Thermal Mass Factors for ICF Walls in the MEC and Manual J

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ABSTRACT

Insulated concrete form (ICF) systems use a prefabricated form made of foam insulation that is assembled into walls at the building site and filled with concrete. ICFs are available from more than 20 manufacturers, and their use in the United States is growing. ICF walls have a high insulation R-value and significant thermal mass.

An analysis was performed to determine whether the thermal mass tables in the Model Energy Code (MEC) fairly represent the performance of ICF walls and, if not, propose an alternative approach. Computer simulations using DOE2 and BLAST were performed to determine the relative performance of ICF and lightweight walls in a prototypical house in a range of climates. The BLAST results fall between the MEC integral and interior insulation position table values. The DOE2 results are consistent with the MEC interior insulation table.

Analyses were also performed to determine cooling load factors for homes with ICF walls. These factors can be used in conjunction with Manual J procedures for designing air-conditioning systems in residences.

INTRODUCTION

Insulated concrete form (ICF) systems use a prefabricated form made of foam insulation that is assembled into walls at the building site and filled with concrete. Proprietary systems vary, but generally the wall has a layer of foam insulation on the outside, a layer of concrete in the middle, and a second layer of foam on the inside. Conventional finishes are applied to suit the building purpose. ICFs are available from more than 20 manufacturers, and their use in the United States is growing. ICF walls have a high insulation R-value and significant thermal mass.

The *Model Energy Code* (MEC) is the model code that is the basis for the residential code in most states. The light opaque wall requirements are in the form of an overall U-factor (*Uo*) and are a function of heating degree-days and whether the building is single family or multifamily. The MEC includes three mass wall insulation requirement tables for exterior, interior, and integral insulation (Tables 502.1.2a,b, and c), which depend on heating degree-days and are designed to produce a total annual heating and cooling load equal to the lightweight wall. The MEC mass wall tables (Christian 1991) were accepted into the MEC in 1988. A major objective of this study was to determine whether these tables fairly represent the performance of ICF walls and, if not, propose an alternative approach.

Analyses were also performed to determine cooling load factors for homes with ICF walls. These factors can be used in conjunction with *Manual J* procedures for designing air-conditioning systems in residences. *Manual J* (ACCA 1986) contains the standard equipment sizing method used by the residential HVAC industry. The current edition contains procedures derived from the *ASHRAE Handbook* reformatted for simplicity. *Manual J* provides equivalent temperature differences (ETDs) for calculating the cooling load impact of exterior walls. The cooling load per square foot of wall is simply the wall's U-factor times the ETD. ETDs are tabulated for different design temperatures and daily temperature ranges. The manual provides ETDs for two types of exterior walls, "frame and veneer-on-frame" and "masonry walls, 8 in. (200 mm) block or brick." A major objective of this study was to develop ETDs for ICF walls.

ANNUAL ENERGY ANALYSIS FOR MEC

Computer simulations were used to determine the relative performance of ICF and wood stud walls in a prototypical house in a range of climates. The energy figure of merit for the

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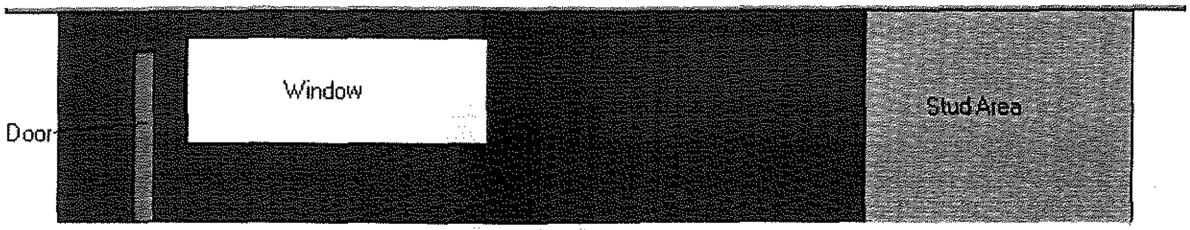

Figure 1 *Elevation of prototype.*

MEC analysis is the sum of annual heating and cooling loads. In all cases studied, the ICF walls had a lower total annual load than a typical stud wall with the same U-factor. For the ICF walls, an equivalent U-factor was calculated and is the U-factor of a wood stud wall with the same total annual load. The simulation analysis is consistent with the approach used to develop the current MEC mass wall tables (Christian 1991). The house prototype, the weather data, and the simulation models were updated to the best currently available technology, and the simulation analysis was expanded to include both DOE2.1E and BLAST.

The prototype house used in the simulation analysis is a 1540 ft^2 (143 m^2) single-story, slab-on-grade house, which has been carefully constructed to have equal wall, glazing, and door areas on each of the four cardinal orientations in order to represent the average performance of houses randomly oriented. It was derived from the prototype used to develop the PEAR database (Huang et al.), the source of energy data for development of *ANSI/ASHRAE Standard 90.2-1993* (ASHRAE 1993). It is similar to Christian's (1991) prototype, which was also derived from Huang's work, but used nonuniform glazing orientation. Figure 1 shows one of the four identical elevations of the house. The shading effects of houses, fences, and vegetation, which surround typical single-family housing, was modeled with a 10 ft (3 m) high, 50% transmittance screen 20 ft (6 m) from the house on each side (not shown in elevation). The house has 185 ft^2 (17 m^2) net of double-glazed windows, or 12% of the floor area in glass.

Constant thermostat settings of 70°F for heating and 78°F for cooling were used in the simulations to be consistent with the MEC analysis. Infiltration was simulated at a constant 0.35 air changes per hour (ACH). Natural ventilation was modeled in both programs to eliminate cooling loads when it was possible to do this by opening windows. The restrictions of the BLAST model required a fixed shading coefficient year-round, so shades reducing the solar gain by 30% were assumed to be closed year-round in both programs.

The Typical Meteorological Year (TMY2) data set derived from 1961-1990 data for the cities shown in Table 1 was used in the *Model Energy Code* analysis (Marion 1995). The cities used are the same as those used by Christian (1991) with the addition of Sacramento. Heating degree-days for the TMY2 data are shown for comparison with the MEC tables. Although cooling climate is not a variable in the MEC tables, cooling degree-hours and mean daily range are also shown to help the reader in understanding the climates.

Simulations were performed using DOE2.1E (LBL 1995), the latest version of the program used to create the original MEC mass tables, and BLAST, a program developed by the U.S. Army (CERL), which features a more fundamental (and presumably more accurate) approach to calculating dynamic loads. The BLAST loads model has been selected by the U.S. Department of Energy for inclusion in EnergyBase, DOE's next generation simulation program (Ellington 1996).

Energy results were calculated for 12 different wall systems: 6 ICF walls and 6 conventional wood stud walls, as shown in Table 2. All the ICF walls were modeled as constructions with four layers. The inside layer was ½ in. (13 mm)

TABLE 1
Climates Analyzed

City	Heating Degree-Days, Base 65°F	Cooling Degree-Hours, Base 74°F	Mean Daily Range, °F
Miami, Florida	141	23296	11
Phoenix, Arizona	1154	64321	26
Atlanta Georgia	3090	17643	19
Sacramento, California	3386	10966	33
Sterling, West Virginia (Washington, D.C.)	5233	7555	20
Denver, Colorado	6007	5850	25
Minneapolis, Minnesota	7986	18747	17

TABLE 2
Wall Properties

Wall Type	#	Concrete Thickness, in.	Concrete Conductivity, Btu/h·°F·ft·ft^2	Foam/sheath R-value, °F·ft^2·h/Btu	Cavity R-value, Btu/h·ft^2·°F	Overall U-factor, Btu/ft^2	Heat Capacity, Btu/ft^2
ICF	1	4	1.333	16.7	na	0.055	10.5
ICF	2	4	1.333	12.5	na	0.071	10.5
ICF	3	4	1.333	8.3	na	0.101	10.4
ICF	4	6	1.333	16.7	na	0.055	15.4
ICF	5	6	1.333	8.3	na	0.100	15.3
ICF	6	4	0.9792	8.3	na	0.101	10.4
STUD	1	None		1.32	11	0.094	1.6
STUD	2	None		1.32	13	0.088	1.6
STUD	3	None		5.0	13	0.065	1.4
STUD	4	None		10.0	13	0.048	1.4
STUD	5	None		15.0	13	0.038	1.4
STUD	6	None		20.0	13	0.032	1.4

gypsum board. The next layer was foam insulation with a thickness that varied by case to give an appropriate range of wall U-factors. The next layer was concrete with a thickness that varied by case in order to test the impact of wall heat capacity. The properties of the concrete were: density of 140 lb/ft^3 (2240 kg/m^3), specific heat of 0.21 Btu/lb°F (880 J/kg·°K), and a thermal conductivity that varied. The outside layer was another foam insulation layer matching the second layer.

Stud walls were modeled with an inside layer of ½ in. (13 mm) gypsum board identical to the one in the ICF wall. The next layer was 2 by 4 in. (50 by 100 mm) wood studs at 16 in. (400 mm) on center with insulation in the cavity of either R-11or R-13 hr·ft^2·°F/Btu (1.9 or 2.2 m^2·K/W). The wood studs were modeled as a separate wall section occupying 25% of the wall area. The outside layer was sheathing, either standard wood fiber with an R-value of 1.32 (0.23) or foam insulation to provide lower U-factor walls.

Annual Energy Results

Results of BLAST and DOE2 runs were analyzed for the seven cities listed in Table 1 (Wilcox 1997a). For each city, the equivalent U-factor of each ICF wall was calculated by interpolating the results of the simulations for the stud walls. Both simulation programs show that ICF walls have significant mass effects, with BLAST showing larger mass benefits in all climates.

The ratio of the equivalent U-factor to the steady-state U-factor was similar for all of the ICF walls in each climate. ICF Wall No. 1 with 4 in. (100 mm) of high conductivity concrete and R-16.7 h·ft^2·°F/Btu (2.94 m^2·K/W) foam had the highest ratio (smallest mass effect) in each climate and therefore is a conservative case to represent the mass effect of all ICF walls with equal or higher heat capacities and U-factors.

Comparison with MEC

The U-factors for ICF walls with performance equivalent to a wood stud wall with a U-factor of 0.06 Btu/h·ft^2·°F (0.34 W/m^2·K) are plotted in Figures 2 and 3 with comparable equivalent U-factors from the MEC tables. The BLAST results fall between the MEC integral and interior insulation position table values. The DOE2 results are consistent with the MEC interior insulation table within the precision of the factors in the table. Results for Sacramento at 3380 heating degree-days show a larger mass effect than those for Atlanta at 3090 because Sacramento has a more favorable climate

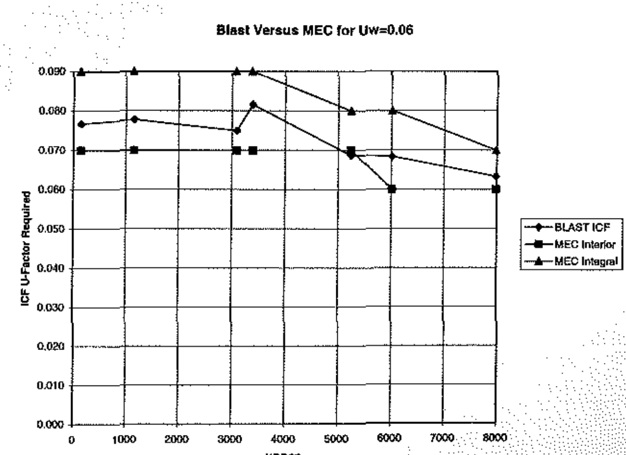

Figure 2 Comparison of BLAST ICF equivalent U-factors with the MEC.

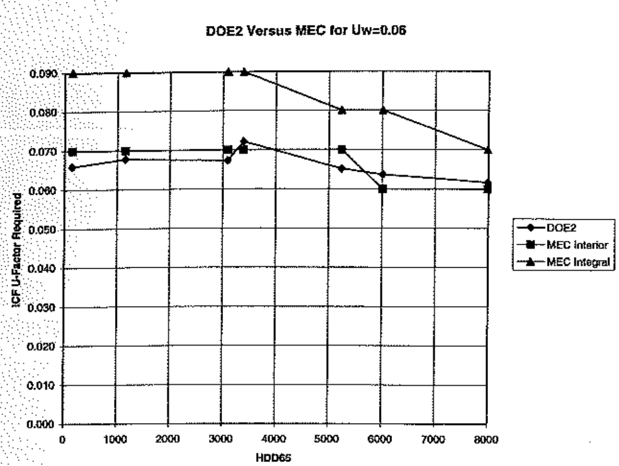

Figure 3 *Comparison of DOE2 ICF equivalent U-factors with the MEC.*

pattern with a larger summer temperature swing (mean daily range).

We believe that the BLAST program provides a technically superior analysis of mass effects. However, the DOE2 analysis and the MEC tables show a slightly smaller mass effect. Based on these results, we recommend ICF compliance be based on the factors in the MEC table for interior insulation position. We believe this will provide conservative results that ensure energy savings in the majority of buildings.

PEAK LOAD ANALYSIS FOR MANUAL J

Computer simulations were used to determine the relative peak cooling loads of ICF and wood stud walls in a prototypical house in 240 climates. For each climate, the operation of the prototype house was simulated for a typical year using the TMY2 weather data sets. For each simulation analysis, the peak cooling load that occurred during the typical year was recorded. Peak cooling loads for ICF walls were compared with the peak cooling loads for wood stud walls and an appropriate ETD for the ICF walls was determined. The average ETDs for the ICF walls were tabulated using the *Manual J* Table 7-4 format.

The prototype house was the same as used for the MEC analysis. The cooling thermostat was held constant at 78°F (26°C).

The Typical Meteorological Year (TMY2) data set derived from 1961-1990 data was used in the simulations. In order to get a significant number of locations in each of the design temperature conditions bins, simulations were run for all of the 239 locations in the data set. Due to a minor bug, BLAST was unable to complete runs in four Alaska locations. We also were unable to obtain DOE2 packed files for three Alaska locations. The design temperature and daily temperature range statistics were determined for each of the TMY2 weather years and used to correlate simulation results with the ETDs in *Manual J* Table 7-4 .

Simulations were carried out using DOE2.1E and BLAST. The BLAST results were used to develop ETDs for ICF walls. The simulation results for cooling and heating peak are listed in Wilcox (1997b).

Peak load results were calculated for three different wall systems: an ICF wall and two conventional wood stud walls as shown in Table 3. The ICF wall was modeled as a construction with four layers. The inside layer was ½ in. (13 mm) gypsum board. The next layer was foam insulation. The next layer was 4 in. (100 mm) of normal weight concrete. The outside layer was another foam insulation layer matching the second layer.

Stud walls were modeled with an inside layer of ½ in. (13 mm) gypsum board identical to the one in the ICF wall. The next layer was 2 by 4 in. (50 by 100 mm) wood studs at 16 in. (400 mm) on center with insulation in the cavity of either R-11 or R-13 h·ft^2·°F/Btu (1.9 or 2.2 m^2·K/W). The wood studs were modeled as a separate wall section occupying 25% of the wall area. The outside layer was sheathing, either standard wood fiber with an R-value of 1.32 (0.23) or foam insulation to provide lower U-factor walls.

Cooling Analysis

Figure 4 shows the peak cooling loads from the BLAST simulations for Sacramento, California, a hot, dry climate with a large summer diurnal temperature variation or daily range. Data point S2 represents the peak for the prototype with Stud Wall No. 2 that has a U-factor of 0.088 Btu/h·ft^2·°F (0.50 W/m^2·K). Point S6 is the peak load for the prototype with Stud Wall No. 6, the wall with the very low U-factor of

TABLE 3
Wall Properties

Wall Type	#	Concrete Thickness, in.	Concrete Conductivity, Btu/h·°F·ft·ft^2	Foam/sheath R-value, °F·ft^2·h/Btu	Cavity R-value, °F·ft^2·h/Btu	Overall U-factor, Btu/h·ft^2·°F	Heat Capacity, Btu/ft^2
ICF	1	4	1.333	16.7	na	0.055	10.5
STUD	2	none		1.32	13	0.088	1.6
STUD	6	none		20.0	13	0.032	1.4

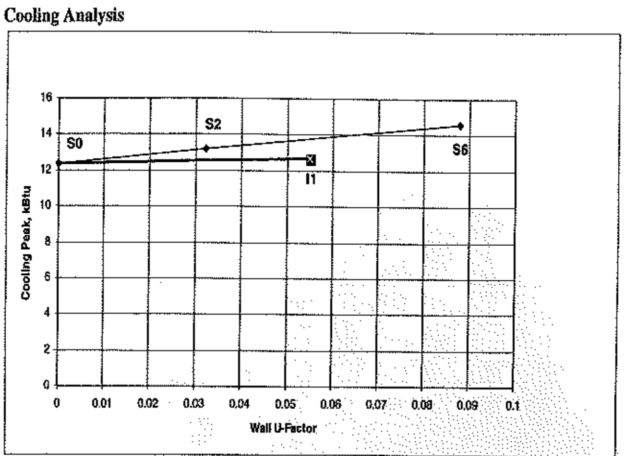

Figure 4 *BLAST peak cooling loads for Sacramento.*

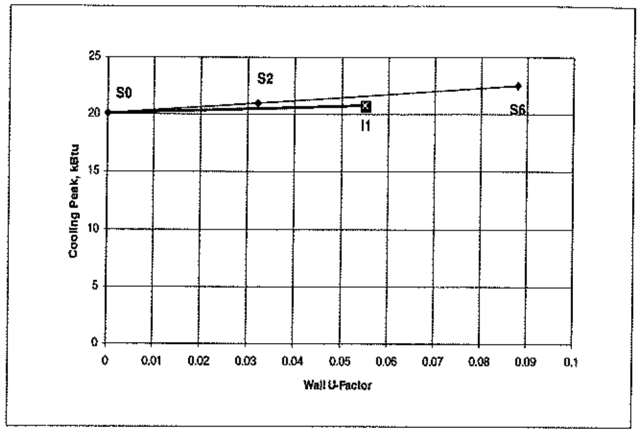

Figure 5 *BLAST peak cooling loads for Miami.*

0.032 Btu/h·ft^2·°F (0.18 W/m^2·K). Point I1 is the peak load for the ICF Wall No. 1 that has a U-factor of 0.055 Btu/h·ft^2·°F (0.31 W/m^2·K). The peak load for the ICF wall is lower than the peak load for either of the stud walls due to the beneficial effect of the concrete mass in the wall.

Figure 5 shows similar results for Miami, a hot, humid climate that does not cool off at night in the summer and has a very small daily range. Although the absolute values of the loads are different, the prototype with the ICF wall again has lower loads than the prototype with a stud wall of the same U-factor. This is the case in all of the climates simulated.

According to the assumptions of *Manual J*, the peak load contributed by a wall of any type is proportional to its U-factor. A wall with infinite insulation and a U-factor of zero has by definition a peak load contribution of zero. In order to make the data for ICF walls usable in *Manual J* procedures, we will make a consistent set of assumptions. Note that this approach does not account for the beneficial effect of mass on loads thermally connected to the indoor room air, which occurs because of interior radiant heat transfer and indoor air temperature swing. However, since ICF walls are always well insulated on the inside, this effect is small for ICF walls and can be ignored for our purposes.

The slope of the line S2-S6 ($Slope_S$) represents the impact of changing the stud wall U-factor on the cooling peak in Sacramento:

$$Slope_S = 1000 * (P2\text{-}P6)/((U2\text{-}U6) * 1140) \qquad (1)$$

where

P2 = peak for Stud Wall No. 2,
P6 = peak for Stud Wall No. 6,
U2 = U-factor for Stud Wall No. 2,
U6 = U-factor for Stud Wall No. 6,
1000 = conversion factor for kBtu to Btu,
1140 = opaque wall area of the prototype house, ft^2.

Table 4 shows the statistics for $Slope_S$ summarized from BLAST. Cities in Alaska and Cut Bank, Montana, have been removed from this and subsequent analysis because the calculated peak loads were small or zero and cooling is not usually installed in homes in these climates.

Point S0 in Figure 4 with peak load P0 represents the peak cooling load for the prototype house if the stud wall is infinitely insulated (U-factor of 0.0). In this case there is no heat transfer through the wall. This value is calculated by extrapolation using Equation 2.

$$P0 = P2 - (U2 * 1140\ Slope_S/1000) \qquad (2)$$

The slope of the line S0-I1 in Figure 4 represents the effect of the mass and U-factor of the ICF wall on the cooling peak. It is calculated using Equation 3.

$$Slope_I = 1000 * (P1\text{-}P0)/(U1 * 1140) \qquad (3)$$

where

P1 = peak load of the prototype with ICF Wall No. 1,
U1 = U-factor of ICF Wall No. 1.

Table 5 shows the statistics for $Slope_I$ from the results. For some of the cities the $Slope_I$ is negative. This means that the peak cooling load for the prototype with the ICF wall is lower than it would have been with a stud wall that has infinite insulation. The ICF wall has a beneficial effect and actually reduces peak load due to its dynamic properties. This effect is largest in climates with low design temperatures and large daily ranges where mass effects are most significant.

ICF Factor

The ICF factor is the relationship between peak cooling load impact of the ICF wall and the stud wall for each climate. It is calculated using Equation 4.

$$\text{ICF Factor} = Slope_I / Slope_S \qquad (4)$$

Table 6 shows the statistics for ICF factor. An ICF factor of 1 would mean that an ICF wall and a wood stud wall of the same U-factor would have the same peak cooling load impact. An ICF factor less than one means the ICF

TABLE 4
Statistics for $Slope_S$ by Climate Bin

Design Temperature Difference, °F	<=5			10			15		20		25		30
Daily Temperature Range	**L**	**M**	**H**	**L**	**M**	**H**	**M**	**H**	**M**	**H**	**M**	**H**	**H**
Analysis Bin Number	1	2	3	4	5	6	7	8	9	10	11	12	13
Average	14.6	20.0	14.2	18.4	21.0	22.1	22.7	24.0	25.8	30.3	31.1	31.0	32.7
Maximum	16.9	28.4	19.1	27.8	31.0	27.2	32.1	35.9	30.2	33.4	31.4	34.2	32.7
Minimum	11.1	14.6	11.5	9.3	8.7	14.8	15.7	15.8	19.8	25.7	30.8	27.7	32.7
Standard Deviation	2.4	4.0	4.2	5.9	4.7	3.8	4.1	4.4	3.2	3.5	0.4	4.6	
Count	6	19	3	15	65	22	49	20	12	5	2	2	1

TABLE 5
Statistics for $Slope_I$ by Climate Bin

Design Temperature Difference, °F	<=5			10			15		20		25		30
Daily Temperature Range	**L**	**M**	**H**	**L**	**M**	**H**	**M**	**H**	**M**	**H**	**M**	**H**	**H**
Analysis Bin Number	1	2	3	4	5	6	7	8	9	10	11	12	13
Average	-3.5	-0.3	-4.2	6.8	4.7	2.3	8.7	5.5	10.0	10.1	15.7	7.4	15.5
Maximum	4.5	7.2	0.0	14.6	16.0	7.8	19.1	12.6	15.3	14.6	16.6	14.8	15.5
Minimum	-12.9	-10.1	-7.3	0.7	-6.6	-5.0	0.1	-1.1	3.3	3.6	14.9	0.0	15.5
Standard Deviation	6.7	3.9	3.5	4.1	4.3	3.3	4.1	4.4	4.0	4.8	1.2	10.5	
Count	11	25	4	15	65	22	49	20	12	5	2	2	1

TABLE 6
Statistics for ICF Factor by Climate Bin

Design Temperature Difference, °F	<=5			10			15		20		25		30
Daily Temperature Range	**L**	**M**	**H**	**L**	**M**	**H**	**M**	**H**	**M**	**H**	**M**	**H**	**H**
Analysis Bin Number	1	2	3	4	5	6	7	8	9	10	11	12	13
Average	-0.4	0.0	-0.4	0.4	0.2	0.1	0.4	0.2	0.4	0.3	0.5	0.2	0.5
Maximum	0.3	0.3	-0.2	1.0	0.6	0.3	1.2	0.5	0.5	0.5	0.5	0.5	0.5
Minimum	-0.9	-0.5	-0.6	0.0	-0.9	-0.2	0.0	-0.1	0.2	0.1	0.5	0.0	0.5
Standard Deviation	0.5	0.2	0.2	0.3	0.2	0.1	0.2	0.2	0.1	0.1	0.0	0.3	
Count	6	19	3	15	65	22	49	20	12	5	2	2	1

TABLE 7
Manual J Equivalent Temperature Difference for Walls

Design Temperature Difference, °F	<=5			10			15			20			25		30	35
Daily Temperature Range	**L**	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**		**M**	**H**	**M**	**H**	**H**	**H**
Frame and veneer on frame				17.6	13.6		22.6	18.6	13.6	27.6	23.6	18.6	28.6	23.6	28.6	33.6
Masonry Walls, 8 in. block or brick				10.3	6.3		15.3	11.3	6.3	20.3	16.3	11.3	21.3	16.3	21.3	26.3
TMY Cities	11	25	4	14	65	22	0	49	20	0	12	5	2	2	1	0
Analysis Bin	1	2	3	4	5	6	X	7	8	Y	9	10	11	12	13	Z

TABLE 8
ICF Equivalent Temperature Differences

Design Temperature Difference, °F	10		15			20			25		30	35
Daily Temperature Range	L	M	L	M	H		M	H	M	H	H	H
ICF Wall	6.5	3.1	15.3	7.1	3.1	20.3	9.1	6.2	14.5	5.7	13.5	26.3

wall would have a smaller cooling load than a stud wall with the same U-factor. The smaller or more negative the ICF factor, the more cooling peak benefit is provided by the ICF wall relative to stud walls. The average ICF factor is less than one in all climate bins. Columbia, S.C., in bin 7 is the only city of the 221 for which the ICF Factor is greater than one.

Equivalent Temperature Difference

Table 7 shows the entries for exterior walls in *Manual J* Figure 7-4 with the corresponding bin number and number of TMY cities from this study. This is the same data as Table 36 in chapter 26 of *ASHRAE Fundamentals,* 1985 edition. It includes three bins (X, Y, Z) for which there are no TMY cities. There are four bins in this study (1,2,3,6) that are not included in *Manual J.*

The *Manual J* factors included in Table 7 were generated using a theoretical calculation rather than measured weather data and an annual simulation (note for example that the ETDs for each daily temperature range are spaced exactly 5°F (2.8°C) apart). In order to make the results of our annual simulations usable in the *Manual J* procedure, we have calculated ICF equivalent temperature differences based on the theoretical ETDs for the stud wall and our ICF factor.

The ICF ETDs have the same relationship to the stud ETDs as the ICF $Slope_I$ has to the stud $Slope_S$. The ICF ETDs are calculated using Equation 5.

$$\text{ICF ETD} = \text{Stud ETD} * \text{ICF Factor} \tag{5}$$

The resulting ICF ETDs are shown in Table 8. For the three bins (X, Y, and Z) for which there are no TMY cities, the stud wall ETD was used for ICF walls. This is not a problem since there are few real locations in these bins. Four bins (1, 2, 3, and 6) that are not included in the *Manual J* table are also not included in Table 8.

Heat Transfer Multipliers for Cooling

Manual J uses heat transfer multipliers (HTMs) to calculate cooling loads. The HTM for a wall is the amount of heat that flows through one square foot of wall at a given temperature difference. For cooling, the HTM is equal to the component thermal transmittance (U-factor) times the summer equivalent temperature difference (ETD).

$$\text{HTM (cooling)} = \text{ETD} \times \text{U} \tag{6}$$

where

HTM = heat transfer multiplier, heat flow through one square foot of a wall at a given temperature difference, Btu/h·ft^2;

ETD = equivalent temperature difference (summer), °F;

U = thermal transmittance of component, Btu/h·ft^2·°F.

The HTM for an ICF wall is the ETD from Table 8 multiplied by the U-factor. Typical HTM values for ICF walls are presented in Table 9. The values for ICF walls in Table 9 are consistent with values in Table 4 of *Manual J*. Values for ICF walls in Table 9 are for flat panel systems with no metal ties.

TABLE 9
Heat Transfer Multipliers (HTMs) for Cooling for ICF Walls (an Addition to Table 4 of Manual J)[1]

No. 14 - Insulated Concrete Form (ICF) Finished - Above Grade	10		15			20			25		30	35	U
	L	M	L	M	H	L	M	H	M	H	H	H	
	HTM (Btu/h per ft^2)												
I. ICF Wall with R-12 Insulation	0.5	0.2	1.1	0.5	0.2	1.5	0.7	0.5	1.1	0.4	1.0	1.9	.074
J. ICF Wall with R-15 Insulation	0.4	0.2	0.9	0.4	0.2	1.2	0.5	0.4	0.9	0.3	0.8	1.6	.060
K. ICF Wall with R-16 Insulation	0.4	0.2	0.9	0.4	0.2	1.2	0.5	0.4	0.8	0.3	0.8	1.5	.057
L. ICF Wall with R-17 Insulation	0.4	0.2	0.8	0.4	0.2	1.1	0.5	0.3	0.8	0.3	0.7	1.4	.054
M. ICF Wall with R-20 Insulation	0.3	0.1	0.7	0.3	0.1	0.9	0.4	0.3	0.7	0.3	0.6	1.2	.046
N. ICF Wall with R-22 Insulation	0.3	0.1	0.6	0.3	0.1	0.9	0.4	0.3	0.6	0.2	0.6	1.1	.042

[1] Values include interior and exterior finishes and are for flat panel systems with no metal ties. For systems with irregular shapes or metal form ties connecting the interior and exterior insulation layers, use U-factors from Appendix A or product manufacturer to calculate the HTM (HTM = ETD × U-factor).

TABLE 10
ICF Cooling Size Multipliers

Design Temperature Difference, °F	<=5			10			15		20		25		30
Daily Temperature Range	**L**	**M**	**H**	**L**	**M**	**H**	**M**	**H**	**M**	**H**	**M**	**H**	**H**
Analysis Bin Number	1	2	3	4	5	6	7	8	9	10	11	12	13
Average	74%	78%	75%	93%	88%	79%	91%	84%	90%	84%	90%	87%	90%
Maximum	93%	87%	77%	99%	96%	85%	98%	90%	92%	88%	90%	88%	90%
Minimum	47%	27%	71%	85%	76%	74%	84%	79%	88%	80%	89%	85%	90%
Standard Deviation	20%	14%	3%	3%	4%	2%	3%	3%	1%	3%	0%	2%	
Count	6	19	3	15	65	22	49	20	12	5	2	2	1

For systems with irregularly shaped insulation or metal form ties connecting the interior and exterior insulation layers, use U-factors for the individual product to calculate the HTM. All *Manual J* cooling HTMs include the effects of thermal mass and solar radiation (see footnote 5 to *Manual J*, Table 4.)

ICF Cooling Size Multipliers

In order to provide a perspective on the significance of the ICF peak cooling load savings, the impact was calculated for changing from a typical wood stud wall (Stud Wall No. 2, R-13 (2.2) insulation) to an ICF wall (ICF Wall No. 1, U-factor = 0.055 (0.31)). Table 10 presents values tabulated using the *Manual J* table format.

The values in Table 10 were calculated directly using the BLAST simulation results and Equation 7. Values for each city are included in Wilcox (1997b).

$$\text{ICF Mult} = P1/P2 \tag{7}$$

where

P1 = peak load of the prototype with ICF Wall No. 1,

P2 = peak for Stud Wall No. 2.

HEATING ANALYSIS

Heat Transfer Multipliers for Heating

Table 2 of *Manual J*, Heat Transfer Multipliers (Heating), includes precomputed factors for a variety of building envelope components for use in calculating heating equipment size for a range of design temperature differences. The heat transfer multipliers (HTMs) are multiplied times the net component area and summed to calculate the total heating system load.

To calculate the HTM for an ICF wall, use Equation 8.

$$\text{HTM} = \text{U-factor} * \Delta T \tag{8}$$

where

U-Factor = steady state U-factor for the ICF wall,

ΔT = difference between the indoor and outdoor heating design temperature, °F.

Typical HTM values for ICF walls are presented in Table 11. The values for ICF walls in Table 11 are consistent with values in Table 2 of *Manual J*. Values for ICF walls in Table 11 are for flat panel systems with no metal ties. For systems

TABLE 11
Heat Transfer Multipliers (HTMs) for Heating for ICF Walls (an Addition to Table 2 of Manual J)[1]

No. 14 - Insulated Concrete Form (ICF) W Finished - Above Grade	Winter Temperature Difference																
	20	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**U**
	HTM (Btu/h per ft²)																
I. ICF Wall with R-12 Insulation	1.5	1.8	2.2	2.6	3.0	3.3	3.7	4.1	4.4	4.8	5.2	5.5	5.9	6.3	6.6	7.0	0.074
J. ICF Wall with R-15 Insulation	1.2	1.5	1.8	2.1	2.4	2.7	3.0	3.3	3.6	3.9	4.2	4.5	4.8	5.1	5.4	5.7	0.060
K. ICF Wall with R-16 Insulation	1.1	1.4	1.7	2.0	2.3	2.6	2.8	3.1	3.4	3.7	4.0	4.3	4.6	4.8	5.1	5.4	0.057
L. ICF Wall with R-17 Insulation	1.1	1.3	1.6	1.9	2.2	2.4	2.7	3.0	3.2	3.5	3.8	4.0	4.3	4.6	4.9	5.1	0.054
M. ICF Wall with R-20 Insulation	0.9	1.2	1.4	1.6	1.9	2.1	2.3	2.6	2.8	3.0	3.2	3.5	3.7	3.9	4.2	4.4	0.046
N. ICF Wall with R-22 Insulation	0.8	1.1	1.3	1.5	1.7	1.9	2.1	2.3	2.5	2.8	3.0	3.2	3.4	3.6	3.8	4.0	0.042

[1] Values include interior and exterior finishes and are for flat panel systems with no metal ties. For systems with irregular shapes or metal form ties connecting the interior and exterior insulation layers, use U-factors from Appendix A or product manufacturer to calculate the HTM (HTM = WTD × U-factor).

with irregularly shaped insulation or metal form ties connecting the interior and exterior insulation layers, use U-factors for the individual product to calculate the HTM.

Heating Mass Effects

The purpose of heating sizing is to ensure that the heating system is large enough to maintain comfort under design, but not necessarily worst case, weather conditions. *Manual J* and standard industry practice make no allowance for mass effects when sizing heating systems. Heating system loads are generally calculated assuming that the indoor and outdoor temperatures are constant at their design values and there is no solar or internal gains. Under these conditions there are no mass effects. For sizing purposes, the calculated loads are often increased by a safety margin to account for morning warm-up where mass effects result in larger rather than smaller equipment size.

The simulations assumed that the houses were continuously occupied with constant heating setpoints and normal internal and solar gains. Under these conditions, the ICF walls have lower peak heating loads than stud walls with the same U-factor. However, this is not necessarily relevant to heating system sizing. We do not recommend reducing heating system size for mass effects.

SUMMARY AND CONCLUSIONS

1. The DOE2 results show ICF walls have thermal mass characteristics represented by the MEC interior insulation table. The BLAST results show larger mass effects.
2. *Manual J* provides equivalent temperature differences (ETDs) and heat transfer multiplier (HTMs) for calculating the cooling load impact of exterior walls. The cooling load per square foot of wall is simply the wall U-factor times the ETD. ETDs for ICF walls are presented in Table 8. The HTM for an ICF wall is the ETD from Table 8 multiplied by the U-factor. Typical HTM values for ICF walls are presented in Tables 9 and 11.

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