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ENERGY USE IN RESIDENTIAL HOUSING: A COMPARISON OF LIGHTWEIGHT CONCRETE MASONRY AND WOOD FRAME WALLS

by John Gajda and Martha VanGeem

KEYWORDS

Concrete, CMU, energy, expanded aggregate, housing, lightweight, masonry, 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 lightweight concrete masonry unit (CMU) walls. Lightweight CMU utilizes expanded aggregate*, rather than traditional mined or quarried aggregate. 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 with typical materials to meet the minimum levels required in the 1998 International Energy Conservation Code (IECC).

In all locations, the lightweight CMU and wood framed exterior wall variations exceeded the minimum requirements of the IECC. In most locations, the wall variations were comparably over-insulated; however, because of the lack of low R-value fiberglass batt insulation products, the wood frame wall in one location was significantly over-insulated. Comparing locations with comparably insulated walls revealed that houses with lightweight CMU walls had greater energy savings than that of the houses with comparably insulated standard wood framed walls. Total energy use, including heating and cooling, cooking, laundry, and other typical occupant energy uses, of houses with lightweight CMU walls ranged from 4 to 5% below that of houses with wood frame walls.

Linear relationships were noted between the effect of over insulation and energy savings of wood frame and lightweight CMU walls. For wood frame walls, the relationship showed that for every 10% increase in the wood frame wall insulation level, total energy savings increased by 1%. A similar relationship was noted for the lightweight CMU wall (in a majority of locations), however, total energy savings were approximately 4% higher

* Expanded aggregate is manufactured by processing select minerals such as shale, clay, or slate in a rotary kiln at temperatures over 1000°C (1800°F). The resulting product has a density that is considerably less than that of traditional mined or quarried aggregate.

for lightweight CMU walls than for wood frame walls. This indicates that when wood frame and lightweight CMU walls have insulation levels equal to that required by the IECC for low mass walls, houses with lightweight CMU walls have energy savings of approximately 4% over that of identical houses with wood frame walls.

Houses with lightweight CMU walls also showed non-energy related savings from a reduction in the required heating, ventilation, and cooling (HVAC) system capacity. Total system capacity for houses with lightweight CMU walls ranged from 12 to 28% less than that of the houses with walls that matched the IECC requirements and 11 to 13% less than that of the houses with wood frame walls in locations where wood frame walls were not significantly over-insulated.

The benefits of thermal mass moderating indoor temperature and peak heating and cooling loads are illustrated by the reduced overall energy use and required HVAC system capacities of houses with lightweight CMU walls compared that of wood frame walls.

In one location, a sensitivity analysis was performed to assess the effects of air infiltration on total energy consumption. Results indicated that small but reasonable changes in air infiltration, from 0.25 to 0.45 air changes per hour, had only minor effects on the total energy use in the modeled houses.

REFERENCE

Gajda, John, and VanGeem, Martha, *Energy Use in Residential Housing: A Comparison of Lightweight Concrete Masonry and Wood Framed Walls*, R&D Serial No. 2439, Portland Cement Association, 2000, 22 pages.

ENERGY USE IN RESIDENTIAL HOUSING: A COMPARISION OF LIGHTWEIGHT CONCRETE MASONRY 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 lightweight concrete masonry unit (CMU) walls. Lightweight CMU utilizes expanded (manufactured) aggregate†, rather than traditional quarried or mined aggregate. The third variation utilized non-mass exterior walls that met prescribed minimum energy code requirements for non-mass walls. 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. Tampa, Florida was selected as a hot humid climate. El Paso, Texas was selected as a hot dry climate. Knoxville, Tennessee was selected as a moderate climate. Providence, Rhode Island and Detroit, Michigan were selected as cold climates.

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† Expanded aggregate is manufactured by processing select minerals such as shale, clay, or slate in a rotary kiln at temperatures over 1000°C (1800°F). The resulting product has a density that is considerably less than that of traditional mined or quarried aggregate.

El Paso has large temperature swings where thermal mass works well. 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 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
Tampa	403	725	22	71	10	18
El Paso	1504	2708	18	64	15	27
Knoxville	2187	3937	15	58	10	19
Providence	3269	5884	10	50	9	17
Detroit	3426	6167	9	48	10	17

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 concrete houses constructed in the United States, as reported by the Portland Cement Acssociation.[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 wood frame walls was assumed to consist of medium colored aluminum siding. The exterior finish of the lightweight CMU walls was assumed to consist of stucco. The absorptance, the fraction (or percent) of solar radiation absorbed by the exterior surface, was assumed to be identical for all exterior walls. 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.

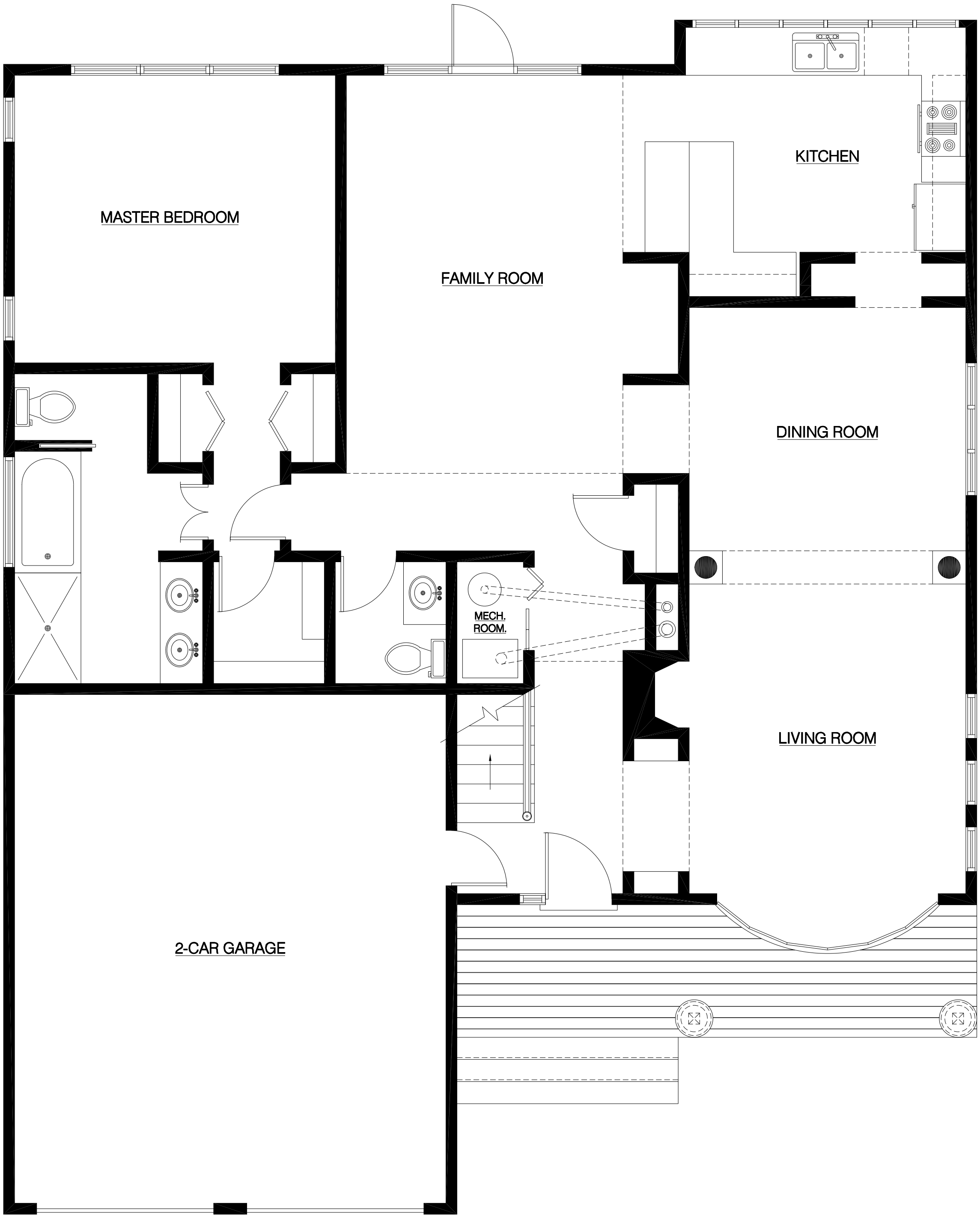

Figure 1 - Floor Plan of the Lower Level

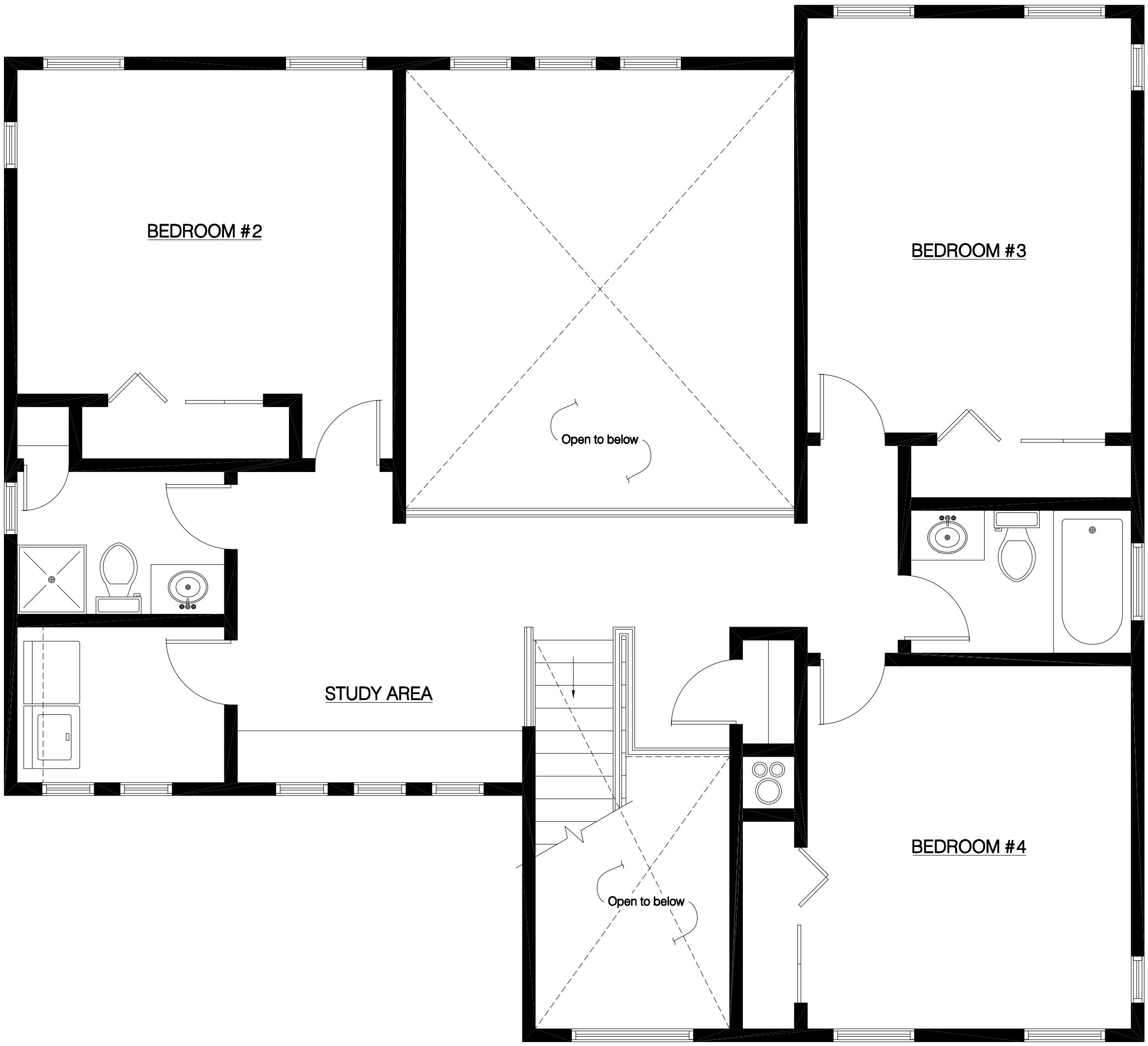

Figure 2 - Floor Plan of the Upper Level

Figure 3 – Front Elevation

Figure 4 – Rear Elevation

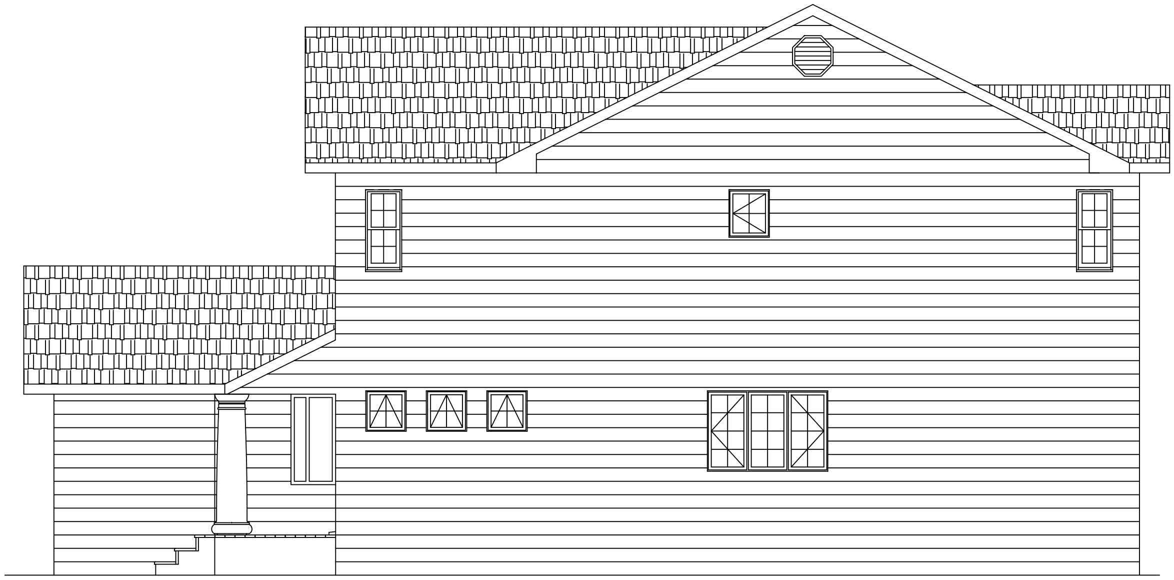

Figure 5 – Right Elevation

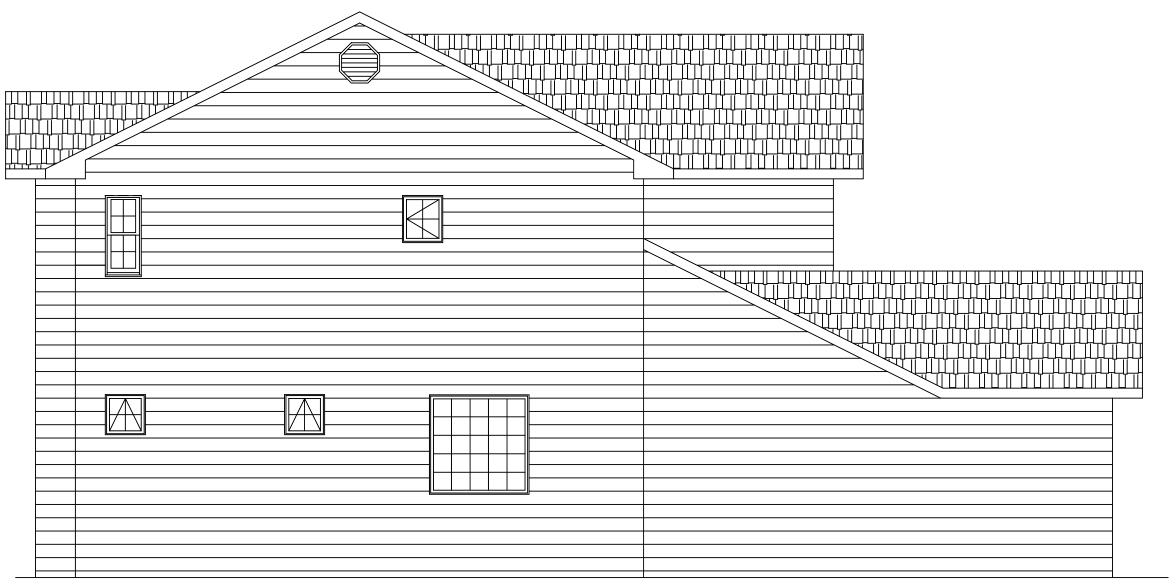

Figure 6 – Left Elevation

Table 2 – IECC Maximum U-factors*

Location	Opaque Walls**				Roof		Windows***	
	Wood Frame		Mass					
	$\frac{W}{m^2 \cdot K}$	$\frac{Btu}{hr \cdot ft^2 \cdot °F}$	$\frac{W}{m^2 \cdot K}$	$\frac{Btu}{hr \cdot ft^2 \cdot °F}$	$\frac{W}{m^2 \cdot K}$	$\frac{Btu}{hr \cdot ft^2 \cdot °F}$	$\frac{W}{m^2 \cdot K}$	$\frac{Btu}{hr \cdot ft^2 \cdot °F}$
Tampa	1.107	0.195	1.374	0.242	0.261	0.046	2.7	0.47
El Paso	0.704	0.124	0.818	0.144	0.204	0.036	2.5	0.44
Knoxville	0.602	0.106	0.715	0.126	0.204	0.036	2.3	0.41
Providence	0.517	0.091	0.574	0.101	0.153	0.027	1.7	0.30
Detroit	0.488	0.086	0.545	0.096	0.148	0.026	1.7	0.30

* 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 Tampa and El Paso.

Roofs were assumed to be of wood frame construction with R_{si}-5.3 or R_{si}-6.7 (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.

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·K (0.27 Btu/hr·ft^2·°F).

Three variations were assumed for exterior walls. Due to the wide range of climates, wall variations required different levels of insulation in different locations. For all locations, 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 12mm (½in.) painted gypsum board.

The lightweight CMU variation for all locations except Tampa was assumed to consist of 16-mm (⅝in.) thick light-colored portland cement stucco, 200-mm (8-in.) lightweight CMU with partly grouted uninsulated cells*, wood furring with R_{si}-1.9 (R-11) fiberglass batt insulation, and 12-mm (½-in.) painted gypsum board. The lightweight CMU variation for Tampa was assumed to be identical, except the wall assembly did not contain fiberglass

* "Partly grouted uninsulated cells" means that some CMU cells were grouted, while others were empty (did not contain insulation or grout). Grouted cells typically contain reinforcing steel. The ratio of grouted to empty cells is defined in ASHRAE Standard 90.1-1999.[3]

insulation. For all locations, the nominal unit weight of the lightweight CMU was assumed to be 1440 kg/m^3 (90 pcf) with U-factors interpolated from those presented in ASHRAE Standard 90.1-1999[3]. Figure 7 presents a sketch of the wood framed and lightweight CMU wall sections.

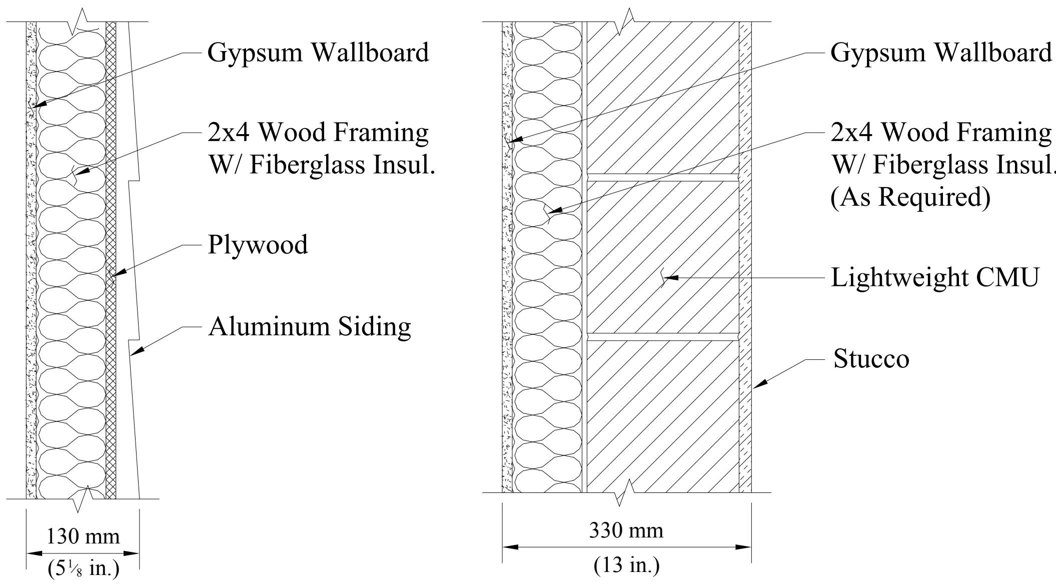

Figure 7 – Wood Framed and Lightweight CMU Walls Sections

The code matching variation was a fictitious wall section with no thermal mass and a U-factor selected to match the non-mass 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·K (0.50 Btu/hr·ft^2·°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 Tampa and El Paso were assumed to be tinted and had air as the gap gas. Windows in Knoxville, Providence, and Detroit 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 housing 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 exceeded the IECC Ufactor requirements. This is especially true for the wood framed walls in Tampa where the insulated wood framed wall was over-insulated by approximately 140%, in comparison to the IECC requirements.

Table 3 – Actual Assembly U-Factors*

<table>
<tr><th rowspan="3">Location</th><th colspan="4">Walls</th><th colspan="2" rowspan="2">Roof**</th><th colspan="2" rowspan="2">Windows</th></tr>
<tr><th colspan="2">Wood Frame</th><th colspan="2">Mass (Lightweight CMU)</th></tr>
<tr><th>$\frac{W}{m^2\cdot K}$</th><th>$\frac{Btu}{hr\cdot ft^2\cdot °F}$</th><th>$\frac{W}{m^2\cdot K}$</th><th>$\frac{Btu}{hr\cdot ft^2\cdot °F}$</th><th>$\frac{W}{m^2\cdot K}$</th><th>$\frac{Btu}{hr\cdot ft^2\cdot °F}$</th><th>$\frac{W}{m^2\cdot K}$</th><th>$\frac{Btu}{hr\cdot ft^2\cdot °F}$</th></tr>
<tr><td>Tampa</td><td rowspan="5">0.47</td><td rowspan="5">0.082</td><td>0.92</td><td>0.162</td><td rowspan="3">0.18</td><td rowspan="3">0.032</td><td rowspan="2">2.4</td><td rowspan="2">0.43</td></tr>
<tr><td>El Paso</td><td rowspan="4">0.43</td><td rowspan="4">0.076</td></tr>
<tr><td>Knoxville</td><td rowspan="3">1.5</td><td rowspan="3">0.27</td></tr>
<tr><td>Providence</td><td rowspan="2">0.15</td><td rowspan="2">0.026</td></tr>
<tr><td>Detroit</td></tr>
</table>

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

** R_{si}-5.3 (R-30) attic insulation was used for Tampa, El Paso and Knoxville. R_{si}-6.7 (R-38) attic insulation was used for Providence and Detroit.

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 setback 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 84.10 MJ/day (23.36 kWh/day). This value was derived from ASHRAE Standard 90.2[6] assuming a family of four lived in the house, and that the house had an electric clothes dryer and electric stove/oven. Energy costs were assumed to utilized average U.S. costs of

$22.22 per GJ ($0.08 per kWh) for electricity and $5.31 per GJ ($0.56 per therm) for natural gas.

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 lightweight CMU 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. For purposes of comparison, Manual J[8], a publication that is widely used for sizing of residential HVAC systems recommends that an average of 0.7 ACH be assumed for houses without a fireplace. The minimum recommended assumption for the air infiltration rate is 0.3 ACH for houses without a fireplace.

RESULTS

Energy Use and Insulation

Because the design of the house is subject to orientation-dependent solar effects, modeling was performed with the house rotated in each of the four cardinal (north, south, east, and west) orientations. Total energy consumption for heating, cooling, hot water, and occupant uses was averaged to produce an 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		
Tampa	Wood Frame	56.4	15,664	59.8	567	116.2	$1,570
	Lightweight CMU	56.6	15,712	60.7	576	117.3	$1,579
	Code Matching	64.7	17,964	67.2	638	131.9	$1,794
El Paso	Wood Frame	54.0	14,987	103.9	985	157.8	$1,750
	Lightweight CMU	51.7	14,367	98.9	938	150.6	$1,675
	Code Matching	56.8	15,787	111.3	1,055	168.1	$1,854
Knoxville	Wood Frame	44.1	12,249	133.9	1,269	177.9	$1,691
	Lightweight CMU	42.3	11,758	127.6	1,210	170.0	$1,618
	Code Matching	45.2	12,548	140.3	1,330	185.5	$1,749
	Wood Frame	39.4	10,946	200.0	1,896	239.4	$1,938

Providence	Lightweight CMU	38.3	10,650	192.0	1,821	230.4	$1,871
	Code Matching	39.7	11,038	203.8	1,932	243.6	$1,965
Detroit	Wood Frame	39.5	10,985	222.2	2,107	261.8	$2,059
	Lightweight CMU	38.6	10,712	213.6	2,025	252.2	$1,991
	Code Matching	39.8	11,042	224.3	2,126	264.0	$2,074

Table 5 compares the total energy use of the wood frame and lightweight CMU variations to the code matching variation. Also presented are the U-factors of the wood frame and lightweight CMU variations in comparison to the code requirements. Figure 8 presents the total energy use of the wood frame and lightweight CMU variations to the code matching variation. Figure 9 presents the U-factors of the wood frame and lightweight CMU variations in comparison to the code requirements.

Table 5 – Comparison of Total Energy and U-Factors

Location	Variation	Annual Energy Use, % Below the Low Mass Code Matching Variation	Actual Wall U-Factor, % in Excess of the Low Mass Code Matching Variation
Tampa	Wood Frame	12%	138%
	Lightweight CMU	11%	20%
El Paso	Wood Frame	6%	51%
	Lightweight CMU	10%	63%
Knoxville	Wood Frame	4%	29%
	Lightweight CMU	8%	39%
Providence	Wood Frame	2%	11%
	Lightweight CMU	5%	20%
Detroit	Wood Frame	1%	5%
	Lightweight CMU	4%	13%

In these comparisons, both the lightweight CMU and wood framed variations were insulated using standard materials to meet IECC requirements. Because of the lack of low R-value fiberglass batt insulation products, the wood framed wall in Tampa was significantly over-insulated. With the exception of this location, wall U-factors for the lightweight CMU and wood framed variations were comparable.

Comparison of total building energy use for locations where exterior walls were not over-insulated reveals that total energy use for houses with lightweight CMU walls ranged from 4 to 10% below that of the houses with code matching walls and 4 to 5% below that of the houses with wood frame walls. It is important to note that these savings are based on total energy use, not HVAC energy use or total energy costs. HVAC energy savings will be greater because of the high daily energy use for hot water, lighting, cooking, and laundry activities. If total energy costs are compared, cost savings will be greater because of the large cost difference per GJ between electricity and natural gas.

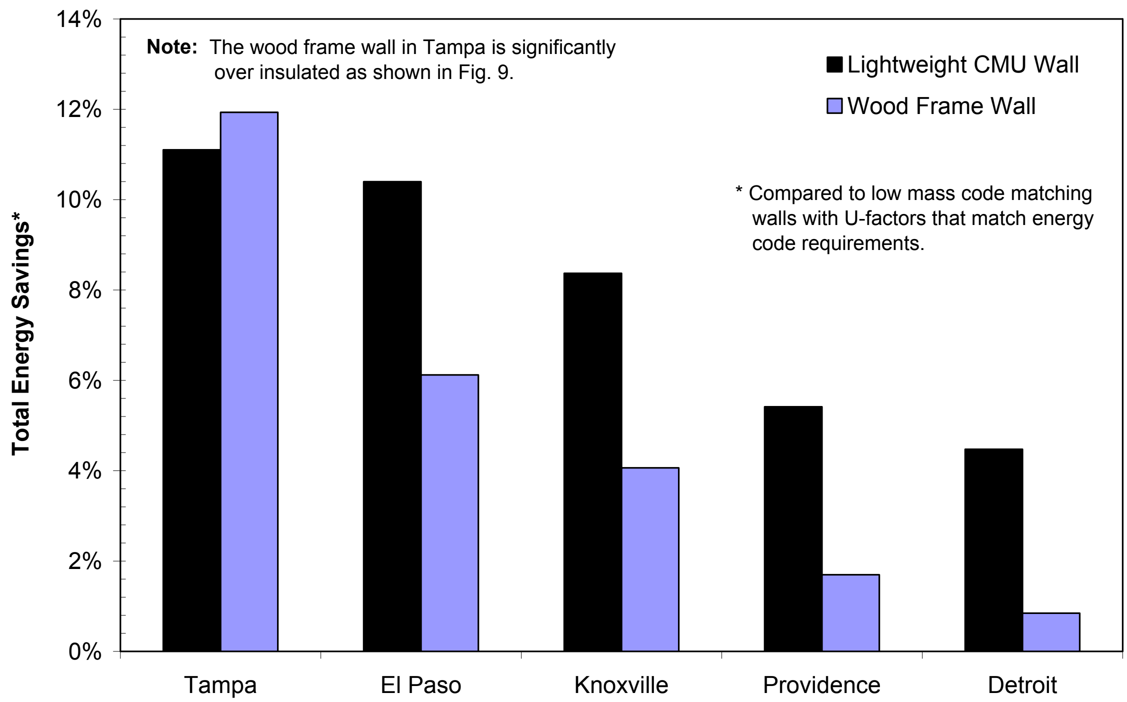

Figure 8 – Comparison of Total Energy Savings

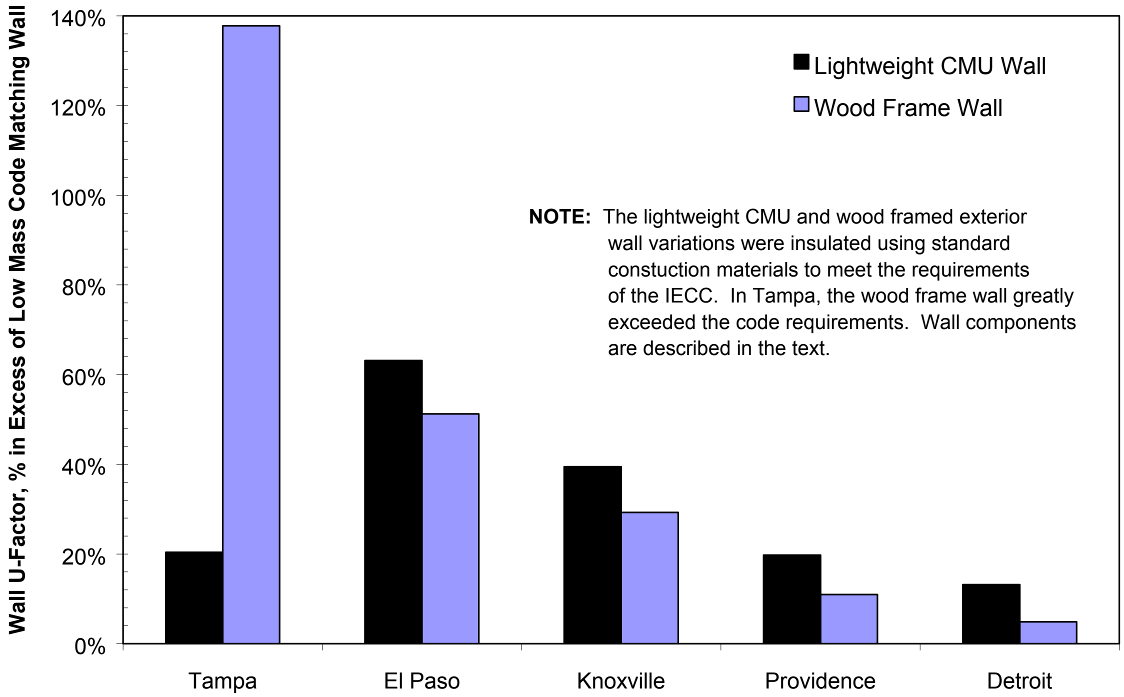

Figure 9 – Comparison of Wall U-Factors

Figure 10 combines data from Figs. 8 and 9 to show the effects of over-insulating exterior walls on total energy savings. Data are presented for the lightweight CMU and wood frame variations. With the wood frame variation, there is a linear relationship between over-insulation and energy savings. This relationship shows that for every 10% increase in wood frame wall insulation, the total energy savings increases by approximately 1%. A similar relationship is noted for the lightweight CMU wall (in all locations except Tampa); however, total energy savings were approximately 4% higher for lightweight CMU walls than for wood frame walls. This indicates that when wood frame and lightweight CMU walls have insulation levels equal to that required by the IECC for low mass walls, houses with lightweight CMU walls have a total energy use of approximately 4% below that of identical houses with wood frame walls. The energy savings is due to the thermal mass in the lightweight CMU walls.

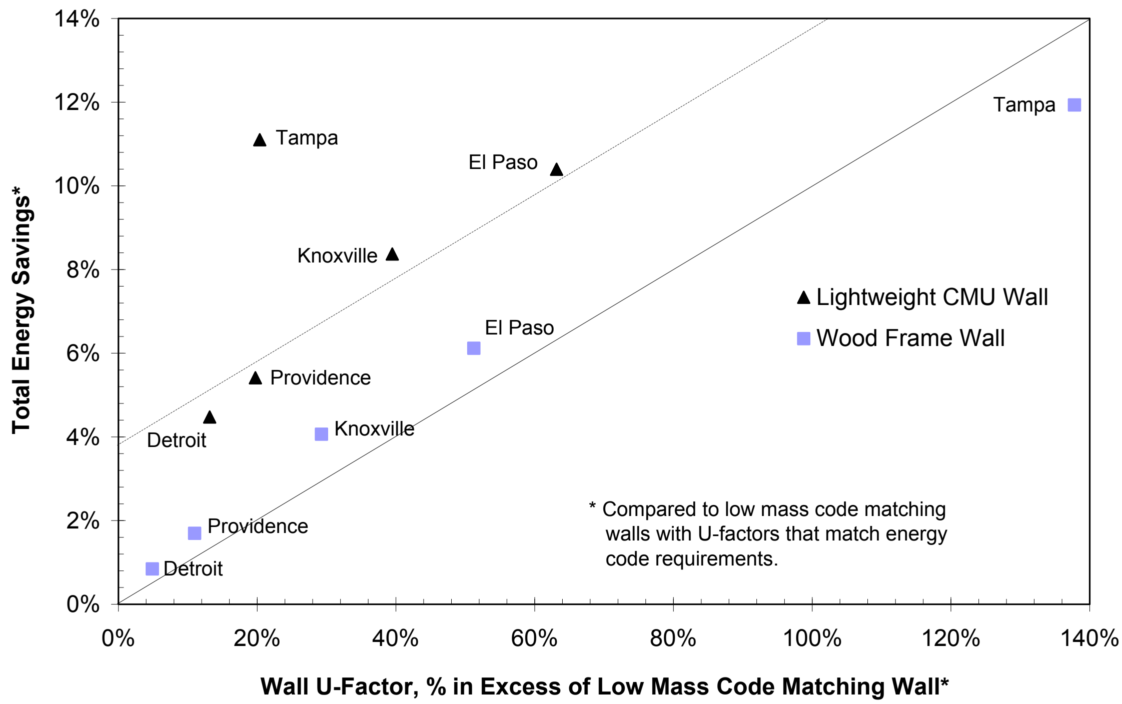

Figure 10 – Effects of Over-Insulation on Total Energy Savings in Lightweight CMU and Wood Frame Walls

HVAC System Sizing

Calculated HVAC system capacities are presented in Table 6. System capacities were automatically sized by the analysis software to maintain indoor temperatures and occupant comfort. Results indicate that thermal mass of the lightweight CMU walls moderates indoor daily temperature swings and peak loads. This results in a smaller required HVAC system capacity for a house with lightweight CMU walls.

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

Location	Variation	System Capacity			
		Heating		Cooling	
		kW	kBtu/hr	kW	kBtu/hr
Tampa	Wood Frame	25	84	13	43
	Lightweight CMU	23	79	12	40
	Code Matching	32	110	16	56

El Paso	Wood Frame	29	99	15	52
	Lightweight CMU	25	86	13	46
	Code Matching	32	110	17	58
Knoxville	Wood Frame	26	89	13	45
	Lightweight CMU	23	77	11	39
	Code Matching	27	94	14	47
Providence	Wood Frame	26	89	13	46
	Lightweight CMU	23	78	12	40
	Code Matching	27	91	14	47
Detroit	Wood Frame	26	88	13	45
	Lightweight CMU	23	78	12	41
	Code Matching	26	89	13	46

Figure 11 presents the reduction in total HVAC system capacity in the lightweight CMU and wood frame house variations in comparison to the code matching house variation. Since all lightweight CMU and wood frame walls were insulated in excess of code requirements, calculated system capacities for these variations were all reduced compared to the code matching variation because these variations required less heating and cooling energy to maintain indoor temperatures and occupant comfort.

Comparison of calculated system capacities for all locations revealed that the HVAC capacities for the lightweight CMU variations ranged from 6 to 13% less than that of the wood frame house variations. If the location where the wood frame wall was not significantly over-insulated in comparison to the code matching and lightweight CMU walls is not considered then, HVAC capacities for the lightweight CMU variations ranged from 11 to 13% less than that of the wood frame house variations. For Tampa, the location where wood framed wall was significantly over-insulated, the calculated HVAC system capacity of houses with lightweight CMU walls was still less than that of the houses with the over-insulated wood framed walls.

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.

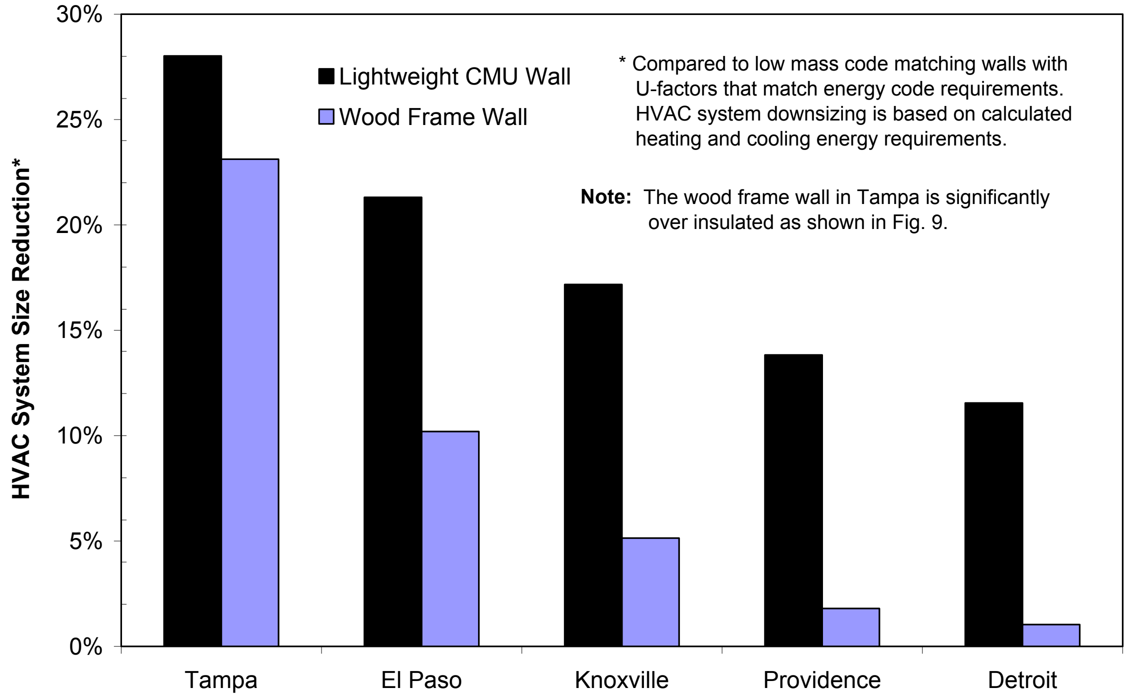

Figure 11 – Comparison of HVAC System Capacities

Air Leakage Sensitivity

A limited sensitivity analysis was performed to determine the effect of infiltration of unconditioned exterior air on the total energy use of the house in Detroit. For the analysis, the air infiltration rate was varied between 0.25 and 0.45 air changes per hour (ACH) and the analysis software automatically sized the HVAC system. For purposes of comparison, 0.25 ACH is typical for many tightly-constructed energy-efficient houses, 0.35 ACH represents the recommended minimum based on ASHRAE Standard 62[7], and 0.45 ACH is representative of most U.S. houses. The ASHRAE Handbook of Fundamentals[9], indicates that measured air infiltration rates in various classes of residential housing vary from 0.02 to well in excess of 2.5 ACH. This range represents the extremes of air infiltration.

Table 7 – Effect of Air Infiltration on the Total Annual Energy in Detroit

Air Infiltration Rate, ACH	Variation	Annual Operating Data					
		Electricity		Natural Gas		Total Energy, GJ	Energy Cost
		GJ	kWh	GJ	therms		
	Wood Frame	39.4	10,954	218.7	2,074	258.2	$2,038

0.25	Lightweight CMU	38.4	10,678	210.2	1,993	248.6	$1,970
	Code Matching	39.6	11,011	220.8	2,094	260.5	$2,053
0.35	Wood Frame	39.5	10,985	222.2	2,107	261.8	$2,059
	Lightweight CMU	38.6	10,712	213.6	2,025	252.2	$1,991
	Code Matching	39.8	11,042	224.3	2,126	264.0	$2,074
0.45	Wood Frame	39.7	11,020	226.0	2,143	265.7	$2,081
	Lightweight CMU	38.7	10,750	217.4	2,061	256.1	$2,014
	Code Matching	39.9	11,077	228.0	2,162	267.9	$2,097

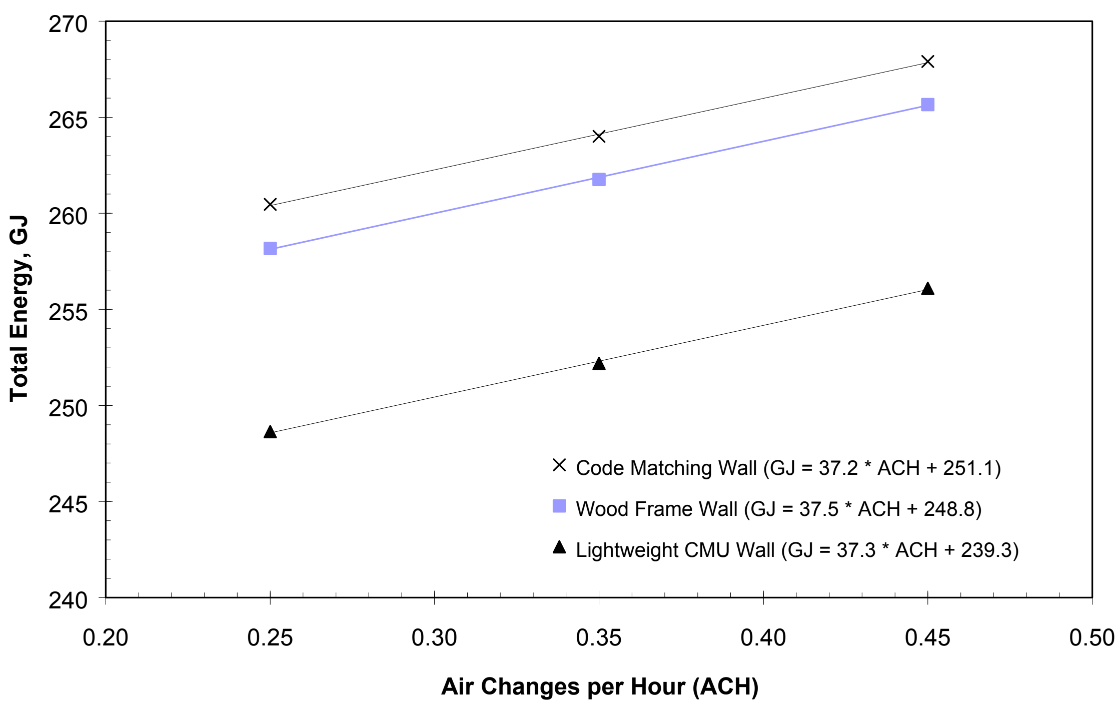

Figure 12 – Effect of Air Infiltration on the Total Energy Use of the Three Wall Variations

Results indicate that the assumed variation in air infiltration rates has a minimal effect on the annual total energy use. Table 7 and Fig. 12 present the total energy use as a function of the air infiltration rate. As is evident in both the table and figure, decreasing the air infiltration by 0.10 ACH has a minimal effect on the total energy (less than 2%). Although not presented, similar changes in the HVAC system size capacities were noted.

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, lightweight concrete masonry unit (CMU) walls, 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 due to the lack of low R-value batt insulation products, the wood frame wall in one location (Tampa) was significantly over-insulated in comparison to lightweight CMU and low-mass code matching walls. In locations where walls were not significantly over insulated, houses with lightweight CMU walls had greater energy savings than that of the houses with standard wood framed walls. Total energy use (including heating and cooling, cooking, laundry, and other typical household energy uses) of houses with lightweight CMU walls in these locations ranged from 4 to 5% below that of houses with wood frame walls.

Linear relationships were noted between the effect of over insulation and energy savings of wood frame and lightweight CMU walls. For wood frame walls, the relationship showed that for every 10% increase in the wood frame wall insulation level, total energy use decreased by 1%. A similar relationship was noted for the lightweight CMU wall (in all locations but Tampa); however, total energy use was approximately 4% less for houses with lightweight CMU walls than for houses with wood frame walls. This indicates that when wood frame and lightweight CMU walls have insulation levels equal to that required by the IECC for low mass walls, houses with lightweight CMU walls have total energy use of approximately 4% below that of identical houses with wood frame walls.

Houses with lightweight CMU walls also showed non-energy related savings from a reduction in the required heating, ventilation, and cooling (HVAC) system capacity. Total system capacity for houses with lightweight CMU walls ranged from 12 to 28% less than that of the houses with walls that matched the IECC requirements and 11 to 13% less than that of the houses with wood frame walls in locations where wood frame walls were not significantly over-insulated.

The benefits of thermal mass moderating indoor temperature and peak heating and cooling loads are illustrated by the reduced overall energy use and required HVAC system capacities of houses with lightweight CMU walls compared to that of wood frame walls.

In one location, a sensitivity analysis was performed to assess the effects of air infiltration on total energy consumption. A linear relationship between total energy use and air infiltration (leakage) was noted for the three wall variations. Results indicated that small but reasonable changes in air infiltration, from 0.25 to 0.45 air changes per hour, had only minor effects on the total energy use in all of the modeled variations.

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