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ENERGY USE IN RESIDENTIAL HOUSING: A COMPARISON OF INSULATING CONCRETE FORM AND WOOD FRAME WALLS

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KEYWORDS

Concrete, energy, housing, insulating concrete forms, ICF, modeling, wood

ABSTRACT

A typical 228 square meter (2,450 square foot) residential house with a contemporary design was modeled for energy consumption in five locations. Locations were selected to represent a range of climates across the United States. Energy simulation software utilizing the DOE 2.1E calculation engine was used to perform the modeling.

In each location, three variations of the house were modeled. The first variation utilized conventional wood framed exterior walls constructed with typical materials. The second variation utilized insulating concrete form (ICF) walls. The third variation had non-mass exterior walls that met minimum energy code requirements. For all variations, all other assemblies such as the roof, floors, windows, and interior partitions were identical. In all locations, the house variations were insulated to meet the minimum levels required in the 1998 International Energy Conservation Code (IECC).

Due to the inherent insulating properties of the ICFs, total energy use (including heating and cooling, cooking, laundry, and other occupant energy) for houses with ICF walls ranged from 8 to 19% below that of the houses with walls that met IECC requirements. Houses with wood frame walls constructed with standard materials also showed total energy saving over that of houses with walls that met IECC requirements. In all locations, houses with ICF walls had total energy requirements that ranged from 5 to 9% below that of houses with wood frame walls.

Houses with ICF walls also showed additional savings resulting from a reduction in the required heating, ventilation, and cooling (HVAC) system capacity. Total system capacity for houses with ICF walls ranged from 16 to 30% less than that of houses with walls that met IECC requirements and 14 to 21% less than that of houses with wood frame walls.

REFERENCE

Gajda, John, and VanGeem, Martha, *Energy Use in Residential Housing: A Comparison of Insulating Concrete Form and Wood Framed Walls*, R&D Serial No. 2415, Portland Cement Association, 2000, 17 pages.

ENERGY USE IN RESIDENTIAL HOUSING: A COMPARISION OF INSULATING CONCRETE FORM AND WOOD FRAME WALLS

by John Gajda and Martha VanGeem*

INTRODUCTION

Energy consumption of a 228 square meter (2,450 square foot) residential house with a contemporary design was modeled in five locations across the United States to compare energy use with three exterior wall variations. The first variation utilized conventional 2x4 wood framed exterior walls constructed with typical materials. The second variation utilized insulating concrete form (ICF) walls. The third variation utilized non-mass exterior walls that met prescribed minimum energy code requirements. For all variations, all other assemblies such as the roofs, floors, windows, interior partitions, and heating, ventilation, and cooling (HVAC) systems were identical.

In all locations, the house variations were insulated to meet the minimum levels required in the 1998 International Energy Conservation Code (IECC)[1] using standard construction materials. The IECC was selected as the energy code for the modeling because it is the most widely used and current energy code. The IECC uses heating degree-days as the basis for determining the minimum insulation requirements.

Five climates, representing the various general climates of the United States, were selected for modeling. Phoenix, AZ was selected as a hot dry climate with large temperature swings where thermal mass works well. Miami, FL was selected as a hot humid climate with lower temperature swings where thermal mass works almost as well. Washington, DC and Seattle, WA were selected as moderate climates. Chicago, IL was selected as a cold climate. Select climate data are summarized in Table 1.

Modeling was performed using Visual DOE 2.6 energy simulation software[2]. This software uses the United States Department of Energy DOE 2.1-E hourly simulation tool as

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the calculation engine so that hourly energy usage and peak demand are accurately simulated and evaluated over a one-year period.

Table 1 – Select Climate Data

Location	Heating Degree Days[3]		Average Annual Temperature[2]		Annual Average Daily Temperature Swing[2]	
	Base 18°C	Base 65°F	°C	°F	°C	°F
Miami	111	200	24	76	7	12
Phoenix	750	1350	23	73	14	26
Seattle	2562	4611	11	52	8	14
Washington DC	2615	4707	13	55	11	19
Chicago	3631	6536	10	50	10	18

HOUSE DESCRIPTION

The residential house used in the modeling was designed by CTL and was based on typical designs currently being constructed in the United States. The house was a two-story single-family building with four bedrooms, 2.7-m (9-ft) ceilings, a two-story foyer and family room, and an attached two-car garage. The house has 228 square meters (2,450 square feet) of living space, which was somewhat larger than the 1998 U.S. average of 203 square meters (2,190 square feet).[4] The size of the house was based on the average size of ICF houses constructed in the United States.[5] Figures 1 and 2 present the floor plans.

In an effort to simplify the analyses and to be able to compare energy use across all locations, typical regional construction material variations were not considered. All houses were assumed to be of slab-on-grade construction. Windows were primarily located on the front and back facades. The overall window-to-exterior wall ratio was 16%. The exterior finish of all exterior walls was assumed to consist of medium colored aluminum siding. Roofs were assumed to be medium colored asphalt shingles. Figures 3 through 6 present the front, back, and side facades.

ASSUMPTIONS

Building components were selected to meet the minimum requirements of the IECC using standard construction materials. IECC minimum requirements (maximum U-factors) are presented in Table 2.

Roofs were assumed to be of wood frame construction with R_{si}-3.3, R_{si}-5.3, R_{si}-6.7 (R19, R-30, or R-38) fiberglass batt insulation. Interior walls were assumed to be of wood frame construction and uninsulated. Interior floors were assumed to be carpeted wood framed assemblies without insulation.

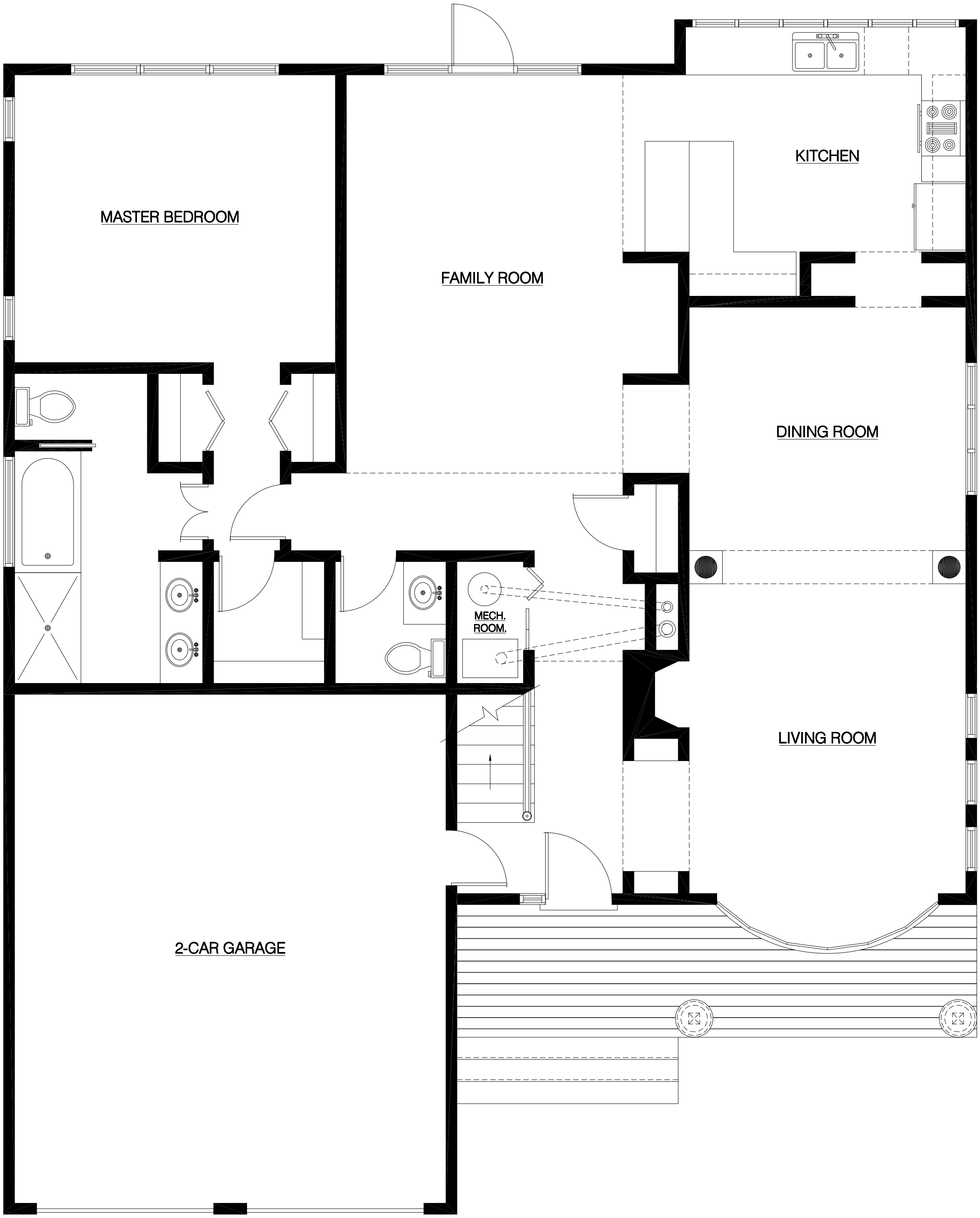

Figure 1 - Floor Plan of the Lower Level

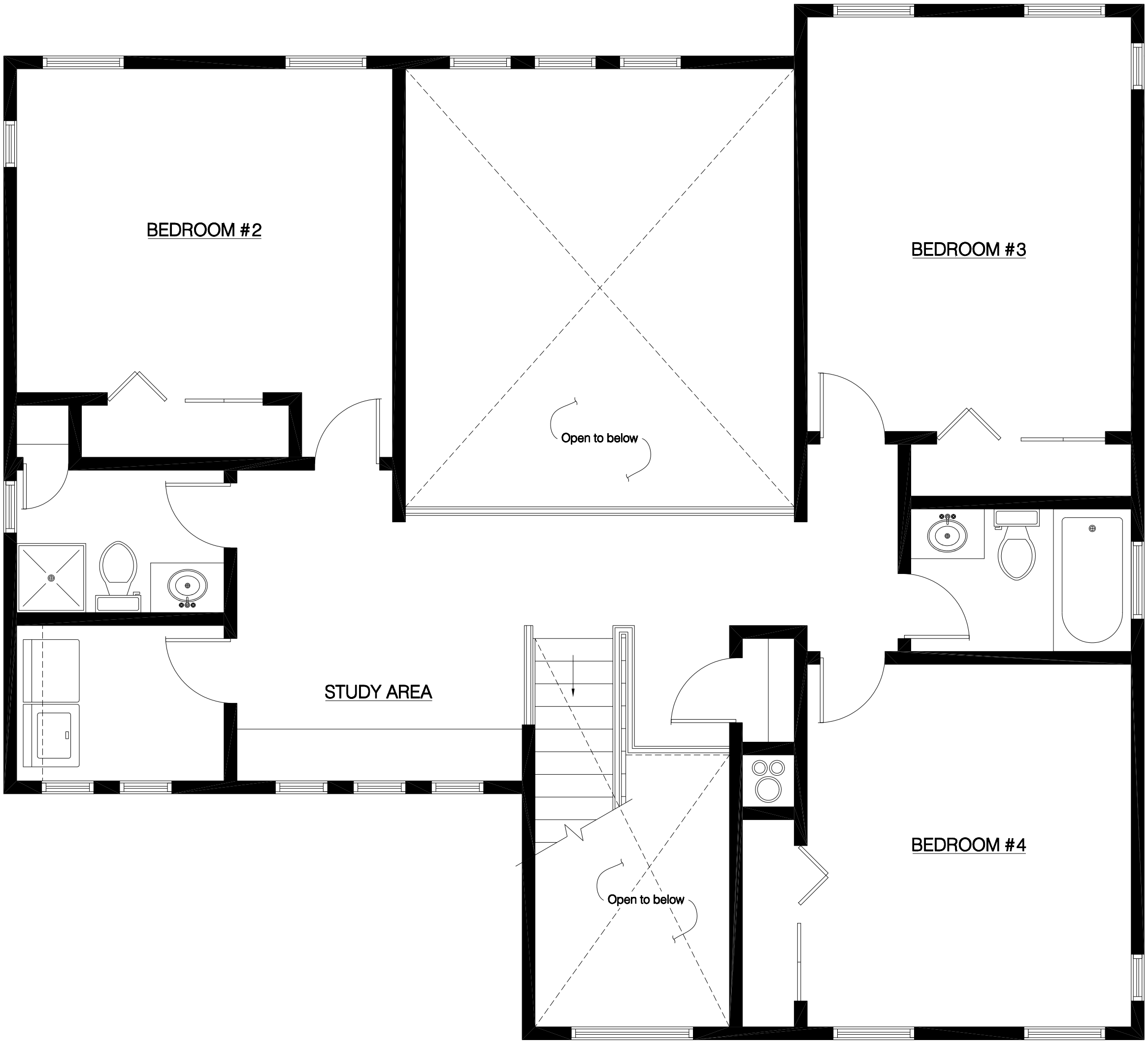

Figure 2 - Floor Plan of the Upper Level

Figure 3 – Front Elevation

Figure 4 – Rear Elevation

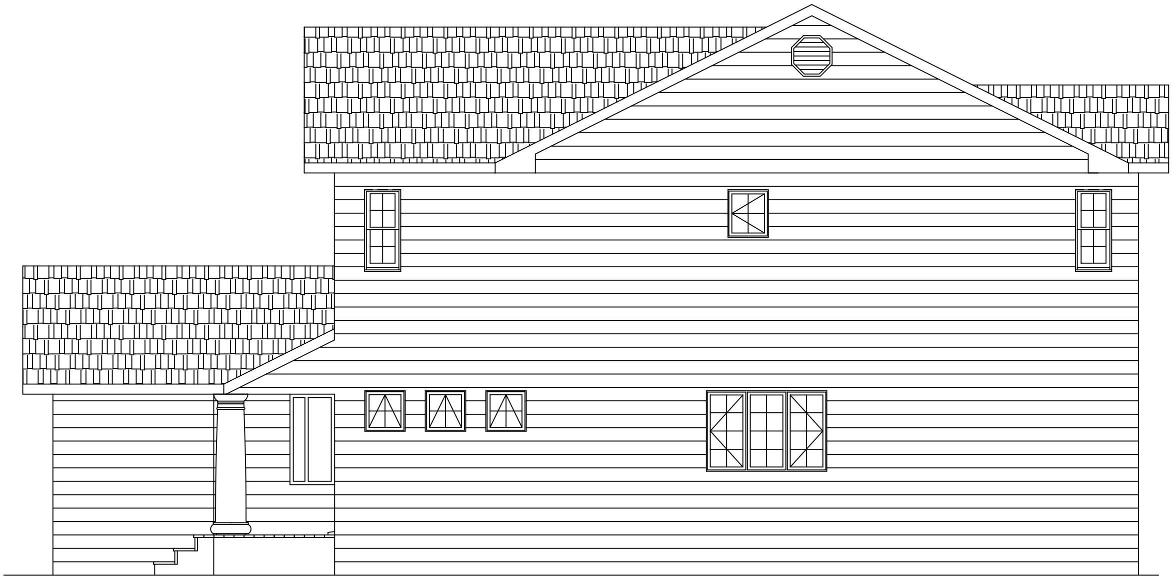

Figure 5 – Right Elevation

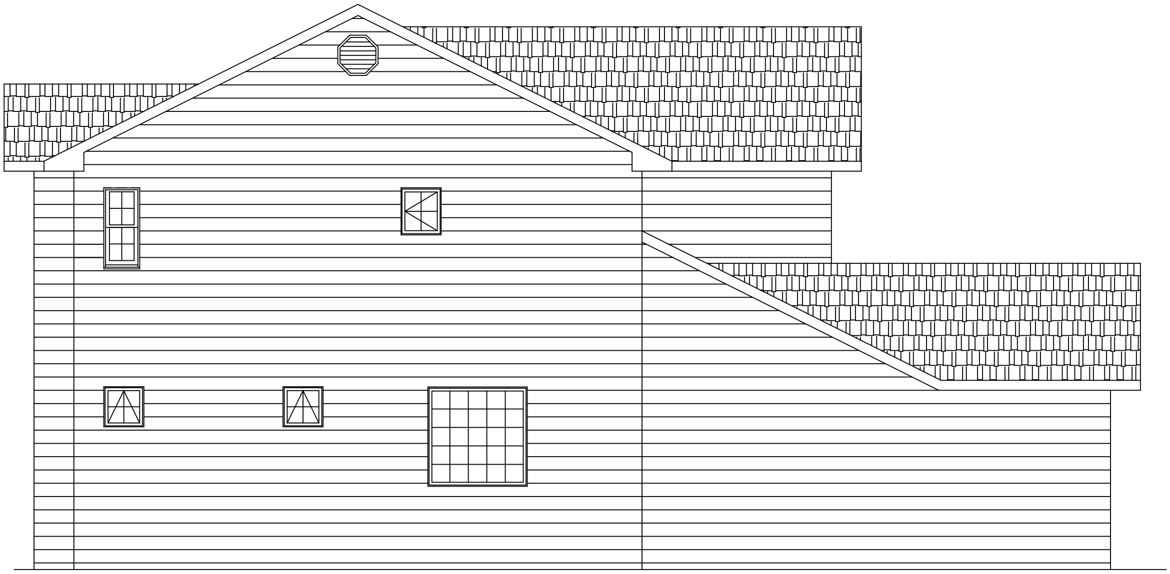

Figure 6 – Left Elevation

The IECC requires perimeter insulation for slabs-on-grade in most locations. Energy modeling software that is commonly used and accepted cannot model perimeter insulation; therefore, perimeter or under-slab insulation was not utilized. The slab-on-grade floor was assumed to consist of carpeted 150-mm (6in.) thick normal-weight concrete cast on soil. The U-factor of the floor was 1.53 $W/m^2\cdot K$ (0.27 $Btu/hr\cdot ft^2\cdot °F$).

Table 2 – IECC Maximum U-factors*

Location	Opaque Walls**				Roof		Windows***	
	Wood Frame		Mass					
	$\frac{W}{m^2\cdot K}$	$\frac{Btu}{hr\cdot ft^2\cdot °F}$	$\frac{W}{m^2\cdot K}$	$\frac{Btu}{hr\cdot ft^2\cdot °F}$	$\frac{W}{m^2\cdot K}$	$\frac{Btu}{hr\cdot ft^2\cdot °F}$	$\frac{W}{m^2\cdot K}$	$\frac{Btu}{hr\cdot ft^2\cdot °F}$
Miami	0.937	0.165	1.164	0.205	0.278	0.049	4.2	0.74
Phoenix	0.960	0.169	1.187	0.209	0.238	0.042	2.4	0.47
Seattle	0.653	0.115	0.750	0.132	0.187	0.033	1.7	0.30
Washington DC	0.642	0.113	0.732	0.129	0.182	0.032	1.7	0.30
Chicago	0.466	0.082	0.466	0.082	0.148	0.026	1.6	0.28

* The maximum U-factor is the inverse of the minimum R-value.
** Calculated based on the house design and the window U-factors prescribed by the IECC.
*** The IECC also requires windows have a solar heat gain coefficient (SHGC) of less than 0.4 in Miami and Phoenix.

Three variations were assumed for exterior walls. The wood framed variation was assumed to consist of medium colored aluminum siding, 12-mm (½-in.) plywood, R_{si}-1.9 (R-11) fiberglass batt insulation, and 12-mm (½-in.) painted gypsum board. The ICF variation was assumed to consist of medium colored aluminum siding, a typical flat panel ICF system with 50 mm (2 in.) of expanded polystyrene, 150 mm (6 in.) of normal weight concrete, and 50 mm (2 in.) of expanded polystyrene with plastic ties, and 12-mm (½-in.) painted gypsum board. The code matching variation was a fictitious wall section with no thermal mass and a U-factor selected to match the IECC requirements for the specific locations modeled. For all variations, the common wall between the house and the garage and all exterior garage walls except the front wall (with the overhead doors) were assumed to be identical to that of the exterior walls of the house. The wall with the overhead doors was assumed to be a low-mass light-colored wall with a U-factor of 2.8 $W/m^2\cdot K$ (0.50 $Btu/hr\cdot ft^2\cdot °F$).

Two window types were utilized to meet the IECC requirements for solar heat gain coefficient (SHGC) and U-factor. Again, for a given location, each variation had identical windows. All windows consisted of double pane glass with a low-E coating. To meet the SHGC requirement, windows in Miami and Phoenix were assumed to be tinted and had air as the gap gas. Windows in Seattle, Washington DC, and Chicago were not tinted and had argon as the gap gas. Interior shades or drapes were assumed to be closed during periods of high solar heat gains. Houses were assumed to be located in new developments without trees or any other means of exterior shading.

Table 3 presents actual assembly U-factors used in the analyses. In most cases, use of typical construction materials resulted in assemblies that greatly exceeded the IECC Ufactor requirements.

Table 3 – Actual Assembly U-Factors*

Location	Walls				Roof**		Windows	
	Wood Frame		Mass (ICF)					
	$\frac{W}{m^2 \cdot K}$	$\frac{Btu}{hr \cdot ft^2 \cdot {}^\circ F}$	$\frac{W}{m^2 \cdot K}$	$\frac{Btu}{hr \cdot ft^2 \cdot {}^\circ F}$	$\frac{W}{m^2 \cdot K}$	$\frac{Btu}{hr \cdot ft^2 \cdot {}^\circ F}$	$\frac{W}{m^2 \cdot K}$	$\frac{Btu}{hr \cdot ft^2 \cdot {}^\circ F}$
Miami	0.47	0.082	0.31	0.055	0.27	0.048	2.4	0.43
Phoenix					0.18	0.032		
Seattle							1.5	0.27
Washington DC								
Chicago					0.15	0.026		

* The maximum U-factor is the inverse of the minimum R-value.

** R_{si}-3.3 (R-19) attic insulation was used for Miami, R_{si}-6.7 (R-38) attic insulation was used for Chicago, and R_{si}-5.3 (R-30) attic insulation was used for the remaining locations.

Hot water was assumed to be provided by a natural gas fired hot water heater with a peak utilization of 24 liters/minute (2.5 gallons/minute). The hot water load profile was taken from ASHRAE Standard 90.2.[6] The HVAC system was assumed to consist of a natural gas fired high efficiency forced air system with a high-efficiency central air conditioner. Efficiencies of the HVAC system components were assumed to be identical for all variations, in all locations.

The HVAC system was controlled by a typical residential set-back thermostat located in the family room. The cooling set-point temperature was assumed to be 24°C (75°F) from 6 AM to 10 PM and 26°C (78°F) from 10 PM to 6 AM. The heating set-point temperature was assumed to be 21°C (70°F) from 6 AM to 10 PM and 18°C (65°F) from 10 PM to 6 AM.

Occupant energy consumption for uses other than heating and cooling were assumed to be 23.36 kWh/day. This value was calculated from ASHRAE Standard 90.2[6] and assumed the house had an electric clothes dryer and electric stove. Energy costs were assumed to utilized average U.S. costs of $22.22 per GJ ($0.08 per kWh) and $5.31 per GJ ($0.56 per therm).

Air infiltration rates of the living areas were based on ASHRAE Standard 62.[7] The air infiltration rates were identical for all variations and were 0.35 air changes per hour (ACH) in the living areas of the house and 2.5 ACH in the unconditioned attached garage. This assumption implies that ICF and wood frame construction have the same air infiltration rates and if a house is tighter than 0.35 ACH, an air exchanger is installed. A family of four was assumed to live in the house.

RESULTS

Because the design of the house is subject to orientation dependent solar effects, modeling of the house was performed with the house rotated in the four cardinal (north, south, east, and west) orientations. Total energy consumption for heating, cooling, hot water, and occupant uses was averaged to produce a building orientation independent energy consumption. Results are presented in Table 4.

Table 4 – Total Annual Energy Use by Location

Location	Variation	Annual Operating Data					
		Electricity		Natural Gas		Total Energy, GJ	Energy Cost
		GJ	kWh	GJ	therms		
Miami	Wood Frame	65.3	18,130	41.1	390	106.4	$1,668
	ICF	61.1	16,979	39.6	375	100.7	$1,568
	Code Matching	72.5	20,128	42.5	403	115.0	$1,836
Phoenix	Wood Frame	75.6	21,001	69.5	659	145.1	$2,049
	ICF	70.2	19,498	63.6	603	133.8	$1,897
	Code Matching	86.8	24,108	77.6	736	164.4	$2,341
Seattle	Wood Frame	35.4	9,837	184.6	1,750	220.0	$1,767
	ICF	34.6	9,605	165.7	1,571	200.3	$1,648
	Code Matching	35.9	9,965	196.8	1,866	232.7	$1,842
Washington DC	Wood Frame	43.4	12,065	170.2	1,614	213.7	$1,869
	ICF	41.5	11,516	155.7	1,476	197.1	$1,748
	Code Matching	43.8	12,158	181.0	1,716	224.8	$1,933

Chicago	Wood Frame	41.5	11,541	214.4	2,033	256.0	$2,062
	ICF	39.8	11,056	195.5	1,853	235.3	$1,922
	Code Matching	41.7	11,587	214.9	2,037	256.6	$2,067

Table 5 compares the total energy use of the wood frame and ICF variations to the code matching variation. Also presented are the U-factors of the wood frame and ICF variations in comparison to the code requirements. Figure 7 presents the total energy use of the wood frame and ICF variations to the code matching variation. Figure 8 presents the U-factors of the wood frame and ICF variations in comparison to the code requirements.

From the data presented in Table 5 and Figures 7 and 8, it is evident that the ICF variation had significant total energy savings over the code matching and wood framed walls. These savings compared the total building energy use, not just that for heating and cooling. Total energy use of houses with ICF walls ranged from 8 to 19% below that of the houses with code matching walls. Additionally, significant energy savings for the ICF house, ranging from 5 to 9%, were noted compared to the wood frame house. It is important to note that these savings are based on total energy use, not energy costs. Because of the large cost difference per GJ between electricity and natural gas, cost savings will be more significant.

In these comparisons, the ICF variation was a standard ICF wall configuration while the wood framed variation was insulated using standard materials to meet IECC requirements. In all cases, except the wood framed variation in Chicago, ICF and wood frame wall Ufactors significantly exceeded the IECC requirements. Wood frame walls had U-factors that ranged from 0 to 106% in excess the IECC requirements, while ICF walls had Ufactors that ranged from 49 to 207% in excess the IECC requirements.

Table 5 – Comparison of Total Energy and U-Factors

Location	**Variation**	**Annual Energy Use, % Below the Code Matching Variation**	**Actual Wall U-Factor, % in Excess of the Code Matching Variation**
Miami	Wood Frame	8%	101%
	ICF	12%	200%
Phoenix	Wood Frame	12%	106%
	ICF	19%	207%
Seattle	Wood Frame	5%	40%
	ICF	14%	109%

Washington DC	Wood Frame	5%	38%
	ICF	12%	105%
Chicago	Wood Frame	0%	0%
	ICF	8%	49%

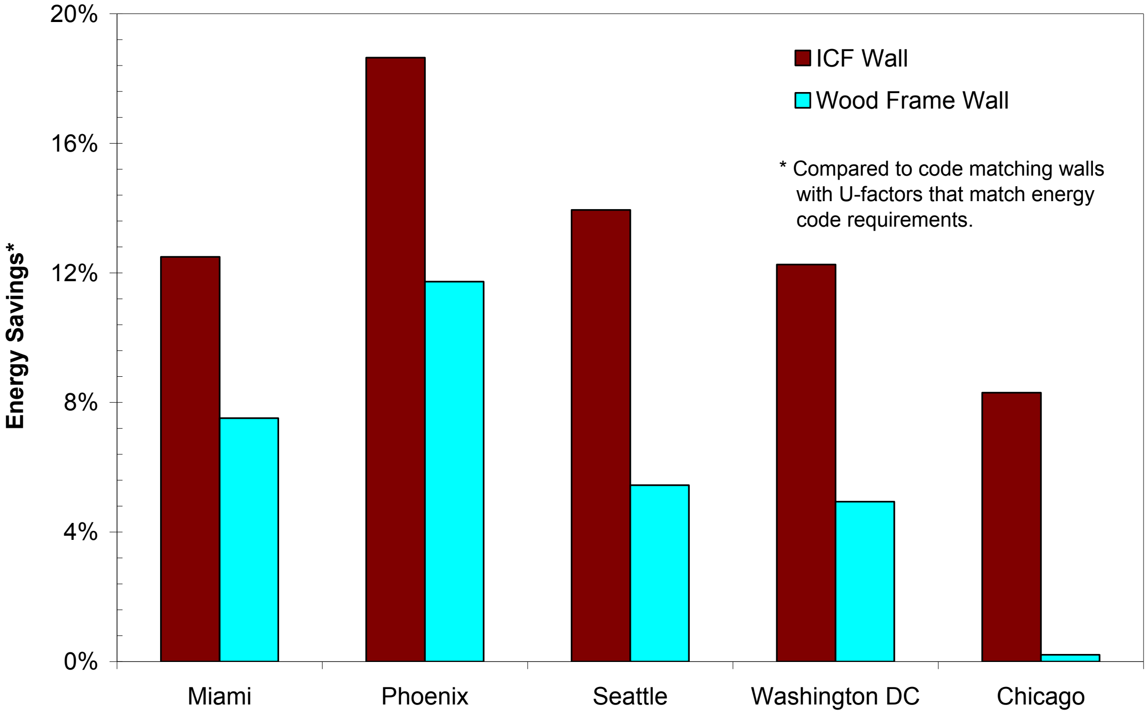

Figure 7 – Comparison of Total Energy Savings

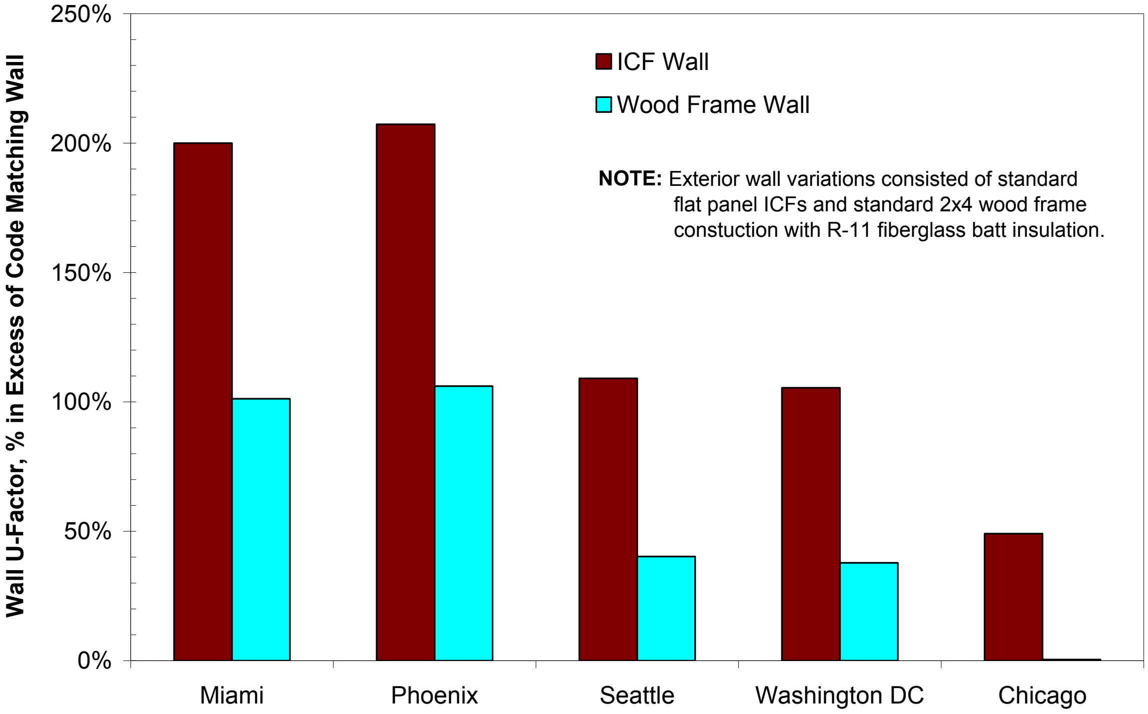

Figure 8 – Comparison of Wall U-Factors

It is important to note that the only difference between house variations for a given location is the exterior wall assembly and the capacity of the HVAC system. The HVAC system capacities were automatically sized by the analysis software and are presented in Table 6. Results indicate that thermal mass moderates temperature swings and peak loads resulting in lower HVAC system capacities. The apparent excessive capacity for all house variations in Phoenix is due to the large daily temperature swing.

Table 6 – HVAC System Capacities as Determined by the Energy Simulation Software

Location	Variation	System Capacity			
		Heating		Cooling	
		kW	kBtu/hr	kW	kBtu/hr
Miami	Wood Frame	25	87	13	44
	ICF	21	73	11	37
	Code Matching	31	105	15	53
	Wood Frame	35	119	21	70

Phoenix	ICF	30	103	18	61
	Code Matching	42	144	25	84
Seattle	Wood Frame	26	90	14	46
	ICF	21	71	11	36
	Code Matching	28	97	15	50
Washington DC	Wood Frame	27	93	14	48
	ICF	23	79	12	41
	Code Matching	29	100	15	52
Chicago	Wood Frame	26	90	14	46
	ICF	22	76	12	39
	Code Matching	27	91	14	46

Figure 9 presents the reduction in total HVAC system capacity in the ICF and wood frame house variations in comparison to the code matching house variation. Comparison of the HVAC system capacities of the ICF and wood frame house variations revealed that the HVAC capacity for the ICF variation ranged from 14 to 21% less than that of the wood frame house variation and 16 to 30% lass than houses that meet the IECC requirements. It is important to note that natural gas fired high efficiency forced air furnaces are typically available in 5.9 kW (20 kBtu/hr) capacity increments and high-efficiency central air conditioners are typically available in 1.8 to 3.5 kW (6 to 12 kBtu/hr [½ to 1 ton]) capacities. Because HVAC systems are typically oversized (the installed capacity is the required capacity rounded to the next larger available capacity), actual installed system capacity savings will be different.

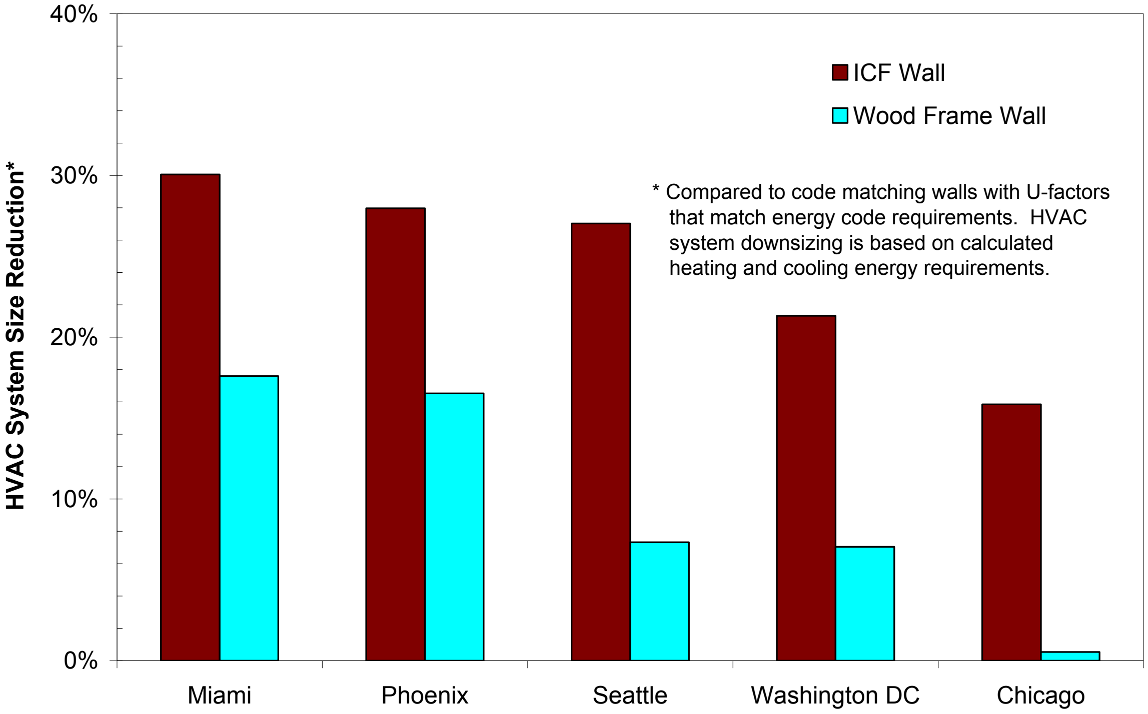

Figure 9 – Comparison of HVAC System Capacities

SUMMARY AND CONCLUSIONS

Energy consumption was modeled for a 228 square meter (2,450 square foot) single-family house with a contemporary design in five locations across the United States to compare the effects of exterior wall variations. Modeling was performed using energy simulation software that uses the DOE 2.1-E calculation engine so that hourly energy usage and peak demand are accurately simulated and evaluated over a one year period using average annual weather data.

In all locations, building components such as roofs, walls, and windows were selected or insulated to meet the minimum levels required in the 1998 International Energy Conservation Code (IECC) using standard construction materials. Exterior wall variations consisted of conventional wood framed exterior walls constructed with standard materials, flat panel insulating concrete form (ICF) walls with plastic ties, and a fictitious non-mass exterior wall that met prescribed minimum IECC requirements.

Modeling was performed so that the only differences between house variations for a given location were the exterior wall assembly and the capacity of the HVAC system. The HVAC system capacity was automatically sized by the analysis software.

Results indicated that the inherent insulating capacity of the standard ICF walls greatly exceeds minimum IECC requirements. Wood frame walls constructed with standard construction materials also exceed the minimum requirements of the IECC, but to a lesser degree. In all cases, houses with the standard ICF wall had greater energy savings than that of the houses with standard wood framed walls. Energy savings of houses with ICF walls ranged from 8 to 19% greater than that of the houses with code matching walls and 5 to 9% greater than the houses with wood frame walls.

Houses with ICF walls also showed additional savings from a reduction in the required HVAC system capacity. Total system capacity for houses with ICF walls ranged from 16 to 30% less than that of the houses with code matching walls and 14 to 21% less than that of the houses with wood frame walls.

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