framed ceilings with attics are presented in Table D3. 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 D4.

If skylights are present, the area of the skylights and roof/ceiling assemblies were determined as part of Step 2. The simplest procedure for determining skylight U-factors is to use MEC Table 102.3a, "U-Value Default Table for Windows, Glazed Doors, and Skylights," as described in Step 3 under "Fenestration."

The proposed U_o of the roof/ceiling is the area weighted average of the opaque roof/ceiling and skylight U-factors:

$$U_o = \frac{[U(\text{opaque}) \times A(\text{opaque})] + [U(\text{skylight}) \times A(\text{skylight})]}{[A(\text{opaque}) + A(\text{skylight})]} \qquad \text{(Eq. 3)}$$

where:

U_o = Thermal transmittance of roof/ceiling, $Btu/hr{\cdot}ft^2{\cdot}°F$

U(opaque) = Thermal transmittance of opaque portion of roof/ceiling, $Btu/hr{\cdot}ft^2{\cdot}°F$

U(skylight) = Thermal transmittance of skylight, $Btu/hr{\cdot}ft^2{\cdot}°F$

A(opaque) = Area of opaque portion of roof/ceiling, ft^2

A(skylight) = Area of skylight, ft^2

If the proposed roof/ceiling has multiple ceiling types or more than one skylight, the U_o of the roof/ceiling is the area weighted average U-factor of all components. Therefore, additional UA terms are added to the numerator of Eq. 3, and the denominator of Eq. 3 is the total roof/ceiling area including all skylights.

Floors

Typical U-factors for intermediate concrete floors with continuous insulation are presented in Table D5. 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.

The MEC provides U-factors for specific wood-frame floor assemblies in Appendix Table 602.2.3, "Floor Assemblies."

Typical U-factors for additional wood frame floors are presented in Table D6. 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.

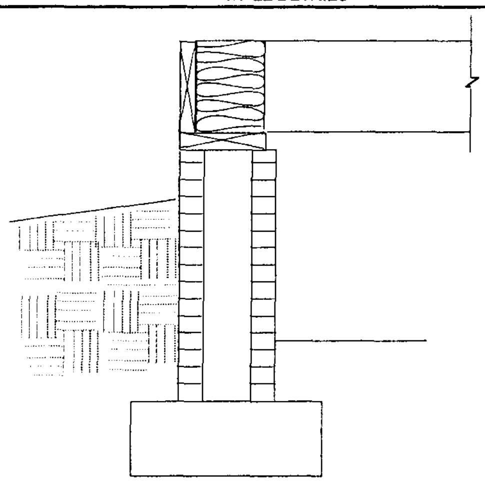
Insulation requirements for slab-on-grade floors are dependent on the climate and not the U-factor of the floor. Therefore, U-factors of slab-on-grade floors do not need to be determined. Criteria are specified in terms of an R-value and length of added perimeter insulation starting at the top surface of the slab.

Crawl Space and Basement Walls

Crawl space walls comprise a part of the building envelope if the floor above the crawl space does not meet the requirements of the code and the crawl space walls do not have vents opening directly to the outdoors. Exterior walls in conditioned basements are part of the building envelope if they are below uninsulated floors. A wall is considered below grade (basement) if more than 50% of the wall area for that story is below grade. If less than 50% of the wall is below grade, the entire wall is classified as above grade. Windows and doors in basements are included in wall U_o calculations performed for Step 3 if the associated basement walls are part of the building envelope

The U-factors for ICF walls in basements and crawl spaces are provided in Table 2 of Section 3 of this manual. For systems not in Table 2, calculate values according to methods in Section 3. The U-factor may also be determined using Fig. 17 for crawl space walls and Fig. 18 for basement walls. These figures are a portion of Proposed Change No. 35-97 submitted by PCA to the MEC Revision Committee. The committee tentatively approved these values at a meeting in April 1997.

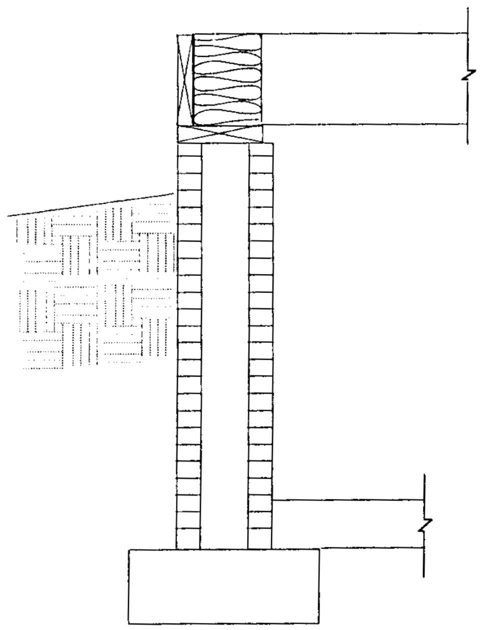
The MEC provides U-factors for other crawl space and basement walls in Appendix Tables 602.2.5 and 602.2.6, denoted "Crawl Space Foundation Wall Assemblies" and "Basement Foundation Wall Assemblies," respectively.

WALL DETAILS [3]	*R-VALUE OF INSULATION*	*U*
	12	0.08
	15	0.06
	16	0.06
	17	0.06
	20	0.05
INSULATING CONCRETE FORM SYSTEM (ICF)[1,2]	22	0.04

1. The R value listed is the sum of values for the exterior and interior insulation layers.
2. The manufacturer shall be consulted for the U value if the insulated concrete form system (ICF) uses metal form ties to connect the interior and exterior insulation layers.
3. These values shall be permitted to be used for concrete masonry wall assemblies with exterior and interior insulation layers.

This figure is a portion of Proposed Change No. 35-97 to the MEC submitted by PCA. These values have been tentatively approved at a meeting in April 1997.

Fig. 17 Heat Transmission Values for ICF Crawl Space Walls in the MEC

WALL DETAILS[3]	R-VALUE OF INSULATION	U
	12	0.07
	15	0.06
	16	0.06
	17	0.05
	20	0.05
INSULATING CONCRETE FORM SYSTEM (ICF)[1,2]	22	0.04

1. The R value listed is the sum of values for the exterior and interior insulation layers.
2. The manufacturer shall be consulted for the U value if the insulated concrete form system (ICF) uses metal form ties to connect the interior and exterior insulation layers.
3. These values shall be permitted to be used for concrete masonry wall assemblies with exterior and interior insulation layers.

This figure is a portion of Proposed Change No. 35-97 to the MEC submitted by PCA. These values have been tentatively approved at a meeting in April 1997.

Fig. 18 Heat Transmission Values for ICF Basement Walls in the MEC

STEP 8 — MEC CRITERIA FOR OTHER PROPOSED COMPONENTS

Criteria for building envelope components other than walls are determined and then compared to properties of the proposed components. Criteria are provided for the thermal transmittance (U) of roof/ceilings, floors over unheated spaces, crawl space walls, and basement walls; and and thermal resistance (R-value) of the proposed slabs-on-grade, where applicable. Criteria are provided in MEC Chapter 8, Figs. 2 through 6 and are the same for Type A-1 (one and two family) and Type A-2 (multifamily.) In lieu of using the figure curves, exact values may be calculated using the formulas based on the heating degree days in the upper right corner of the figures. Criteria for components may be entered on Worksheet C1 in the row corresponding to each component, under the column labeled "Required Ureqd."

Roof / Ceilings

The roof/ceiling U_0 required by the MEC for a given climate is determined using MEC Chapter 8, Fig. 2, "Uo Roof/Ceilings - Types A-1 and A-2 Buildings." To use the figure, enter the HDD65 along the horizontal axis and move vertically up to the curve. Then move left to read the required Uo in Btu/hr·ft^2·°F.

Floors

Floors are classified as slab-on-grade, over unheated space, or over exterior ambient conditions. Basement floors do not require insulation.

Slab-on-Grade Floor Slab-on-grade floors are classified as unheated or heated. The classification "heated slab" are those containing wires, cables, pipes, or ducts that transfer heat to the conditioned space. These include radiant systems such as hydronic piping.

The additional insulation required by the MEC for slabs-on-grade are determined for a given climate using MEC Chapter 8, Fig. 3, "R-Values - Slab-on-Grade." Insulation requirements are the added insulation required around the slab perimeter and are only for slabs 12 in. or less below grade. There are no requirements for unheated slabs in locations with less than 2500 HDD65 and heated slabs in locations with less than 500 HDD65. Insulation must be installed to a depth of 24 in. for locations with less than 6000 HDD65, and to a depth of 48 in. for locations with greater than or equal to 6000 HDD65. Insulation must start at the top of the slab and extend downwards to at least the bottom of the slab, and then may extend horizontally to the interior or exterior as long as the total length requirements are met. When horizontal insulation is used, it must be covered by at least 10 in. of earth or pavement.

Floors over Unheated Spaces The floor U-factor required by the MEC for floors over unheated spaces is determined using MEC Chapter 8, Fig. 4, "U_0 -Values - Floor over Unheated Spaces." These values are used for floors over enclosed unheated spaces such as garages, crawl spaces, and unheated basements.

Floors Over Outdoor Air Floors over exterior ambient conditions (outside air) must meet the requirements for roof/ceiling in MEC Chapter 8, Fig. 2, "Uo Roof/Ceilings - Types A-1 and A-2 Buildings." These include floors over carports, cantilevered floors, the bottom portion of bay windows, or floors of a home built on stilts.

Crawl Space and Basement Walls

Crawl space walls must meet requirements in MEC Chapter 8, Fig. 5, "U_0-Values - Crawl Space Walls," if the floor above the crawl space does not meet the requirements of the code and the walls do not have vents opening directly to the outdoors. The insulation must be installed to a certain length and depth as described in Detail 502.2.5, "Crawl Space Wall Insulation," in the MEC Appendix.

Basement walls must meet requirements in MEC Chapter 8, Fig. 5, "U_o-Values - Basement Walls," if the basements are below uninsulated floors or are heated. Insulation is required to a depth of 10 ft below grade or to the basement floor, whichever is less.

STEP 9 — COMPARE PROPOSED AND CRITERIA TO DETERMINE COMPLIANCE

The properties of the proposed components, determined in Steps 3 and 7, are compared to criteria for those components, determined in Steps 4, 5, and 8. The U-factors of each proposed component 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. If this is the case, the building can be reevaluated using the envelope trade-off procedure described in Step 10.

Appendix E of the Draft Commentary for the MEC (Ref. 6) provides approximate criteria required by the MEC in all regions of the continental United States for walls, windows, unheated and heated slabs-on-grade, floors over unconditioned spaces, crawl space walls, and basement walls.

STEP 10 — TRADE-OFF PROCEDURE

If the building does not comply using Steps 1 through 9, the trade-off procedure may be used to assess compliance. This step requires calculation of the UA of the proposed building and criteria.

The envelope trade-off procedure is more complicated than Steps 1 through 9 but nevertheless is a straightforward method of showing compliance when previous steps do not. This method is 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 amount of insulation required in the ceiling. However, prudence should be used when considering less insulation than the prescriptive requirements. Not using enough insulation for any given component may increase heat losses through that component in a disproportionate manner, and increase overall energy costs for the building.

The envelope trade-off procedure uses previously determined U-factors of the proposed building and criteria. Data using the trade-off procedure, Step 10, may be entered on "Worksheet C2 — Worksheet to Determine Compliance with the Trade-Off Option of the Component Performance Approach (Section 502.1.1) of the MEC" in Appendix C.

The trade-off compares the area weighted U-factors of the proposed building to the area-weighted U-factors of a similar building meeting the criteria. The analysis must include the proposed components not meeting the criteria, but do not need to include the entire building. For example, if the basement walls do not meet the criteria, the trade-off may be performed for only the basement and other walls, or the entire building.

Areas of Building Components

The only additional information required for this step is the area of the components with U-factor or R-value requirements. The areas of the wall components were previously determined in Step 2 and may be transferred to Worksheet C2. The areas of the opaque roof/ceiling, skylight, crawl space wall, basement wall, floor over unheated space, floor over outdoor air, and slab-on-grade should be determined and entered on Worksheet C2. The slab-on-grade area is the area of the perimeter insulation required by the MEC. If no perimeter insulation for slabs is required by the MEC, do not consider slab insulation in the trade-off procedure.

Proposed U-Factors - U_p

The U-factors of the proposed components, U_p from Worksheet C1, are entered in the appropriate rows of Worksheet C2. For ICF walls, use MEC Table 502.1.2b to determine the U_w of the non mass wall corresponding to the mass wall U_w. First determine the appropriate row based on the HDD65 for the location. Select the U_w in that row closest to the mass wall U_w of the proposed building. The U_w of the non mass wall is the U-factor at the top of the column of the row with the appropriate U_w for the mass wall. Interpolation is permissible. Enter this non mass wall U_w in Worksheet C2.

For slab-on-grade perimeter insulation, the U_p is the inverse of the sum of 1 plus the R-value of the added insulation (1/(1+R)).

Required U-Factors - Ureqd

The required U-factor for the wall is the Uo(reqd) from Worksheet C1. Transfer this value and the Ureqd for the ceiling, floor, crawl space wall, and basement wall to Worksheet C2. For slab-on-grade perimeter insulation, the Ureqd is the inverse of the sum of 1 plus the R-value of the required added insulation.

Calculations

The next step is to multiply the areas of the individual components times the U_p of the components and place these values in the column denoted "U_p x A." Then, sum the values in this column and place the total at the bottom of the column. To determine Ureqd x A, (1.) multiply U_o times A_o and (2.) multiply the Ureqd for the ceiling, floor, slab, crawl space wall, and basement wall by their areas and place these values in the column denoted "Ureqd x A." Sum these values and place the total at the bottom of the column. The sum of the U_p x A must be less than the sum of the Ureqd x A in order for the building to comply.

Calculations are repetitive and ideally suited for a computer spreadsheet.

If the envelope trade-off procedure does not show compliance, the method in MEC Chapter 4, Systems Analysis and Design Utilizing Renewable Energy Resources, is a more comprehensive and rigorous analysis method that may show compliance.

COMPONENT PERFORMANCE APPROACH EXAMPLES

Example 2:

Problem: Determine if a 30 by 60 ft (1800 sq ft) ranch house meets the component performance approach of the code. The house is constructed of 8-ft high ICF walls with a U-factor of 0.057 as described in Example 1 (Section 3 of this manual). The house, located in St. Louis, has slab-on-grade construction, 173 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. The amount of slab-on-grade insulation is not specified. In addition, determine the amount of slab-on-grade perimeter insulation required to meet the component performance approach.

Solution: Worksheet C1 in Appendix C is used to show compliance. Table 5 is a completed Worksheet C1 with values for Example 2.

The U-factor for the ICF walls is 0.057 and listed under "Proposed." The U-factors of the windows and doors are 0.56 and 0.40, respectively, from MEC Tables 102.3a and 102.3b, respectively. Chapter 9 of the ASHRAE 90.2 standard[3] shows St. Louis has 4948 HDD65.

Using the equation in Step 6 shows the U_w(reqd) for the opaque lightweight wall is 0.073. The U_w(mass,reqd) is 0.80 as determined by interpolation using MEC Table 502.1.2b. Since the U-factor of the ICF wall, $U_w = 0.057$, is less than U_w(mass,reqd) = 0.080, the exterior wall complies.

The U_0(reqd) for the roof / ceiling, from MEC Fig. 2, is 0.031. The U-factor of the ceiling with R30 insulation is 0.03 from MEC Table 602.2.2. The required slab-on-grade perimeter insulation is R4.3 for a depth of 2 ft from MEC Fig. 3. Since the roof/ceiling complies, and the exterior wall was shown to comply, the building complies.

TABLE 5 - EXAMPLE 2

WORKSHEET C1 – Worksheet to Determine Compliance with the Component Performance Approach (Chapter 5) of Model Energy Code (MEC)

Building Name: 1800 sq ft Ranch Prepared by: J. Gajda
Building Location: St. Louis, MO Date: 6-25-97

STEP 1 - BUILDING TYPE

Check the appropriate building type:

Type A1 (single family or duplex) X
Type A2 (multifamily) ______

STEPS 2 AND 3: ABOVE GRADE WALL, WINDOW, AND DOOR AREAS AND U-FACTORS

Component	Type	Area, ft^2	Proposed U-factor (U_p)	U_p x A
Opaque above-grade wall	ICF wall	A_w =1222	U_w =0.057	69.7
	____			____
Opaque door above-grade	Solid Wood	A_{d1} =22.5	U_{d1} =0.40	9
	Solid Wood	22.5	0.40	9
Opaque door below-grade	____	A_{d2} =	U_{d2} =	____
Window in wall above-grade	Double Glazed Vinyl Frame	A_{g1} =173	U_{g1} =0.56	97
	____			____
Window in wall below-grade	____	A_{g2} =	U_{g2} =	____
Window in door above-grade	____	A_{g3} =	U_{g3} =	____
Window in door below-grade	____	A_{g4} =	U_{g4} =	____
	A_o (sum)=	1440	Sum $\Sigma(U_p x A)$ =	184.7

STEP 4: CLIMATE FACTOR

HDD65 = 4948 HDD65 Source ASHRAE 90.2 Standard (Ref.3)

STEP 5: WALL U_o REQUIRED BY MEC (SEE MEC FIGURE 1)

Wall U_o (reqd) = 0.142 Btu/hr·ft^2·°F

WORKSHEET C1 (continued)

STEP 6: OPAQUE WALL U_w REQUIRED BY MEC

$$U_w\ (\text{reqd}) = \frac{U_o(\text{reqd}) \times A_o - \Sigma(U_{di} \times A_{di}) - \Sigma(U_{gi} \times A_{gi})}{A_w}$$

$$= \frac{U_o(\text{reqd}) \times A_o - \Sigma(U_p \times A)}{A_w}$$

$$= \frac{0.142 * 1440 - 9 - 9 - 97}{1222}$$

$= 0.073$

U_w (mass, reqd) from MEC Table No. 502.1.2b = 0.08

Compare U_w (mass, required) to U_w

U_w = 0.057 *(from top row of Table in Steps 2 and 3)*

Complies if $U_w < U_w$ (mass, reqd) Complies? (Yes or No) Yes

STEPS 7, 8, AND 9: OTHER COMPONENT U-FACTORS AND CRITERIA

Component	Type	Area*, ft^2	Proposed U-factor (U_p)	Required U-factor (U_{reqd})	Complies - yes or no ($U_p < U_{reqd}$)
Opaque roof/ceiling	R-30 Wood frame	1800	U_r =0.03	U_r =0.031	Yes
Skylight	——		U_{sky} =	U_{sky} =	——
Crawlspace wall	——		U_{cs} =	U_{cs} =	——
Basement wall	——		U_b =	U_b =	——
Floor over unheated crawlspace	——		U_{f1} =	U_{f1} =	——
Floor over outdoor air	——		U_{f2} =	U_{f2} =	——
Slab-on-grade (added R of insulation)	as req'd	as req'd	R_s =	R_s =4.3 2 ft	Yes

* Required only for skylights and ceilings if skylights are present, or for trade-off method.

Building Complies if $U_p < U_{reqd}$ for all items in the above table and Step 6 comply.

Building complies? (Yes or No) Yes

Example 3 (Trade-Off Ceiling Insulation):

Problem: Use the trade-off procedure to determine if less insulation can be used on the ceiling of the home in Example 2.

Solution: For this example, the extra energy efficiency in the walls is traded to reduce the ceiling insulation. Table 6 is completed Worksheet C2 for this example.

Chapter 9 of the ASHRAE 90.2 standard(3) shows St. Louis has 4948 HDD65. The U-factor of the mass wall is entered in MEC Table 502.1.2b in the row corresponding to 4948 HDD65. The value at the top of the column is the U-factor required for a non mass wall. This value, interpolated to be 0.0513, is entered as U_w of the proposed building on Worksheet C3.

The areas and U-factors for other building components determined in Example 2 are entered on Worksheet C2. The area of the slab insulation is the perimeter multiplied by the depth of the insulation, or 180 linear ft times 2 ft (deep). The U-factor of the slab insulation is 1/(1+R) = 1/(1+4.3) = 0.189. The proposed UA (U_p x A) and the required UA (U_{reqd} x A) are calculated and totaled. The difference between the proposed and calculated UA's is 28.7. Adding 28.7 to 54 provides the total allowable heat loss through the ceiling, a value of 82.7. Dividing this value by the ceiling area, 1800 sq ft, provides the maximum U-factor allowed by the ceiling, U_r(reqd) = 0.047. Therefore, a roof assembly with an R-value of approximately 20 (1/0.047)complies.

TABLE 6 - EXAMPLE 3

WORKSHEET C2 – Worksheet to Determine Compliance with Trade-off Option of the Component Performance Approach (Section 502.1.1) of the Model Energy Code (MEC)

Building Name: 1800 ft^2 Ranch Prepared by: J. Gadja

Building Location: St. Louis Date: 6-27-97

STEP 1 - BUILDING TYPE

Check the appropriate building type:

Type A1 (single family or duplex) X

Type A2 (multifamily) ____

Component	Type	Area*, ft^2	Proposed (U_p)	Required (U_{reqd})	Proposed U_p x A	Required U_{reqd} x A
Opaque above-grade wall	ICF	A_w =1222	U_w =0.0513		62.7	
	——					
Opaque door above-grade	Solid Wood	A_{d1} =22.5	U_{d1} =0.04		9	
	Solid Wood	22.5	0.04		9	
Opaque door below-grade	——	A_{d2} =	U_{d2} =	U_o =0.142		U_{reqd} x A = 204.5
Window in wall above-grade	Vnyl Fr Dbl Glaze	A_{g1} =173	U_{g1} =0.56		96.9	
	——					
Window in wall below-grade	——	A_{g2} =	U_{g2} =			
Window in door above-grade	——	A_{g3} =	U_{g3} =			
Window in door below-grade	——	A_{g4} =	U_{g4} =			
Opaque roof/ceiling	R-30 Wd Framed	A_r =1800	U_r =0.03	U_r =0.031	54	55.8
Skylight	——	A_{sky} =	U_{sky} =	U_{sky} =		
Crawlspace wall	——	A_{cs} =	U_{cs} =	U_{cs} =		
Basement wall	——	A_b =	U_b =	U_b =		
Floor over unheated crawlspace	——	A_{f1} =	U_{f1} =	U_{f1} =		
Floor over outdoor air	——	A_{f2} =	U_{f2} =	U_{f2} =		
Slab-on-grade (added insulation)	R-4.3 2 ft	A_s =360	U_s =0.189	U_s =0.189	68.0	68.0
				Sum $\Sigma(U \times A)$ =	299.6	328.3

Compliance if $\Sigma(U_p \text{ x } A) < \Sigma(U_{reqd} \text{ x } A)$ Building Complies? (Yes or No) Yes

$\Sigma(U_{reqd} \text{ x } A) - \Sigma(U_p \text{ x } A)$ = 28.7; Total allow. heat loss thru ceiling = 54+28.7 = 82.7

$U_{r(reqd)}$ = 82.7/1800 sq ft = 0.047 which corresponds to R = 20.3 (R20).

6. ACCEPTABLE PRACTICE

The Acceptable Practice, Chapter 6, is similar to the Component Performance Approach but is somewhat simpler. This method is based solely on U-factors and does not allow ICF walls to take advantage of thermal mass. However, since many ICF walls have a relatively low U-factor, many may comply with this method even though their mass effects have not been considered. The Acceptable Practice method emphasizes, but does not require, the use of precalculated U-factors listed in appendices of the MEC.

A residential building must have a gross floor area, including basements, less than 5000 sq ft to use the Acceptable Practice method. Also, the skylight area in limited to less than 1% of the roof/ceiling area. Walls, floors, and ceilings must meet specific prescriptive requirements for this method, and no trade-off procedure is allowed.

Using Acceptable Practice, the prescriptive criteria for each component is compared to the U-factor or R-value of the proposed component. Components with prescriptive criteria include walls, roof/ceilings, slabs-on-grade (unheated and heated), floor over unheated spaces, crawl space walls, and basement walls. 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.)

This method requires the calculation of an overall thermal transmittance value, U_o, for the exterior walls. This value is the area-weighted average of the thermal transmittances of the above-grade opaque walls, U_w, and the windows, U_f.

Generally, the components that comprise the building envelope must meet the criteria specified in the MEC. The components that separate the conditioned space from the outdoor environment define the building envelope, as previously shown in Fig. 15.

Follow these steps to determine compliance with Acceptable Practice:

Step 1 Verify the building has less than 5000 sq ft in gross floor area, is three stories or less in height, and has less than 1% of the roof/ceiling area as skylights. These conditions must be met to use this method. Otherwise, use the Component Performance Approach, MEC Chapter 5.

Step 2 Determine whether the building is one and two family (Type A-1) or multifamily (Type A-2).

Step 3 Determine areas of the opaque portions of above-grade walls, windows, and doors. The U-factor of the glazing (window) in the door is also required for this step.

Step 4 Determine the U-factor of the above-grade walls and windows in the proposed building.

Step 5 Determine the wall U_o for the proposed building.

Step 6 Determine climate factor (heating degree days base 65°F) based on location.

Step 7 Determine the wall U_o required by the MEC.

Step 8 Determine U-factor of the proposed roof/ceilings, floor over unheated spaces, crawl space walls, and basement walls; and R-value of the proposed slabs-on-grade, where applicable.

Step 9 Determine MEC criteria for each of the proposed components from Step 8 based on climate.

Step 10 Compare properties of the proposed components (Steps 5 and 8) to criteria (Steps 7 and 9).

Data determined from the first nine steps may be entered on "Worksheet C3 — Worksheet to Determine Compliance by Acceptable Practice (Chapter 6) of the MEC" in Appendix C.

STEP 1 — BUILDING SIZE AND SKYLIGHT LIMITATIONS

A residential building must be three stories or less in height and have a gross floor area, including basements, less than 5000 sq ft to use the Acceptable Practice method. The gross floor area of the building may be entered on Worksheet C3.

For buildings with skylights, the skylight area must be less than 1% of the roof/ceiling area. The skylight area includes the curbing and other framing elements. For skylights that are not flat, the skylight area includes the entire glazing and framing surface area, not just the rough opening. The ceiling/roof area is the nominal area covered by insulation. For insulation between framing above a ceiling, this is the horizontal surface area of the ceiling. For a cathedral ceiling, the appropriate area is actual area of the sloped ceiling. Skylight and roof/ceiling areas in sq ft may entered on Worksheet C3.

The conditions in this step must be met to use this method. Otherwise, use the Component Performance Approach, MEC Chapter 5.

STEP 2 — BUILDING TYPE

The MEC provides separate wall U_0 criteria for "Type A-1" and "Type A-2" dwellings.

"Type A-1" is defined as "detached one and two family dwellings" and includes single family residences and duplexes regardless of height.

"Type A-2" is considered multi-family and is defined as "all other residential buildings, three stories or less in height." Generally, the MEC covers congregate residences with complete facilities including kitchens. This includes apartments, condominiums, rooming houses, rectories, monasteries, convents, boarding houses, and sorority and fraternity houses. The code does not include hotels, motels, dormitories, nursing homes, hospitals, barracks, and jails.

STEP 3 — WALL, WINDOW, AND DOOR AREA

To determine the wall U_0, the areas of the above-grade opaque walls, windows, and doors are required. The area of the opaque portion of the above-grade walls is generally the total area of the exterior walls less the nominal or rough opening areas of the windows and doors. The window area includes all non-opaque glazing such as sliding glass doors and window panes in doors. For conditioned basements below uninsulated floors, the glazing in exterior basement windows and doors is included in this window area. The window area includes the surface area of the entire assembly including the glass, sash, and other framing elements. For bay windows and other glazing that is not flat, the window area includes the entire window and framing area, not just the rough opening.

The door area is included in the opaque wall area if the door has no windows or if the U-factor of the glazing in the door, U_f, is 0.6 Btu/hr·ft²·°F or less. If the U-factor of the fenestration in the door is greater than 0.6 Btu/hr·ft²·°F, one-half of the door area is considered opaque wall area and one-half is considered window area. For conditioned basements below uninsulated floors, the doors in exterior basement walls are included in this door area.

Glazing U-factors are presented in MEC Table 102.3a, "U-Value Default Table for Windows, Glazed Doors, and Skylights." This table provides values depending on the frame material and whether the window is single or double glazed.

Door assumptions, opaque wall areas, and window areas may be entered on Worksheet C3. Note that the U_o calculation **does not** include basement walls, but **does** include basement windows and doors if the basement walls are part of the building envelope. The MEC has separate requirements for exterior walls in conditioned basements below uninsulated floors. These provisions are covered in Step 8 of this section.

STEP 4 — U-FACTOR OF ABOVE-GRADE WALLS AND WINDOWS

The U-factor of the above-grade opaque walls and windows in the proposed building are required to determine the wall U_o. U-factors of the proposed components may be entered on Worksheet C3 in the row corresponding to each component, under the column labeled "Proposed U_p."

Walls

ICF Walls. The U-factors for above-grade ICF walls are provided in Table 2 of Section 3 of this manual. For systems not in Table 2, calculate values according to methods in Section 3. The U-factor may also be determined using Fig. 16. This figure is a portion of Proposed Change No. 35-97 submitted by PCA to the MEC Revision Committee. The committee tentatively approved these values at a meeting in April 1997.

Frame Walls. The MEC provides U-factors for specific insulated wood and metal frame walls in Appendix Table 602.2.1a, "Wall Assemblies." Values for cavity insulation are for insulation placed between wood or metal studs. Values for sheathing are for insulation continuously spanning the wall and uninterrupted by wood or metal studs. Values from Appendix D, Tables D1 and D2 may also be used. The MEC provides specific procedures in Section 502.2.1 for calculating the U_w of a metal frame wall. The MEC procedure may provide different results than values presented in Table D2.

Other Concrete and Masonry Walls. The MEC provides U-factors for specific concrete block, clay brick, and concrete walls in Appendix Tables 602.2.1b and c, also denoted "Wall Assemblies."

Fenestration

The simplest procedure for determining window and skylight U-factors is to use MEC Table 102.3a, "U-Value Default Table for Windows, Glazed Doors, and Skylights." This table provides values depending on the frame material and whether the window is single or double glazed. The glazing indicates the numbers of panes of glass in the window separated by an air space. For example, double glazing indicates the window has two panes of glass separated by an air space. A single glazed window with a storm window qualifies as double glazed. The values in MEC Table 102.3a may be conservative.

It is also acceptable to use values provided by window and skylight manufacturers provided these are determined in accordance with National Fenestration Rating Council (NFRC) 100-91, "Procedure for Determining Fenestration Product Thermal Properties," by an accredited, independent laboratory, and labeled and certified by the manufacturer. A product directory of glazing U-factors listed according to manufacturer and model number is available from NFRC (1300 Spring Street, Suite 120, Silver Spring, MD, 20910.)

STEP 5 — WALL U_O OF PROPOSED BUILDING

The wall U_o of the proposed building is the area weighted average of the U-factors determined in Step 4 for the windows and above-grade opaque walls.

$$U_o = \frac{U_w \times A_w + \Sigma(U_{fi} \times A_{fi})}{A_o} \qquad \text{(Eq. 4)}$$

$$U_o = \frac{U_w \times A_w + (U_{f1} \times A_{f1}) + (U_{f2} \times A_{f2}) + \ldots}{A_o}$$

where:

U_o = Thermal transmittance of exterior wall, Btu/hr·ft^2·°F

U_w = Thermal transmittance of opaque above grade wall, Btu/hr·ft^2·°F

U_{fi} = Thermal transmittance of the *i*th window, Btu/hr·ft^2·°F

A_o = Area of the exterior wall, ft^2

A_w = Area of the opaque above-grade wall, ft^2

A_{fi} = Area of the *i*th window, ft^2

This calculation and the resulting wall U_o for the proposed building may be shown on Worksheet C3.

STEP 6 — CLIMATE FACTOR

The MEC criteria are based on the location of the proposed building. The climate parameters used are heating degree days base 65 °F (HDD65). The HDD65 for a particular location may be obtained from "NOAA Annual Degree Days to Selected Bases Derived from the 1961-1990 Normals," or other references acceptable to the building official. Chapter 9 of Reference 3 and Appendix A of Reference 4 list HDD65 by state for the United States and by province for Canada. The HDD65 may be entered on Worksheet C3.

STEP 7 — WALL U_O REQUIRED BY THE MEC

The Wall U_o required by the MEC for a given climate and building type is determined using MEC Chapter 8, Fig. 1, "Uo Walls - Group R Buildings - Heating." To use the figure, enter the HDD65 along the horizontal axis and move vertically up to the appropriate curve (A-1 for one and two family, and A-2 for multifamily.) Then move left to read the required

U_0 in Btu/hr·ft^2·°F. The exact U_0 may also be calculated using the formulas in the upper right corner of Figure 1. Formulas are provided based on the building type and heating degree days.

Buildings in locations with low heating requirements, defined as less than 500 HDD65, have separate requirements than those in MEC Fig. 1. These are presented in footnote 5 of MEC Table 502.2.1a. If the building is heated only and not cooled, the MEC provides no limit on the wall U_0 required. If the building will be mechanically cooled, the maximum required wall U_0 is 0.30 Btu/hr·ft^2·°F for Type A-1 (one and two family) and 0.38 Btu/hr·ft^2·°F for Type A-2 (multifamily.)

Criteria may be entered on Worksheet C3.

STEP 8 — THERMAL PROPERTIES OF OTHER PROPOSED COMPONENTS

Properties of the building envelope components other than walls must also be determined so they may be compared to criteria. Required properties are thermal transmittance (U) of the proposed roof/ceilings, floors over unheated spaces, crawl space walls, and basement walls; and thermal resistance (R-value) of the proposed slabs-on-grade, where applicable. U-factors of the proposed components found in the following subsections may be entered on Worksheet C3 in the row corresponding to each component, under the column labeled "Proposed U-factor U_p."

Roof / Ceilings

The MEC provides U-factors for specific roof/ceiling assemblies in Appendix Table 602.2.2, "Roof/Ceiling Assemblies." Values in Tables D3 and D4 may also be used. If skylights are present and the skylight area is less than 1% of the roof/ceiling area, their effect is ignored. Only the U-factor of the roof/ceiling assemblies are required.

Floors

Typical U-factors for intermediate concrete floors with continuous insulation are presented in Table D5.

The MEC provides U-factors for specific wood-frame floor assemblies in Appendix Table 602.2.3, "Floor Assemblies." Values in Table D6 may also be used.

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.

Crawl Space and Basement Walls

Crawl space walls comprise a part of the building envelope if the floor above the crawl space does not meet the requirements of the code. Basement walls are part of the building envelope if they are below uninsulated floors. A wall is below grade if more than 50% of the wall area for that story is below grade or the basement is heated. If less than 50% of the wall is below grade, the entire wall is classified as above grade. Windows and doors below grade are included in wall U_0 calculations performed for Step 3.

The U-factors for ICF walls in basements and crawl spaces are provided in Table 2 of Section 3 of this manual. For systems not in Table 2, calculate values according to methods in Section 3. The U-factor may also be determined using Fig. 17 for crawl space walls and Fig. 18 for basement walls. These figures are a portion of Proposed Change No. 35-97 to the MEC submitted by PCA to the International Code Council (ICC). The ICC tentatively approved these values at a meeting in April 1997.

The MEC provides U-factors for other crawl space and basement walls in Appendix Tables 602.2.5 and 602.2.6, denoted "Crawl Space Foundation Wall Assemblies" and "Basement Foundation Wall Assemblies," respectively.

STEP 9 — MEC CRITERIA FOR OTHER PROPOSED COMPONENTS

Criteria for building envelope components other than walls are determined and then compared to properties of the proposed components. Criteria are provided for the thermal transmittance (U) of roof/ceilings, floors over unheated spaces, crawl space walls, and basement walls; and and thermal resistance (R-value) of the proposed slabs-on-grade, where applicable. Criteria are provided in MEC Chapter 8, Figs. 2 through 6 and are the same for Type A-1 (single family and duplexes) and Type A-2 (multifamily.) In lieu of using the figure curves, exact values may be calculated using the formulas based on the heating degree days in the upper right corner of the figures. Criteria for components may be entered on the Worksheet C3 in the row corresponding to each component, under the column labeled "Required Ureqd."

Roof / Ceilings

The roof/ceiling U_0 required by the MEC for a given climate is determined using MEC Chapter 8, Fig. 2, "U_0 Roof/Ceilings - Types A-1 and A-2 Buildings." To use the figure, enter the HDD65 along the horizontal axis and move vertically up to the curve. Then move left to read the required U_0 in Btu/hr·ft^2·°F.

Floors

Floors are classified as slab-on-grade, over unheated space, or over exterior ambient conditions. Basement floors do not require insulation.

Slab-on-Grade Floor Slab-on-grade floors are classified as unheated or heated. The classification "heated slab" are those containing wires, cables, pipes, or ducts that transfer heat to the conditioned space. These include radiant systems such as hydronic piping.

The additional insulation required by the MEC for slabs-on-grade are determined for a given climate using MEC Chapter 8, Fig. 3, "R-Values - Slab-on-Grade." Insulation requirements are the added insulation required around the slab perimeter and are only for slabs 12 in. or less below grade. There are no requirements for unheated slabs in locations with less than 2500 HDD65 and heated slabs in locations with less than 500 HDD65. Insulation must be installed to a depth of 24 in. for locations with less than 6000 HDD65, and to a depth of 48 in. for locations with greater than or equal to 6000 HDD65. Insulation must start at the top of the slab and extend downwards to at least the bottom of the slab, and then may extend horizontally to the interior or exterior as long as the total length requirements are met. When horizontal insulation is used, it must be covered by at least 10 in. of earth or pavement.

Floors over Unheated Spaces The floor U_o required by the MEC for floors over unheated spaces is determined using MEC Chapter 8, Fig. 4, "U_o -Values - Floor over Unheated Spaces." These values are used for floors over enclosed unheated spaces such as garages, crawl spaces, and unheated basements.

Floors Over Outdoor Air Floors over exterior ambient conditions (outside air) must meet the requirements for roof/ceiling in MEC Chapter 8, Fig. 2, "Uo Roof/Ceilings - Types A-1 and A-2 Buildings." These include floors over carports, cantilevered floors, the bottom portion of bay windows, or floors of a home built on stilts.

Crawl Space and Basement Walls

Crawl space walls must meet requirements in MEC Chapter 8, Fig. 5, "U_o-Values - Crawl Space Walls," if the floor above the crawl space does meet the requirements of the code. The insulation must be installed to a certain length and depth as described in Detail 502.2.5, "Crawl Space Wall Insulation," in the MEC Appendix.

Basement walls must meet requirements in MEC Chapter 8, Fig. 5, "Uo-Values - Basement Walls," if the basements are below uninsulated floors or are heated. Insulation is required to a depth of 10 ft below grade or to the basement floor, whichever is less.

STEP 10 — COMPARE PROPOSED AND CRITERIA TO DETERMINE COMPLIANCE

The properties of the proposed components, determined in Steps 5 and 8, are compared to criteria for those components, determined in Steps 7 and 9. The U-factors of each proposed component 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. If this is the case, the building can be reevaluated using the Component Performance Approach.

Appendix E of the Draft Commentary for the MEC (Ref. 6) provides approximate criteria required by the MEC in all regions of the continental United States. Approximate criteria are provided for walls, windows, unheated and heated slabs-on-grade, floors over unconditioned spaces, crawl space walls, and basement walls.

ACCEPTABLE PRACTICE EXAMPLE

Example 4:

Problem: Determine if a 30 by 60 ft (1800 sq ft) ranch house meets Acceptable Practice requirements of the code. The house is constructed of 8-ft high ICF walls with a U-factor of 0.057 as described in Example 1 (Section 3 of this manual). The house, located in St. Louis, has slab-on-grade construction, 173 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. The amount of slab-on-grade insulation is not specified. In addition, determine the amount of slab-on-grade perimeter insulation required to meet acceptable practice requirements. (This is the same as house as used in Example 2.)

Solution: Worksheet C3 in Appendix C is used to show compliance. Table 7 is a completed Worksheet C3 with values for Example 4.

The building meets the floor area and skylight criteria in Step 1. For Step 3, the door area is included as wall area because the doors do not have windows. For Steps 4 and 5, The U-factor for the ICF walls is 0.057 and listed under "Proposed." The U-factor of the windows is 0.56 from MEC Table 102.3a. The exterior wall U_0 of the proposed building is calculated to be 0.117. Chapter 9 of the ASHRAE 90.2 standard(3) shows St. Louis has 4948 HDD65. The required U_0 of the exterior wall is 0.142 from MEC Fig. 1. Since the exterior wall U_0 of the proposed building is less than that required, the exterior wall complies.

The U_0(reqd) for the roof / ceiling, from MEC Fig. 2, is 0.031. The U-factor of the ceiling with R30 insulation is 0.030 from MEC Table 602.2.2. The required slab-on-grade perimeter insulation is R4.3 for a depth of 2 ft from MEC Fig. 3. Since the roof/ceiling complies, and the exterior wall was shown to comply, the building complies.

TABLE 7 - EXAMPLE 4

WORKSHEET C3 – Worksheet to Determine Compliance by Acceptable Practice (Chapter 6) of Model Energy Code (MEC)

Building Name: 1800 ft^2 Ranch   Prepared by: J. Gajda

Building Location: St. Louis   Date: 6-27-97

STEP 1 - FLOOR AND SKYLIGHT AREAS

Gross floor area including all basements: 1800 ft^2 {*must be less than 5000 ft^2 to use this method*}

Skylight area 0 ft^2 **(A)**
Roof / ceiling area 1800 ft^2 **(B)**

% Skylight area = **A / B * 100** = 0 % {*must be less than 1% to use this method*}

STEP 2 - BUILDING TYPE

Check the appropriate building type:

Type A1 (single family or duplex) X
Type A2 (multifamily) ____

STEP 3 - WALL, WINDOW, AND DOOR AREA

Doors: Do doors have glazing (windows)? Yes ____ No X
If no, door area is included as *opaque wall area.*

U-value (U_f) of glazing in doors N.A. *(if applicable)*
If $U_f \leq 0.6$, door area is included as *opaque wall area.*
If $U_f > 0.6$, 50% of door area is *Window area* and 50% is *Opaque wall area.*

Total perimeter wall area (A_o) = 1440 ft^2 **(C)** (60 + 30 + 60 + 30) x 8

Window area (A_f) = 173 ft^2 **(D)**

Opaque wall area (A_w) = **C - D** = 1267 ft^2

STEPS 4 AND 5 - WALL U-FACTOR (U_o)

Component	Type	Area, ft^2	Proposed (U_p)	U_p x A
Opaque wall above-grade	ICF	A_w = 1267	U_w = 0.057	72.2
Windows in walls above-grade	Dbl Glazed Vnyl Fr	A_{f1} = 173	U_{f1} = 0.56	96.9
Windows in walls below-grade	——	A_{f2} =	U_{f2} =	
	A_o (sum)=	1440	Sum $\Sigma(U_p x A)$ =	169.1

WORKSHEET C3 (continued)

STEPS 4 AND 5 (continued)

$$U_o = \frac{U_w \times A_w + \sum(U_{fi} \times A_{fi})}{A_o}$$

$$= \frac{\sum(U_p \times A)}{A_o}$$

$$= \frac{169.1}{1440}$$

$=0.117$

STEP 6: CLIMATE FACTOR

HDD65 = 4948 HDD65 Source ASHRAE 90.2 Standard (ref 3)

STEP 7: WALL U_o REQUIRED BY MEC (SEE MEC FIGURE 1)

Wall U_o (reqd) = 0.142 Btu/hr·ft^2·°F

Compare U_o (reqd) to U_o from Steps 4 and 5. Complies if $U_o < U_o$ (reqd)

Complies? (Yes or No) Yes

STEPS 8, 9 AND 10: COMPONENT U-FACTORS AND CRITERIA

Component	Type	Proposed U-factor (U_p)	Required U-factor (U_{reqd})	Complies - yes or no ($U_p < U_{reqd}$)
Opaque roof/ceiling	R30 Wood framing	U_r =0.03	U_r =0.031	Yes
Crawlspace wall	——	U_{cs} =	U_{cs} =	
Basement wall	——	U_b =	U_b =	
Floor over unheated crawlspace	——	U_{f1} =	U_{f1} =	
Floor over outdoor air	——	U_{f2} =	U_{f2} =	
Slab-on-grade (added insulation)	as req'd	U_s = as req'd	U_s =4.3 2 ft	Yes

Building Complies if $U_p < U_{reqd}$ for all items in the above table and Step 7 comply.

Building complies? (Yes or No) Yes

7. SYSTEMS ANALYSIS AND DESIGN UTILIZING RENEWABLE ENERGY RESOURCES

The method in Chapter 4, Systems Analysis and Design Utilizing Renewable Energy Resources, is used to assess compliance when the Component Performance Approach and the Acceptable Practice methods do not show compliance. This method requires considerably more effort than the Component Performance Approach and Acceptable Practice methods. Use of an energy load computer program or complex hand calculations are required. Using this method, the calculated energy cost of a proposed building is compared to the calculated energy cost of a budget building that meets the requirements of the Component Performance Approach, Chapter 5. The proposed building meets the requirements of the MEC if its annual energy cost is less than or equal to that of a budget building meeting the requirements of Chapter 5.

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 4 of the MEC provides guidelines and rules for determining the energy cost of the proposed and budget buildings. Reference 6 also provides practical information on this method.

8. ADDITIONAL MANDATORY REQUIREMENTS

The code has additional requirements that must be met for compliance. The heating and cooling equipment and service water heating requirements are described Reference 6. A separate manual is available for sizing heating and cooling equipment in homes with ICF systems[16].

The code has air leakage and moisture prevention requirements that must be met regardless of the compliance method used. Generally, attics and crawl spaces are ventilated as required by the local building code.

AIR LEAKAGE

The air leakage requirements are intended to reduce the energy losses associated with uncontrolled air leakage. To comply with section 502.3 of the code, the home must meet the following requirements:

(1.) Windows and doors are required to meet minimum air leakage requirements listed in Section 502.3.2 in the code. These are manufacturer's requirements. The purchaser should request windows and doors that meet MEC requirements. Site constructed doors and windows must be sealed with durable caulking materials or closed with gasketing systems.

(2.) Joints that potentially allow for unwanted air infiltration into the building envelope must be appropriately sealed with durable caulking materials, closed with gasketing systems, taped, or covered with moisture vapor permeable house-wrap. 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.) At openings in the attic floor
- (h.) At service doors and access hatches
- (i.) Around utility or service openings
- (j.) Around recessed lighting fixtures
- (k.) Around through-the-wall air-conditioners
- (l.) Around tubs and showers
- (m.) At edges of below grade unheated spaces with HVAC equipment

(3.) Recessed lighting fixtures must meet requirements listed in Section 502.3.4 in the code.

VAPOR RETARDERS

Vapor retarders are generally used in cold climates to avoid condensation within building components. Section 502.1.4 of the MEC requires vapor retarders in walls, floors and ceilings that comprise the building envelope except in hot and humid climates. Vapor retarders are not required on components ventilated to allow the escape of moisture. Vapor retarders should be durable to resist tearing or other failure under normal construction practices. The code requires they be installed on the "warm-in-winter", or conditioned side, of the insulation. 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 when tested in accordance with the desiccant (dry cup) method of ASTM E96[17].

Vapor retarders are not required and should be discouraged in hot and humid climates. Hot and humid climates are generally located within 200 to 300 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[13]:

(1.) 67°F or higher wet-bulb outdoor ambient temperature for 3000 or more hours during the warmest six consecutive months of the year

(2.) 73°F or higher wet-bulb outdoor ambient temperature for 1500 or more hours during the warmest six consecutive months of the year

According to Reference 6, vapor retarders are not required for the MEC in Florida, Hawaii, Louisiana, and Mississippi and portions of Alabama, Arkansas, Georgia, North Carolina, Oklahoma, South Carolina, Texas, and Tennessee. Requirements can be determined by county using this reference.

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

CRAWL SPACE REQUIREMENTS FOR ACCEPTABLE PRACTICE

When the Acceptable Practice is used for compliance, special requirements pertain to a crawl space vented directly outdoors with an uninsulated floor above. This special case requires a moisture barrier and minimum ventilation requirements according to MEC Section 602.2.5. In this case, the code requires a ventilation opening area of at least 1.0 sq ft for each 1500 sq ft of crawl space floor area. The code also requires a moisture barrier with a permeance of 1 perm or less over exposed soils. It is generally recommended the moisture barrier have at least a 6 mil thickness and extend 1.0 ft up the walls. Joints in the moisture barrier material should overlap by at least 1.0 ft and be taped or held in place with durable materials.

9. REFERENCES

1. *Model Energy Code, 1995 Edition*, Council of American Building Officials, BOCA, Country Club Hills, Il.

2. Van Geem, Martha G., *Guidelines for Using ASHRAE 90.2-1993 with Insulating Concrete Forms*, Portland Cement Association, Skokie, IL, 1997.

3. *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.

4. *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.

5. *Energy Code for Commercial and High-Rise Residential Buildings,* Codification of ASHRAE/IESNA 90.1-1989, *Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings,* American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, 1993.

6. *Draft Commentary for Model Energy Code,* Council of American Building Officials, Falls Church, VA, 1996.

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

8. DOE2 computer program, Lawrence Berkeley Laboratory, University of California.

9. BLAST computer program, Construction Engineering Research Laboratory, P.O. Box 4005, Champaign, IL.

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

11. 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.

12. 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.

13. *1997 ASHRAE Handbook — Fundamentals*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, 1997.

14. 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.

15. 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.

16. 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.

17. ASTM E96, "Standard Test Methods for Water Vapor Transmission of Materials," *Annual Book of ASTM Standards*, American Society for Testing and Materials, West Conshohocken, PA, 1996.

18. 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.

ACKNOWLEDGEMENT

This manual (PCA R&D Serial No. 2150) was prepared by Construction Technology Laboratories, Inc., unless otherwise noted, with the sponsorship of the Portland Cement Association (PCA Project No. 96-04). The contents of this manual reflect the views of the author, who is responsible for the facts and accuracy of the data presented. The contents do not necessarily reflect the views of the Portland Cement Association.

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·ft²·°F/Btu
R_i = Thermal resistance of inside surface film (still air), usually 0.68 hr·ft²·°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·ft²·°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.

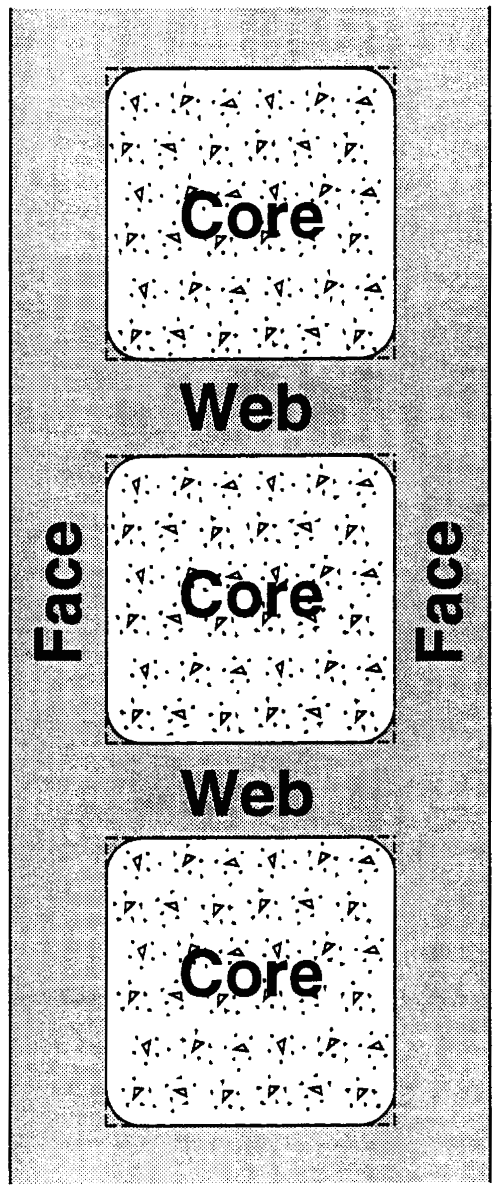
Insulation shapes in ICF systems are generally curved in multiple dimensions and therefore do not easily lend themselves to simplified one or two dimensional calculations such as the isothermal planes method. The following example indicates the types of assumptions required for many ICF systems.

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·ft²·°F.

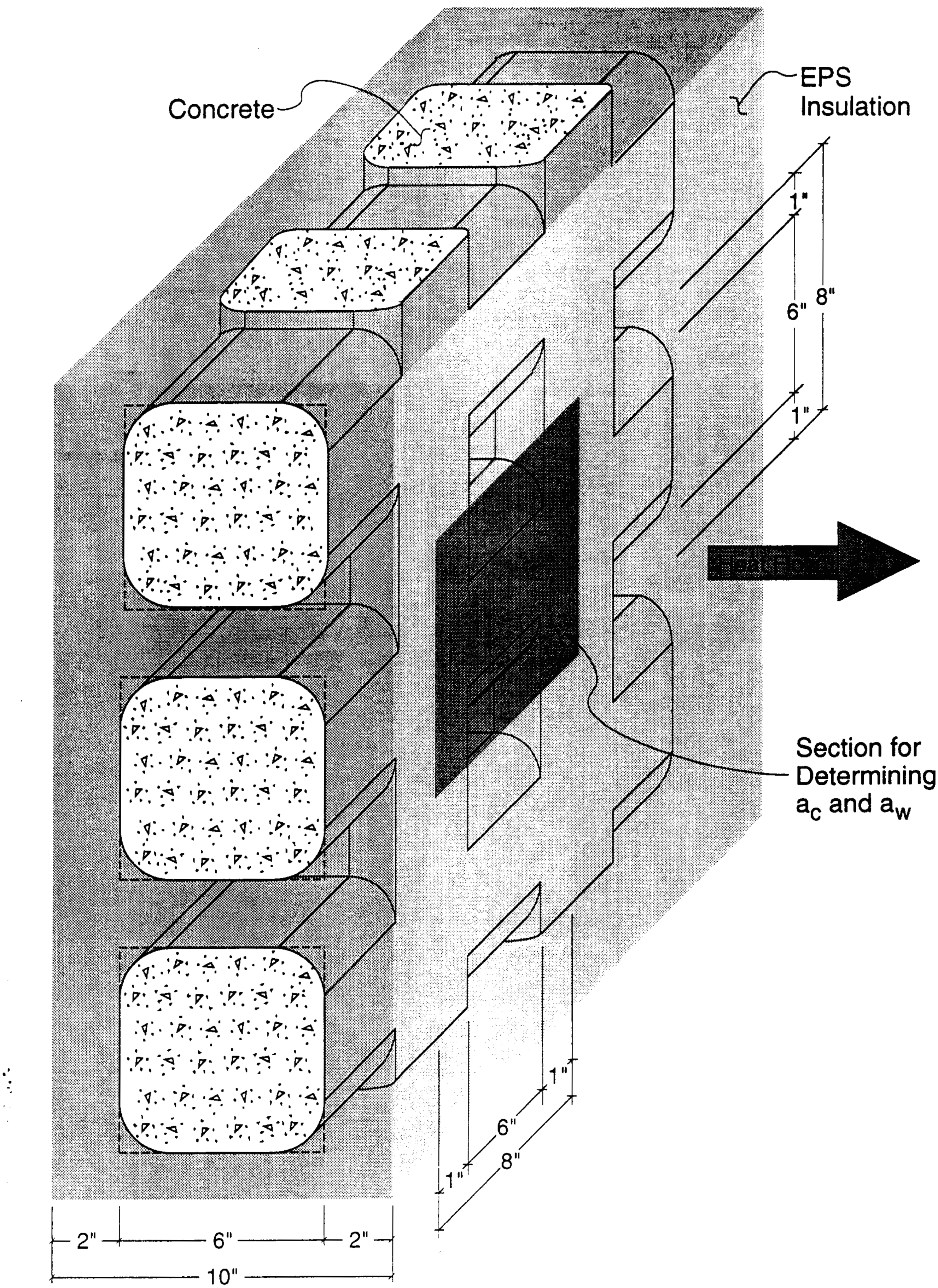
Solution: Thermal resistance for a homogeneous material is equal to its thickness divided by thermal conductivity. Assume the cores are square in cross-section, with the dimension equal to the maximum concrete thickness. (Assuming an average concrete thickness will underestimate the effects of thermal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

R_i = 0.68 hr·ft²·°F/Btu
R_f = 2 x (2 in. / (0.23 Btu·in./hr·ft²·°F)) = 17.4 hr·ft²·°F/Btu
R_w = 6 in. / (0.23 Btu·in./hr·ft²·°F) = 26.1 hr·ft²·°F/Btu
R_c = 6 in. / (16 Btu·in./hr·ft²·°F) = 0.375 hr·ft²·°F/Btu
R_o = 0.17 hr·ft²·°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:

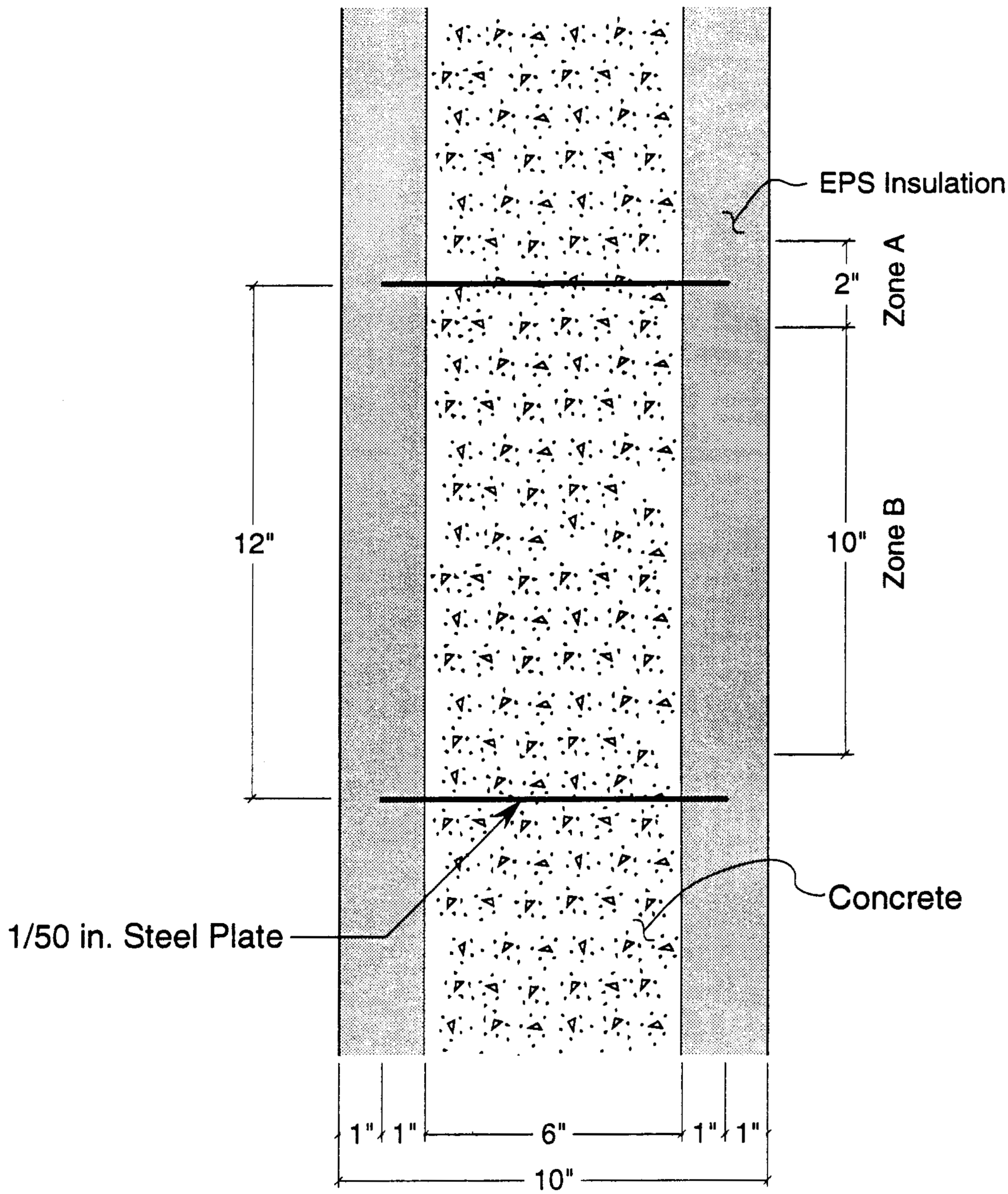
m = width or diameter of metal heat path
d = distance from panel surface to metal

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

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

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

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

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

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

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

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

APPENDIX C — ENVELOPE COMPLIANCE WORKSHEETS

WORKSHEET C1 – Worksheet to Determine Compliance with the Component Performance Approach (Chapter 5) of Model Energy Code (MEC)

Building Name: ______________________ Prepared by: ____________________

Building Location: ____________________ Date: _________________________

STEP 1 - BUILDING TYPE

Check the appropriate building type:

Type A1 (single family or duplex) ______
Type A2 (multifamily) ______

STEPS 2 AND 3: ABOVE GRADE WALL, WINDOW, AND DOOR AREAS AND U-FACTORS

Component	Type	Area, ft^2	Proposed U-factor (U_p)	U_p x A
Opaque above-grade wall		A_w =	U_w =	
Opaque door above-grade		A_{d1} =	U_{d1} =	
Opaque door below-grade		A_{d2} =	U_{d2} =	
Window in wall above-grade		A_{g1} =	U_{g1} =	
Window in wall below-grade		A_{g2} =	U_{g2} =	
Window in door above-grade		A_{g3} =	U_{g3} =	
Window in door below-grade		A_{g4} =	U_{g4} =	
	A_o (sum)=		Sum $\sum(U_p x A)$ =	

STEP 4: CLIMATE FACTOR

HDD65 = ____________ HDD65 Source ______________________

STEP 5: WALL U_o REQUIRED BY MEC (SEE MEC FIGURE 1)

Wall U_o (reqd) = _________ Btu/hr·ft^2·°F

WORKSHEET C1 (continued)

STEP 6: OPAQUE WALL U_w REQUIRED BY MEC

$$U_w\ (\text{reqd}) = \frac{U_o(\text{reqd}) \times A_o - \Sigma(U_{di} \times A_{di}) - \Sigma(U_{gi} \times A_{gi})}{A_w}$$

$$= \frac{U_o(\text{reqd}) \times A_o - \Sigma(U_p \times A)}{A_w}$$

= ______________________________

=

U_w (mass, reqd) from MEC Table No. 502.1.2b = __________

Compare U_w (mass, required) to U_w

U_w = __________ *(from top row of Table in Steps 2 and 3)*

Complies if $U_w < U_w$ (mass, reqd)   Complies? (Yes or No) ________

STEPS 7, 8, AND 9: OTHER COMPONENT U-FACTORS AND CRITERIA

Component	Type	Area*, ft^2	Proposed U-factor (U_p)	Required U-factor (U_{reqd})	Complies - yes or no ($U_p < U_{reqd}$)
Opaque roof/ceiling			U_r =	U_r =	
Skylight			U_{sky} =	U_{sky} =	
Crawlspace wall			U_{cs} =	U_{cs} =	
Basement wall			U_b =	U_b =	
Floor over unheated crawlspace			U_{f1} =	U_{f1} =	
Floor over outdoor air			U_{f2} =	U_{f2} =	
Slab-on-grade (added R of insulation)			R_s =	R_s =	

* Required only for skylights and ceilings if skylights are present, or for trade-off method.

Building Complies if $U_p < U_{reqd}$ for all items in the above table and Step 6 comply.

Building complies? (Yes or No) ____________

WORKSHEET C2 – Worksheet to Determine Compliance with Trade-off Option of the Component Performance Approach (Section 502.1.1) of the Model Energy Code (MEC)

Building Name: ______________________ Prepared by: ____________________

Building Location: ____________________ Date: _________________________

STEP 1 - BUILDING TYPE

Check the appropriate building type:

Type A1 (single family or duplex)______
Type A2 (multifamily) ______

Component	Type	Area*, ft^2	Proposed (U_p)	Required (U_{reqd})	Proposed U_p x A	Required U_{reqd} x A
Opaque above-grade wall		A_w =	U_w =			
Opaque door above-grade		A_{d1} =	U_{d1} =			
Opaque door below-grade		A_{d2} =	U_{d2} =	U_o =		U_{reqd} x A =
Window in wall above-grade		A_{g1} =	U_{g1} =			
Window in wall below-grade		A_{g2} =	U_{g2} =			
Window in door above-grade		A_{g3} =	U_{g3} =			
Window in door below-grade		A_{g4} =	U_{g4} =			
Opaque roof/ceiling		A_r =	U_r =	U_r =		
Skylight		A_{sky} =	U_{sky} =	U_{sky} =		
Crawlspace wall		A_{cs} =	U_{cs} =	U_{cs} =		
Basement wall		A_b =	U_b =	U_b =		
Floor over unheated crawlspace		A_{f1} =	U_{f1} =	U_{f1} =		
Floor over outdoor air		A_{f2} =	U_{f2} =	U_{f2} =		
Slab-on-grade (added insulation)		A_s =	U_s =	U_s =		
				Sum Σ(U×A) =		

Compliance if $\Sigma(U_p \times A) < \Sigma(U_{reqd} \times A)$ Building Complies? (Yes or No) ________

WORKSHEET C3 – Worksheet to Determine Compliance by Acceptable Practice (Chapter 6) of Model Energy Code (MEC)

Building Name: ______________________ Prepared by: ____________________

Building Location: ____________________ Date: _________________________

STEP 1 - FLOOR AND SKYLIGHT AREAS

Gross floor area including all basements: _________ ft^2 {*must be less than 5000 ft^2 to use this method*}

Skylight area _________ ft^2 **(A)**

Roof / ceiling area _________ ft^2 **(B)**

% Skylight area = **A / B * 100** = _________% {*must be less than 1% to use this method*}

STEP 2 - BUILDING TYPE

Check the appropriate building type:

Type A1 (single family or duplex) _____

Type A2 (multifamily) _____

STEP 3 - WALL, WINDOW, AND DOOR AREA

Doors: Do doors have glazing (windows)? Yes _______ No ______

If no, door area is included as *opaque wall area.*

U-value (U_f) of glazing in doors ___________ *(if applicable)*

If $U_f \leq 0.6$, door area is included as *opaque wall area.*

If $U_f > 0.6$, 50% of door area is *Window area* and 50% is *Opaque wall area.*

Total perimeter wall area (A_o) = ____________ ft^2 **(C)**

Window area (A_f) = ____________ ft^2 **(D)**

Opaque wall area (A_w) = **C - D** = ____________ ft^2

STEPS 4 AND 5 - WALL U-FACTOR (U_o)

Component	Type	Area, ft^2	Proposed (U_p)	U_p x A
Opaque wall above-grade		A_w =	U_w =	
Windows in walls above-grade		A_{f1} =	U_{f1} =	
Windows in walls below-grade		A_{f2} =	U_{f2} =	
	A_o (sum)=		Sum $\Sigma(U_p x A)$ =	

WORKSHEET C3 (continued)

STEPS 4 AND 5 (continued)

$$U_o = \frac{U_w \times A_w + \sum(U_{fi} \times A_{fi})}{A_o}$$

$$= \frac{\sum(U_p \times A)}{A_o}$$

= ______________________________

=

STEP 6: CLIMATE FACTOR

HDD65 = ____________ HDD65 Source ______________________

STEP 7: WALL U_o REQUIRED BY MEC (SEE MEC FIGURE 1)

Wall U_o (reqd) = ________ Btu/hr·ft^2·°F

Compare U_o (reqd) to U_o from Steps 4 and 5. Complies if $U_o < U_o$ (reqd)

Complies? (Yes or No) ______________

STEPS 8, 9 AND 10: COMPONENT U-FACTORS AND CRITERIA

Component	Type	Proposed U-factor (U_p)	Required U-factor (U_{reqd})	Complies - yes or no ($U_p < U_{reqd}$)
Opaque roof/ceiling		U_r =	U_r =	
Crawlspace wall		U_{cs} =	U_{cs} =	
Basement wall		U_b =	U_b =	
Floor over unheated crawlspace		U_{f1} =	U_{f1} =	
Floor over outdoor air		U_{f2} =	U_{f2} =	
Slab-on-grade (added insulation)		U_s =	U_s =	

Building Complies if $U_p < U_{reqd}$ for all items in the above table and Step 7 comply.

Building complies? (Yes or No) ______________

APPENDIX D — TYPICAL U-FACTORS FOR WALLS, CEILINGS, AND FLOORS (18)

Table D1
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

Table D2
Assembly U-Factors for Metal 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
METAL																								
(3.5 in.	None (0.0)	0.438	0.305	0.234	0.189	0.159	0.137	0.121	0.108	0.097	0.089	0.081	0.075	0.070	0.065	0.061	0.058	0.045	0.037	0.031	0.027	0.024	0.019	0.016
depth)	R-11 (5.5)	0.143	0.125	0.111	0.100	0.091	0.083	0.077	0.071	0.067	0.063	0.059	0.056	0.053	0.050	0.048	0.045	0.037	0.031	0.027	0.024	0.021	0.018	0.015
	R-13 (6.0)	0.134	0.118	0.105	0.095	0.087	0.080	0.074	0.069	0.065	0.061	0.057	0.054	0.051	0.049	0.047	0.044	0.036	0.031	0.027	0.024	0.021	0.017	0.015
	R-15 (6.4)	0.127	0.112	0.101	0.092	0.084	0.078	0.072	0.067	0.063	0.059	0.056	0.053	0.050	0.048	0.046	0.044	0.036	0.030	0.026	0.023	0.021	0.017	0.015
(6.0 in.	R-19 (7.1)	0.116	0.104	0.094	0.086	0.079	0.074	0.069	0.064	0.060	0.057	0.054	0.051	0.049	0.046	0.044	0.042	0.035	0.030	0.026	0.023	0.021	0.017	0.015
depth)	R-21 (7.4)	0.112	0.101	0.092	0.084	0.078	0.072	0.067	0.063	0.059	0.056	0.053	0.050	0.048	0.046	0.044	0.042	0.035	0.030	0.026	0.023	0.020	0.017	0.015
METAL																								
(3.5 in.	None (0.0)	0.417	0.294	0.227	0.185	0.156	0.135	0.119	0.106	0.096	0.088	0.081	0.075	0.069	0.065	0.061	0.057	0.045	0.036	0.031	0.027	0.024	0.019	0.016
depth)	R-11 (6.6)	0.124	0.110	0.099	0.090	0.083	0.076	0.071	0.066	0.062	0.059	0.055	0.052	0.050	0.047	0.045	0.043	0.036	0.030	0.026	0.023	0.021	0.017	0.015
	R-13 (7.2)	0.115	0.103	0.094	0.086	0.079	0.073	0.068	0.064	0.060	0.057	0.054	0.051	0.048	0.046	0.044	0.042	0.035	0.030	0.026	0.023	0.021	0.017	0.015
	R-15 (7.8)	0.108	0.097	0.089	0.081	0.075	0.070	0.065	0.061	0.058	0.055	0.052	0.049	0.047	0.045	0.043	0.041	0.034	0.029	0.025	0.023	0.020	0.017	0.014
(6.0 in.	R-19 (8.6)	0.099	0.090	0.083	0.076	0.071	0.066	0.062	0.059	0.055	0.052	0.050	0.047	0.045	0.043	0.042	0.040	0.033	0.028	0.025	0.022	0.020	0.017	0.014
depth)	R-21 (9.0)	0.095	0.087	0.080	0.074	0.069	0.065	0.061	0.057	0.054	0.051	0.049	0.047	0.044	0.043	0.041	0.039	0.033	0.028	0.025	0.022	0.020	0.017	0.014

Table D3
Assembly U-Factors for Attic Roofs with Wood Joists

Rated R-Value of Insulation Alone	Overall U-Factor for Entire Assembly
WOOD FRAMED ATTIC, STANDARD FRAMING	
None	0.613
R-11	0.091
R-13	0.081
R-19	0.053
R-30	0.034
R-38	0.027
R-49	0.021
R-60	0.017
R-71	0.015
R-82	0.013
R-93	0.011
R-104	0.010
R-115	0.009
R-126	0.008
R-137	0.008
R-148	0.007
WOOD FRAMED ATTIC, ADVANCED FRAMING	
None	0.613
R-11	0.088
R-13	0.078
R-19	0.051
R-30	0.032
R-38	0.026
R-49	0.020
R-60	0.016
R-71	0.014
R-82	0.012
R-93	0.011
R-104	0.010
R-115	0.009
R-126	0.008
R-137	0.007
R-148	0.007
WOOD JOISTS, SINGLE RAFTER ROOF	
None	0.417
R-11	0.088
R-13	0.078
R-15	0.071
R-19	0.055
R-21	0.052
R-25	0.043
R-30	0.036
R-38	0.028

Table D4
Assembly U-Factors for Attic Roofs with Metal Joists

Rated	Overall
R- 0	U- 1.282
R- 4	U- 0.215
R- 5	U- 0.179
R- 8	U- 0.120
R- 10	U- 0.100
R- 11	U- 0.093
R- 12	U- 0.086
R- 13	U- 0.080
R- 15	U- 0.072
R- 16	U- 0.068
R- 19	U- 0.058
R- 20	U- 0.056
R- 21	U- 0.054
R- 24	U- 0.049
R- 25	U- 0.048
R- 30	U- 0.041
R- 35	U- 0.037
R- 38	U- 0.035
R- 40	U- 0.033
R- 45	U- 0.031
R- 50	U- 0.028
R- 55	U- 0.027

Table D5

Assembly U-Factors for Mass Floors (I-P)

FRAMING TYPE & SPACING WIDTH (Actual depth)	CAVITY INSULATION R-VALUE: Rated/ (Effective Installed)	OVERALL U-FACTOR FOR ENTIRE BASE FLOOR ASSEMBLY	OVERALL U-FACTOR FOR ASSEMBLY OF BASE FLOOR PLUS CONTINUOUS INSULATION (uninterrupted by framing) Rated R-Value of Continuous Insulation																					
			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
CONCRETE FLOOR WITH RIGID FOAM																								
	None (0.0)	0.322	0.243	0.196	0.164	0.141	0.123	0.110	0.099	0.090	0.083	0.076	0.071	0.066	0.062	0.058	0.055	0.043	0.036	0.030	0.026	0.023	0.019	0.016
CONCRETE FLOOR WITH PINNED BOARDS																								
	R-4.2(4.2)	0.137	0.121	0.108	0.097	0.089	0.081	0.075	0.070	0.065	0.061	0.058	0.056	0.052	0.049	0.047	0.045	0.037	0.031	0.027	0.024	0.021	0.017	0.015
	R-6.3(6.3)	0.107	0.096	0.088	0.081	0.075	0.070	0.065	0.061	0.058	0.054	0.052	0.049	0.047	0.045	0.043	0.041	0.034	0.029	0.025	0.023	0.020	0.017	0.014
	R-8.3(8.3)	0.087	0.080	0.074	0.069	0.065	0.061	0.057	0.054	0.051	0.049	0.047	0.045	0.043	0.041	0.039	0.038	0.032	0.027	0.024	0.022	0.019	0.016	0.014
	R-10.4(10.4)	0.074	0.069	0.064	0.060	0.057	0.054	0.051	0.049	0.046	0.044	0.042	0.041	0.039	0.038	0.036	0.035	0.030	0.026	0.023	0.021	0.019	0.016	0.014
	R-12.5(12.5)	0.064	0.060	0.057	0.054	0.051	0.048	0.046	0.044	0.042	0.041	0.039	0.038	0.036	0.035	0.034	0.033	0.028	0.025	0.022	0.020	0.018	0.015	0.013
	R-14.6(14.6)	0.056	0.053	0.051	0.048	0.046	0.044	0.042	0.040	0.039	0.037	0.036	0.035	0.034	0.033	0.032	0.031	0.027	0.023	0.021	0.019	0.017	0.015	0.013
	R-16.7(16.7)	0.051	0.048	0.046	0.044	0.042	0.040	0.039	0.037	0.036	0.035	0.034	0.032	0.031	0.030	0.030	0.029	0.025	0.022	0.020	0.018	0.017	0.014	0.013
CONCRETE FLOOR W/ SPRAY-ON INSULATION																								
(1 in.)	R-4 (4.0)	0.141	0.123	0.110	0.099	0.090	0.083	0.076	0.071	0.066	0.062	0.058	0.055	0.052	0.050	0.047	0.045	0.037	0.031	0.027	0.024	0.021	0.018	0.015
(2 in.)	R-8 (8.0)	0.090	0.083	0.076	0.071	0.066	0.062	0.058	0.055	0.052	0.050	0.047	0.045	0.043	0.041	0.040	0.038	0.032	0.028	0.024	0.022	0.020	0.016	0.014
(3 in.)	R-12 (12.0)	0.066	0.062	0.058	0.055	0.052	0.050	0.047	0.045	0.043	0.041	0.040	0.038	0.037	0.036	0.034	0.033	0.028	0.025	0.022	0.020	0.018	0.015	0.013
(4 in.)	R-16 (16.0)	0.052	0.050	0.047	0.045	0.043	0.041	0.040	0.038	0.037	0.036	0.034	0.033	0.032	0.031	0.030	0.029	0.026	0.023	0.020	0.018	0.017	0.014	0.013
(5 in.)	R-20 (20.0)	0.043	0.041	0.040	0.038	0.037	0.036	0.034	0.033	0.032	0.031	0.030	0.029	0.028	0.028	0.027	0.026	0.023	0.021	0.019	0.017	0.016	0.014	0.012
(6 in.)	R-24 (24.0)	0.037	0.036	0.034	0.033	0.032	0.031	0.030	0.029	0.028	0.028	0.027	0.026	0.026	0.025	0.024	0.024	0.021	0.019	0.018	0.016	0.015	0.013	0.011

Table D6
Assembly U-Factors for Wood Joist Floors

FRAMING TYPE & SPACING WIDTH (Actual depth)	CAVITY INSULATION R-VALUE: Rated/ (Effective Installed)	OVERALL U-FACTOR FOR ENTIRE BASE FLOOR ASSEMBLY	OVERALL U-FACTOR FOR ASSEMBLY OF BASE FLOOR PLUS CONTINUOUS INSULATION (uninterrupted by framing) Rated R-Value of Continuous Insulation																					
			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 JOISTS																								
(5.5 in.	None (0.0)	0.282	0.220	0.180	0.153	0.132	0.117	0.105	0.095	0.087	0.080	0.074	0.069	0.064	0.060	0.057	0.054	0.042	0.035	0.030	0.026	0.023	0.019	0.016
depth)	R-11 (11.0)	0.074	0.069	0.064	0.060	0.057	0.054	0.051	0.048	0.046	0.044	0.042	0.040	0.039	0.037	0.036	0.035	0.030	0.026	0.023	0.020	0.019	0.016	0.014
	R-13 (13.0)	0.066	0.062	0.058	0.055	0.052	0.049	0.047	0.045	0.043	0.041	0.039	0.038	0.036	0.035	0.034	0.033	0.028	0.025	0.022	0.020	0.018	0.015	0.013
	R-15 (15.0)	0.060	0.057	0.053	0.050	0.048	0.046	0.044	0.042	0.040	0.038	0.037	0.036	0.034	0.033	0.032	0.031	0.027	0.024	0.021	0.019	0.017	0.015	0.013
	R-19 (18.0)	0.051	0.048	0.046	0.044	0.042	0.040	0.038	0.037	0.036	0.034	0.033	0.032	0.031	0.030	0.029	0.028	0.025	0.022	0.020	0.018	0.017	0.014	0.012
	R-21 (21.0)	0.046	0.043	0.042	0.040	0.038	0.037	0.035	0.034	0.033	0.032	0.031	0.030	0.029	0.028	0.027	0.027	0.023	0.021	0.019	0.017	0.016	0.014	0.012
(7.25 in.	R-25 (25.0)	0.039	0.037	0.036	0.035	0.033	0.032	0.031	0.030	0.029	0.028	0.028	0.027	0.026	0.025	0.025	0.024	0.022	0.019	0.018	0.016	0.015	0.013	0.012
depth)	R-30C(30.0)	0.034	0.033	0.032	0.031	0.030	0.029	0.028	0.027	0.026	0.026	0.025	0.024	0.024	0.023	0.023	0.022	0.020	0.018	0.016	0.015	0.014	0.012	0.011
(9.25 in.	R-30 (30.0)	0.033	0.032	0.031	0.030	0.029	0.028	0.027	0.027	0.026	0.025	0.024	0.024	0.023	0.023	0.022	0.022	0.020	0.018	0.016	0.015	0.014	0.012	0.011
depth)																								
(11.25 in.	R-38C(38.0)	0.027	0.026	0.025	0.025	0.024	0.024	0.023	0.022	0.022	0.021	0.021	0.020	0.020	0.020	0.019	0.019	0.017	0.016	0.015	0.014	0.013	0.011	0.010
depth)																								
(13.25 in.	R-38 (38.0)	0.026	0.026	0.025	0.024	0.024	0.023	0.023	0.022	0.022	0.021	0.021	0.020	0.020	0.019	0.019	0.019	0.017	0.016	0.015	0.014	0.013	0.011	0.010
depth)																								