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Using the MEC and Manual J for ICF Walls

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Abstract

Insulated Concrete Form (ICF) systems use a prefabricated form made of foam insulation which 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 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.

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 alternate approach. The MEC is the model code which is the basis for the residential code in most states. The light weight (frame) 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 light weight wall. Results for ICF walls are consistent with the MEC interior insulation table.

Analysis 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, a publication of the Air Conditioning Contractors of America, contains the standard equipment sizing method used by the residential HVAC industry. Manual J provides Equivalent Temperature Differences (ETD's) 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. ETD's are tabulated for different design temperatures and daily temperature ranges. The manual provides ETD's for 2 types of exterior walls "frame and veneer-on-frame" and "masonry walls, 8-in. block or brick." ETD factors for ICF walls are provided and can be used in calculating cooling loads for ICF wall homes in the standard Manual J sizing method.

15 YEARS OF PROGRESS

ICF SYSTEMS

Insulating concrete forming systems (ICF) filled with concrete are used as energy-efficient structural walls in residences, including basements, up to three stories. ICFs are available from more than 20 manufacturers and their use in the United States and Canada is growing. The Portland Cement Association has helpful information on selecting and using ICFs. The walls uniquely combine the thermal mass of the concrete with the high thermal resistance of insulated sides to provide an energy efficient system in any climate. Compared to conventional frame construction, ICF walls are more durable, stronger, quieter, and more resistant to natural disasters.

The features of ICF systems vary between manufacturers and are differentiated by the type of insulation unit, the shape of the cavity, and the method of connecting the two sides of insulation. ICFs are panels, planks, or hollow blocks usually made of expanded polystyrene (EPS) or extruded expanded polystyrene (XPS) insulation. Figure 1 shows a block system with teeth so they interlock. Figure 2 shows a panel system with plastic ties connecting insulation panels and plastic strips for mounting interior and exterior finishes. After ICF's are erected at the job site, concrete is placed between the insulation layers (Fig. 3). Although dimensions vary, the two insulation layers in ICF walls are each generally 2-in. thick and the concrete is 4- to 6-in. thick. Figures 4 and 5 show a home constructed using ICF's before and after the exterior finish is applied.

Thermal resistance (R-value) of ICF walls without interior or exterior finishes vary by manufacturer but are generally in the range of 12 to 22 hr·ft2·°F/Btu. A typical value for a wall with 2-in. of polystyrene insulation in flat panels, 4-in. of concrete, and plastic ties is 18 hr·ft2·°F/Btu.

Fig. 1 Block System (PCA No. 64048)

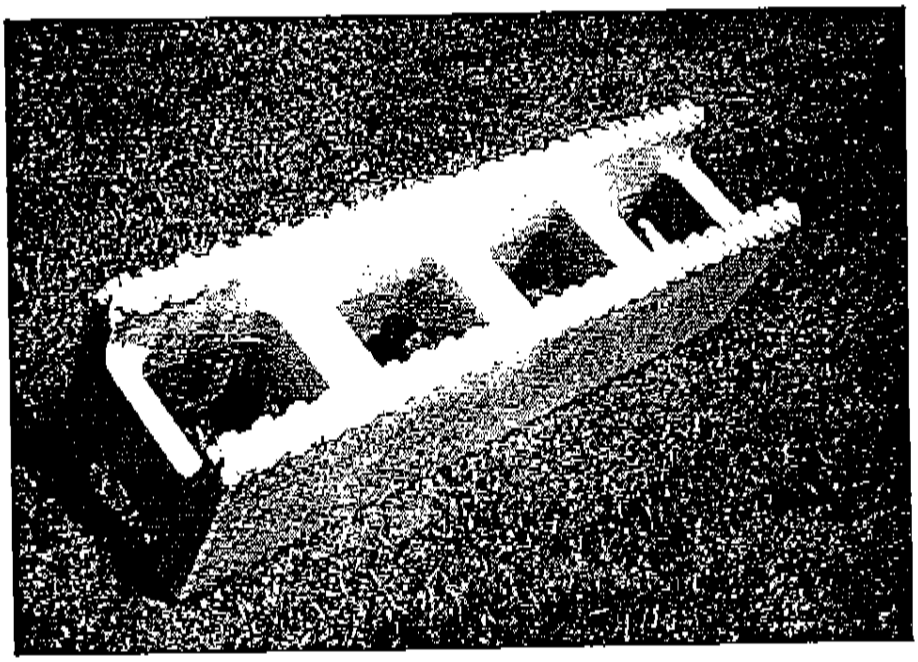


Fig. 2 Panel System with Plastic Ties Connecting Insulation Layers and Plastic Strips for Mounting Interior and Exterior Finishes (PCA No. 64245)

Fig. 3 Concrete Placed Between Insulation Layers (PCA No. 67365)

15 YEARS OF PROGRESS

Fig. 4 Home Constructed of ICF's Before Exterior Finish is Applied (PCA No. 67361)

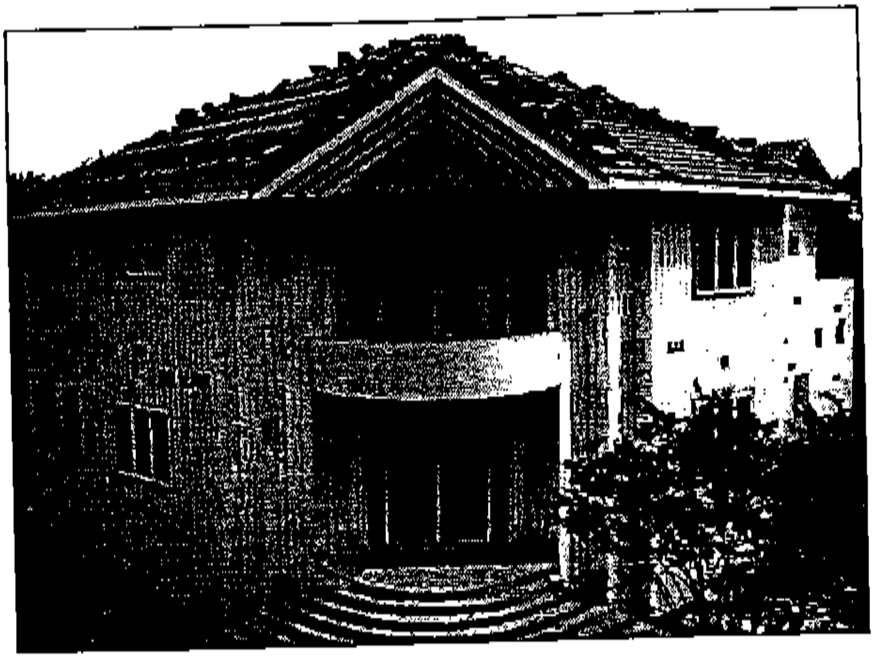


Fig. 5 Home Constructed of ICF's After Exterior Finish is Applied (PCA No. 67366)

Analysis for Model Energy Code Provisions

The Model Energy Code (MEC) is the model code which 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 (Table 502.1.2a,b,c) which depend on heating degree days and are designed to produce a total annual heating and cooling load equal to the light wall. The MEC mass wall tables were developed by Jeff Christian at Oak Ridge National Laboratory and accepted into the MEC in 1988. A major objective of this study is to determine whether these tables fairly represent the performance of ICF walls, and if not propose an alternate approach.

Approach

We have used computer simulations 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 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 we calculated an equivalent U-factor which is the U-factor of a wood stud wall with the same total annual load. The simulation analysis is consistent with the approach used by Christian at ORNL to develop the current MEC mass wall tables. We updated the house prototype, the weather data and the simulation models to the best currently available technology and expanded the simulation analysis to include both DOE2.1E and BLAST.

Prototype

The prototype house used in the simulation analysis is a 1540 square foot single story, slab on grade house. The house used in the analysis 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 by Huang at Lawrence Berkeley National Laboratory to develop the PEAR database, source of energy data for the ASHRAE 90.2-1993 standard development. It is similar to Christian's prototype which was also derived from Huang's work, but Christian used nonuniform glazing orientation.

Weather

The Typical Meteorological Year (TMY2) data set derived from 1961-1990 data for Miami, Phoenix, Atlanta, Sacramento, Sterling WV (Washington, DC), Denver, and Minneapolis was used in the simulation. The cities used are the same as those used by Christian with the addition of Sacramento.

Simulation Models

We carried out the simulations using DOE2.1E, the latest version of the program used to create the original MEC mass tables, and BLAST, a program developed by the US Army which features a more fundamental (and presumably more accurate) approach to calculating dynamic loads. The BLAST loads model has been selected by the US Department of Energy for inclusion in EnergyPlus, DOE's next generation simulation program.

Walls

All the ICF walls were modeled as constructions with 4 layers. The inside layer was 1/2-in. 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 140 lb/ft3 and specific heat 0.21 Btu/lb with a conductivity that varied. The outside layer was another foam insulation layer matching the second layer.

Stud walls were modeled with an inside layer of 1/2-in. gypsum board identical to the one in the ICF wall. The next layer was 2 by 4 wood studs at 16 inches on center with insulation in the cavity of either R-11 or R-13. 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 (R=1.32) or foam insulation to provide lower U-factor walls.

Energy Results
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. Results for ICF walls with slightly different mass and thermal resistance properties showed similar effects.

Comparison with MEC
The U-factors for ICF walls with performance equivalent to a wood stud wall with a U-factor of 0.06 are plotted in Figs. 6 and 7 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. Based on this results we recommend that ICF compliance be based on the factors in the MEC table for interior insulation position.

Fig. 6 Comparison of BLAST ICF Equivalent U-factors with the MEC

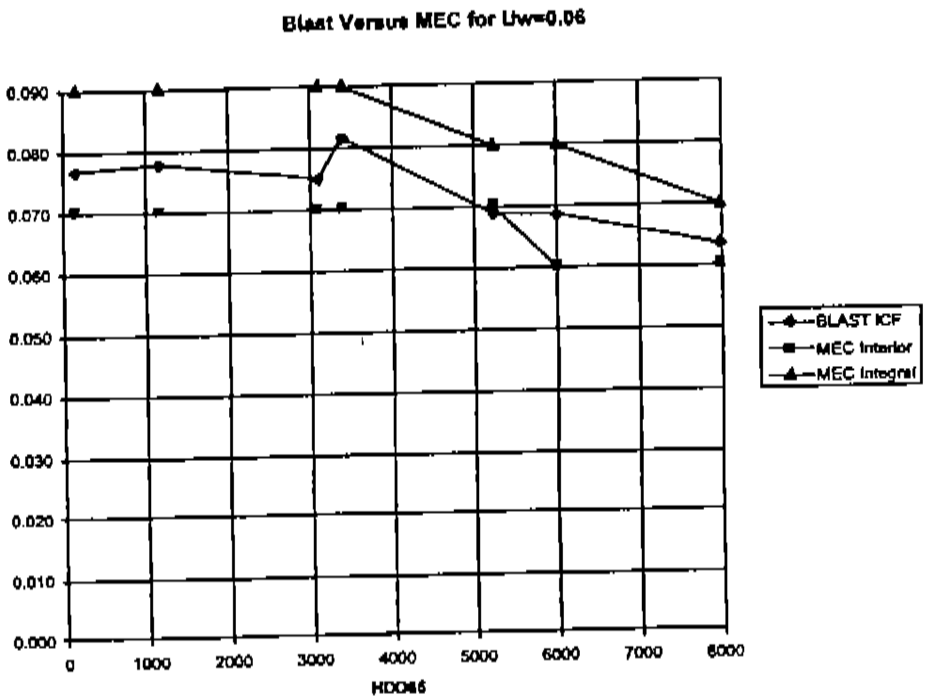
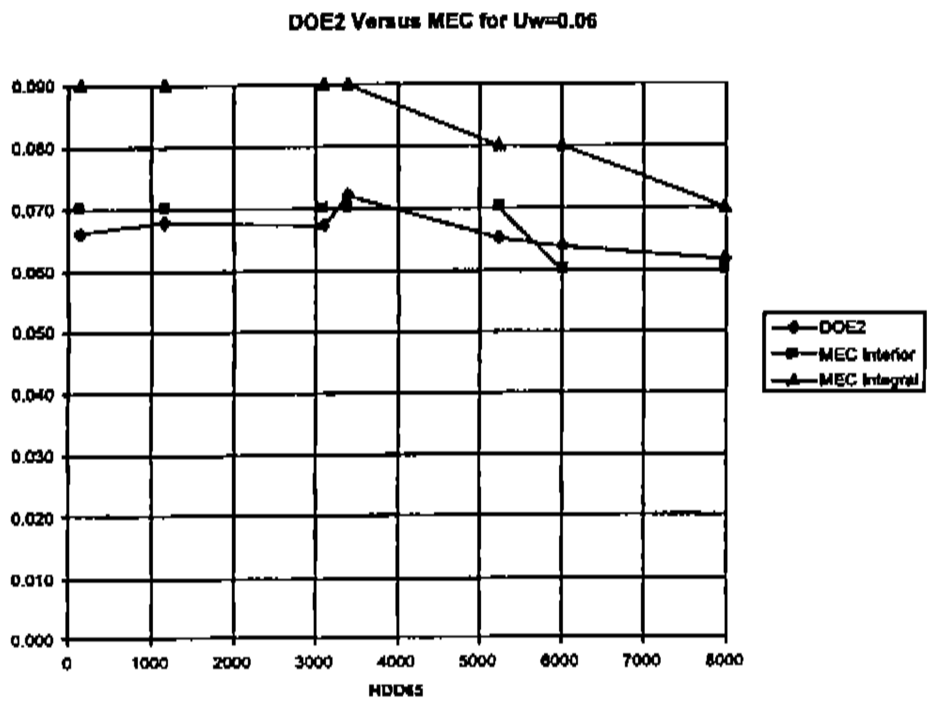


Fig. 7 Comparison of DOE2 ICF Equivalent U-factors with the MEC



15 YEARS OF PROGRESS

Analysis for Manual J

Manual J, a publication of the Air Conditioning Contractors of America, contains the standard equipment sizing method used by the residential HVAC industry. The current (1986) edition contains procedures derived from the ASHRAE Handbook reformatted for simplicity. Manual J Table 7-4 provides Equivalent Temperature Differences (ETD) 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. ETD's are tabulated for different design temperatures and daily temperature ranges. The table provides ETD's for 2 types of exterior walls ìframe and veneer-on-frameî and ìMasonry walls, 8-in block or brickî

ICF ETD's

BSG derived calculated peak cooling loads for ICF and frame walls for the 240 locations in the Typical Meteorological Year 1961-1990 (TMY2) data set using the BLAST and DOE2 simulation programs. By comparing the peak loads for frame walls and ICF walls BSG calculated ETD's for ICF walls shown in Table 1. These ETD factors are usable in calculating cooling loads for ICF wall homes in the standard Manual J sizing method. Values in the existing Manual J for ìFrame and veneer-on-frameî and ìMasonry walls, 8-in block or brickî are also presented in Table 1. Since the cooling load per square foot of wall is simply the wall U-factor times the ETD, the smaller values for ICF walls in Table 1 reflect the benefits of thermal mass in the ICF walls.

Table 1 is formatted according to Table 7-4 of Manual J. The Design Temperature Difference is the difference between the indoor temperature and the outdoor temperature at the cooling design condition. Daily Temperature Range is the difference between the average daily low and high temperature in the hottest month. L stands for low daily range of 15 degrees F or less. M or medium is for a daily range of 15 to 25 degrees. H is for locations with a high daily range of 25 degrees or more. The summer daily ranges for United States and Canadian locations are listed in Table 1 of Manual J.

ICF ETD's

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).

$$\text{HTM (cooling)} = \text{ETD} \times U \qquad \text{(Eq. 1)}$$

where:

HTM	=	Heat transfer multiplier; heat flow through one sq ft of a wall at a given temperature difference, Btu/hr-ft^2
ETD	=	Equivalent temperature difference (summer), °F
U	=	Thermal transmittance of component, Btu/hr-ft^2-°F

The HTM for any wall is the ETD from Table 1 multiplied by the U-factor. Typical HTM values for ICF walls are presented in Table 2. The values for ICF walls in Table 2 are consistent with values in Table 4 of Manual J. Values for ICF walls in Table 2 are for flat panel systems with no metal ties. For systems with irregular 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 HTM's include the effects of thermal mass and solar radiation (see footnote 5 to Manual J, Table 4.)

Summary and Conclusions

The DOE2 results show ICF walls have thermal mass characteristics represented by the MEC interior insulation table. The BLAST results show larger mass effects.

Manual J provides Equivalent Temperature Differences (ETD's) and Heat Transfer Multiplier (HTM's) 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. ETD's for ICF walls are presented in Table 1. The HTM for any wall is the ETD from Table 1 multiplied by the U-factor. Typical HTM values for ICF walls are p_937114217

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Table 1 - Equivalent Temperature Differences (ETD's) for Exterior Walls

Design Temperature Difference, °F	10		15			20			25		30	35
Daily Temperature Range	L	M	L	M	H	L	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
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
Frame and Veneer-on-frame Walls	17.6	13.6	22.6	18.6	13.6	27.6	23.6	18.6	28.6	23.6	28.6	33.6

Table 2 - Heat Transfer Multipliers (HTM's) for Cooling for ICF Walls (an addition to Table 4 of Manual J)

No. 14 - Insulated Concrete Form (ICF) Walls Finished - Above Grade	10		15			20			25		30	35	U
	L	M	L	M	H	L	M	H	M	H	H	H	
	HTM (Btuh per sq. ft.)												
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