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

by John Gajda and Martha VanGeem

**KEYWORDS**
Concrete, CMU, energy, housing, 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 medium-weight concrete masonry unit (CMU) 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).

Because of the lack of low R-value batt insulation products, wood frame walls in warm climates were significantly over-insulated based on the U-value requirements in the IECC. For these locations, comparisons of total energy use (energy associated with heating and cooling, cooking, laundry, and other occupant energy uses) revealed that the houses with wood frame and CMU walls had similar energy use, within 2%, even though the wood frame walls were over-insulated by approximately 55%. This shows the benefits of thermal mass walls in warm climates. In moderate and cold climates, comparison of total energy use for houses with CMU and wood frame walls showed energy savings of 2 to 5% for houses with CMU walls. In these climates CMU walls had insulation levels that ranged from 1 to 5% above that of the wood frame walls.

A linear relationship was noted between over-insulating and energy savings of wood frame walls. This relationship shows that for every 10% increase in the wood frame wall insulation level, total energy savings increase by approximately 1%. Because of the inherent thermal mass of CMU, this relationship is not applicable to houses with CMU walls. These houses have total energy savings greater than 1% for every 10% in increase in the insulation level, and this relationship was found to be climate dependent.

Houses with CMU walls also showed non-energy related savings from a reduction in the required HVAC system capacity. Total system capacity for houses with CMU walls ranged from 11 to 24% less than that of the houses with walls that matched the IECC requirements and 10 to 16% less than that of the houses with wood frame walls in locations where wood frame walls were not significantly over-insulated. The reduction in the HVAC

system capacity is due to the thermal mass of the CMU walls, which moderates indoor temperatures swings and peak heating and cooling loads.

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Gajda, John, and VanGeem, Martha, *Energy Use in Residential Housing: A Comparison of Concrete Masonry and Wood Framed Walls*, R&D Serial No. 2429, Portland Cement Association, 2000, 20 pages.

# ENERGY USE IN RESIDENTIAL HOUSING: A COMPARISION OF 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 typical medium-weight concrete masonry unit (CMU) walls. 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 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. Lake Charles, LA was selected as a hot humid climate. Tucson, AZ was selected as a hot dry climate. St. Louis, MO was selected as a moderate climate. Denver, CO and Minneapolis, MN were selected as cold climates. Denver and Tucson have 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

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* Senior Engineer and Principal Engineer, Construction Technology Laboratories, Inc. (CTL), 5420 Old Orchard Road, Skokie, IL 60077, U.S.A. (847) 965-7500

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 |
| Lake Charles | 898 | 1616 | 19 | 67 | 10 | 18 |
| Tucson | 932 | 1678 | 20 | 68 | 14 | 25 |
| St. Louis | 2643 | 4758 | 13 | 55 | 10 | 19 |
| Denver | 3344 | 6020 | 10 | 50 | 15 | 26 |
| Minneapolis | 4434 | 7981 | 7 | 45 | 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 Insulating Concrete Form (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 wood frame exterior walls was assumed to consist of medium colored aluminum siding. The exterior finish of the 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.

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.

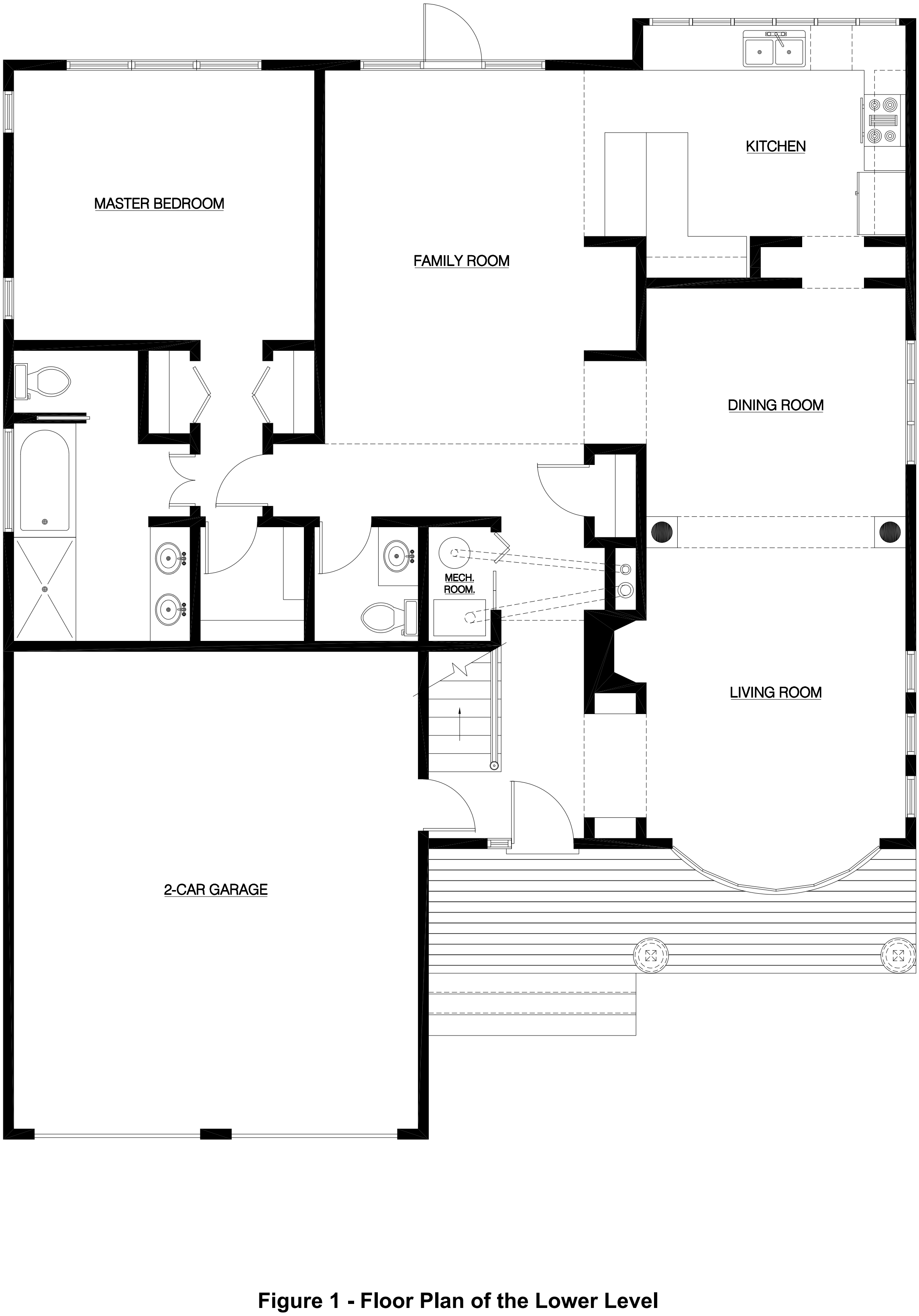

**Figure 1 - Floor Plan of the Lower Level**

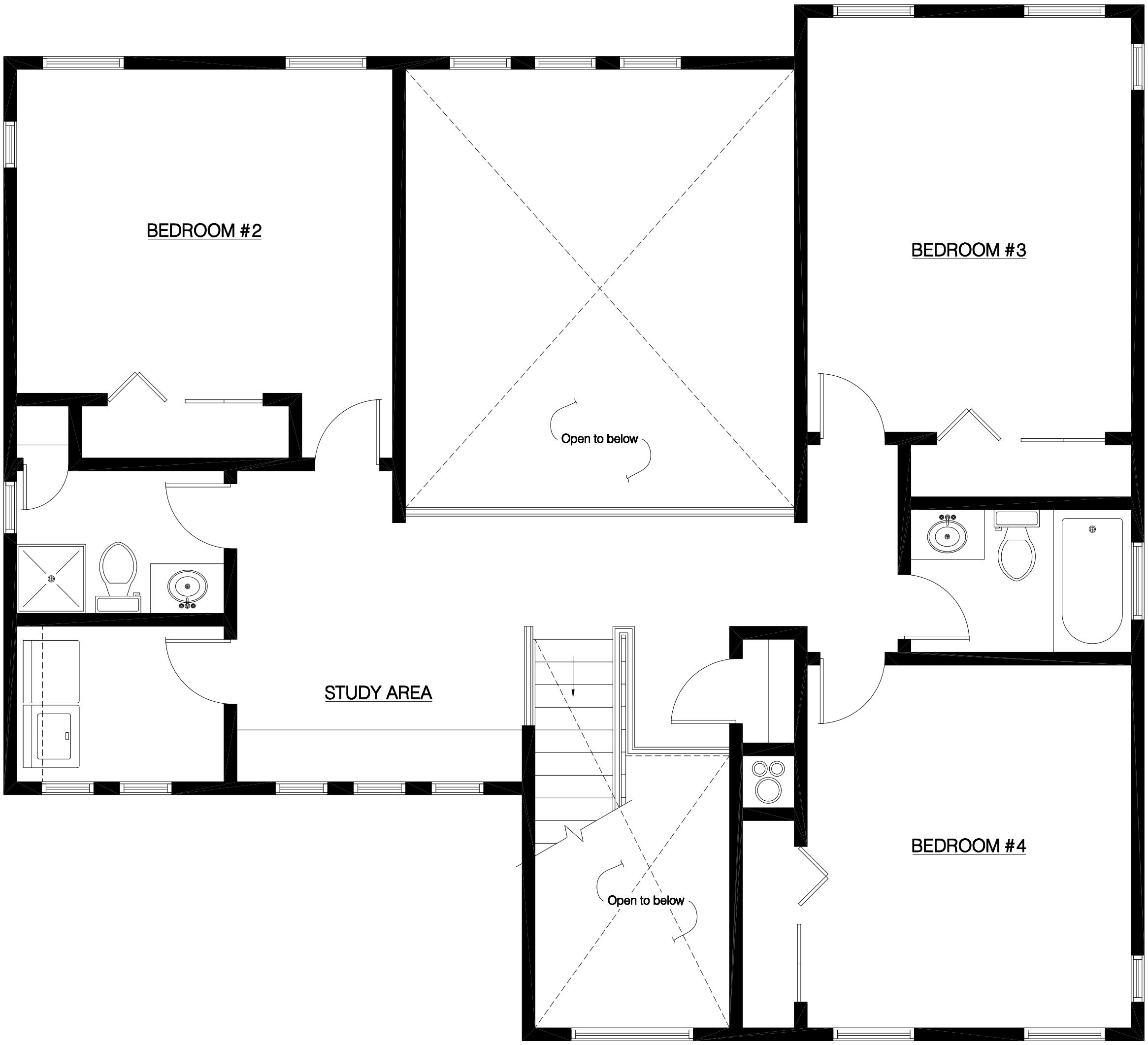

Figure 2 - Floor Plan of the Upper Level

Figure 3 – Front Elevation

Figure 4 – Rear Elevation

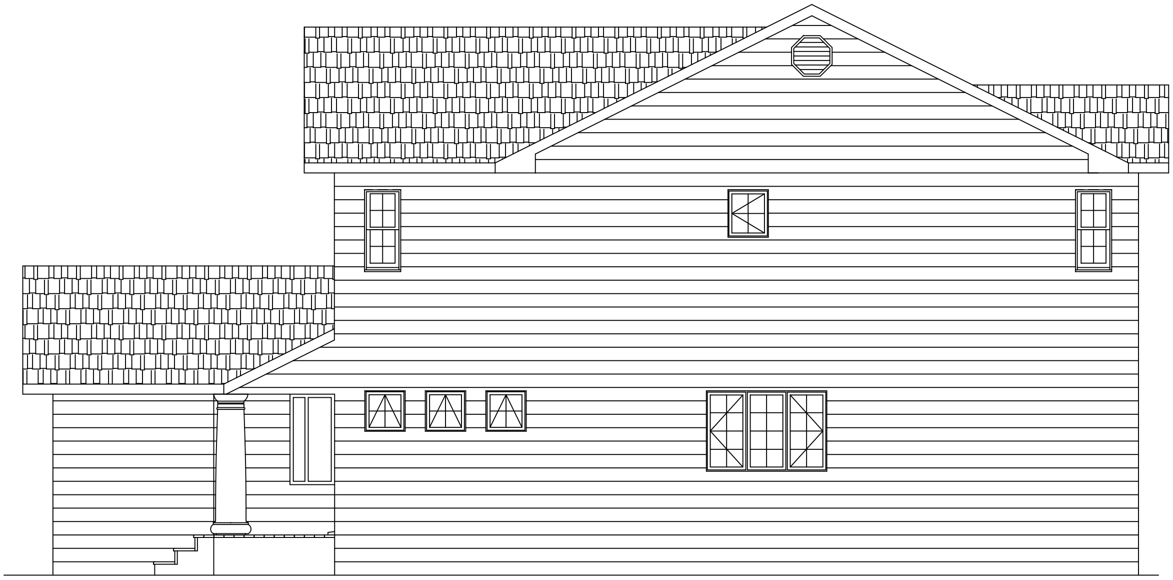

**Figure 5 – Right Elevation**

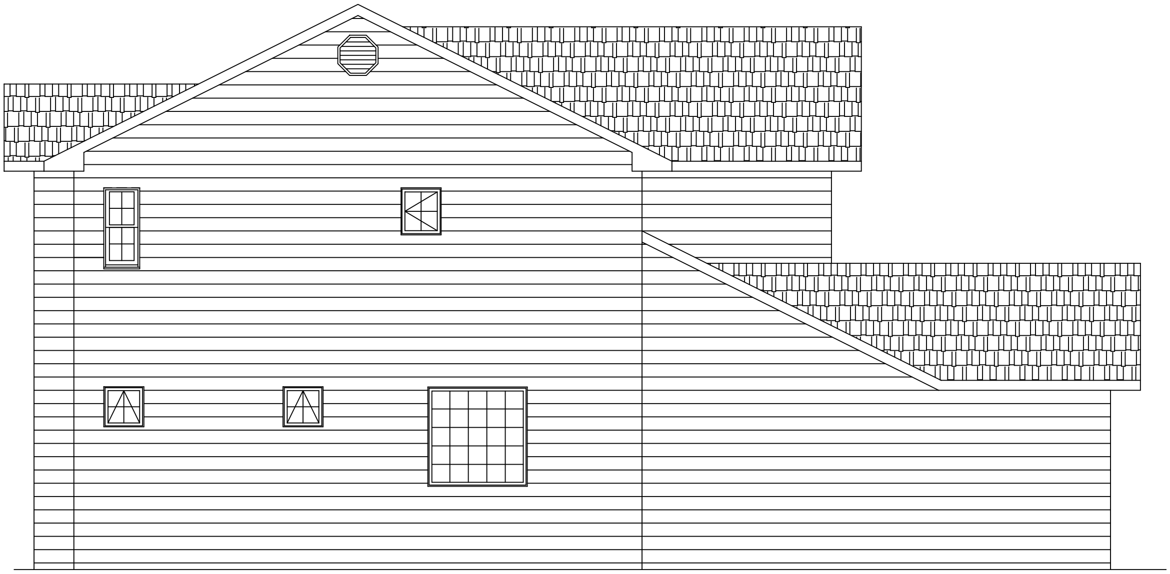

**Figure 6 – Left Elevation**

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$^2$·K (0.27 Btu/hr·ft$^2$·°F).

**Table 2 – IECC Maximum U-factors***

| Location | Opaque Walls** | | | | Roof | | Windows*** | |
|---|---|---|---|---|---|---|---|---|
| | Wood Frame | | Mass | | | | | |
| | $\frac{W}{m^2\cdot K}$ | $\frac{Btu}{hr\cdot ft^2\cdot{}^\circ F}$ | $\frac{W}{m^2\cdot K}$ | $\frac{Btu}{hr\cdot ft^2\cdot{}^\circ F}$ | $\frac{W}{m^2\cdot K}$ | $\frac{Btu}{hr\cdot ft^2\cdot{}^\circ F}$ | $\frac{W}{m^2\cdot K}$ | $\frac{Btu}{hr\cdot ft^2\cdot{}^\circ F}$ |
| Lake Charles | 0.897 | 0.158 | 1.124 | 0.198 | 0.233 | 0.041 | 2.4 | 0.47 |
| Tucson | 0.886 | 0.156 | 1.102 | 0.194 | 0.233 | 0.041 | 2.4 | 0.47 |
| St. Louis | 0.636 | 0.112 | 0.727 | 0.128 | 0.182 | 0.032 | 1.7 | 0.30 |
| Denver | 0.500 | 0.088 | 0.556 | 0.098 | 0.148 | 0.026 | 1.7 | 0.30 |
| Minneapolis | 0.420 | 0.074 | 0.420 | 0.074 | 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 Lake Charles and Tucson.

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 except Minneapolis, 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 wood framed variation in Minneapolis was assumed to consist of medium colored aluminum siding, 12-mm (½-in.) insulated sheathing, R$_{si}$-2.3 (R-13) fiberglass batt insulation, and 12-mm (½-in.) painted gypsum board.

The CMU variation for Lake Charles and Tucson was assumed to consist of 16-mm (⅝in.) thick light-colored portland cement stucco, 200-mm (8-in.) CMU with partly grouted insulated cells*, wood furring, and 12-mm (½-in.) painted gypsum board. The CMU variation for St. Louis and Denver was assumed to consist of 16-mm (⅝in.) thick light-

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* "Partly grouted insulated cells" means that some CMU cells were grouted, while others contained insulation. Likewise, "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 non-grouted cells is defined in ASHRAE Standard 90.1-1999.[3]

colored portland cement stucco, 200-mm (8-in.) 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 CMU variation for Minneapolis was assumed to consist of 16mm (⅝in.) thick light-colored portland cement stucco, 200-mm (8-in.) CMU with partly grouted uninsulated cells, wood furring with $R_{si}$-2.3 (R-13) fiberglass batt insulation, and 12-mm (½-in.) painted gypsum board. For all locations, the nominal unit weight of the CMU was assumed to be 1840 kg/$m^3$ (115 pcf) with U-factors as presented in ASHRAE Standard 90.1-1999[3].

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 Lake Charles and Tucson were assumed to be tinted and had air as the gap gas. Windows in St. Louis, Denver, and Minneapolis 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 Lake Charles and Tucson where the wood framed walls have U-factors that are approximately 90% in excess of the IECC requirements.

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.

**Table 3 – Actual Assembly U-Factors***

| Location | Walls | | | | Roof** | | Windows | |
|---|---|---|---|---|---|---|---|---|
| | Wood Frame | | Mass (CMU) | | | | | |
| | $\frac{W}{m^2 \cdot K}$ | $\frac{Btu}{hr \cdot ft^2 \cdot {}^\circ F}$ | $\frac{W}{m^2 \cdot K}$ | $\frac{Btu}{hr \cdot ft^2 \cdot {}^\circ F}$ | $\frac{W}{m^2 \cdot K}$ | $\frac{Btu}{hr \cdot ft^2 \cdot {}^\circ F}$ | $\frac{W}{m^2 \cdot K}$ | $\frac{Btu}{hr \cdot ft^2 \cdot {}^\circ F}$ |
| Lake Charles | 0.47 | 0.082 | 0.85 | 0.150 | 0.18 | 0.032 | 2.4 | 0.43 |
| Tucson | | | | | | | | |
| St. Louis | | | 0.44 | 0.078 | | | 1.5 | 0.27 |
| Denver | | | | | 0.15 | 0.026 | | |
| Minneapolis | 0.42 | 0.074 | 0.41 | 0.073 | | | | |

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

** $R_{si}$-5.3 (R-30) attic insulation was used for Lake Charles, Tucson and St. Louis. $R_{si}$-6.7 (R-38) attic insulation was used for the remaining locations.

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] 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 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. A family of four was assumed to live in the house.

## RESULTS

### *Energy Consumption*

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

**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 | | |
| Lake Charles | Wood Frame | 52.8 | 14,660 | 91.5 | 868 | 144.3 | $1,659 |
| | CMU | 52.2 | 14,509 | 94.3 | 894 | 146.5 | $1,661 |
| | Code Matching | 57.4 | 15,954 | 102.1 | 968 | 159.5 | $1,818 |
| Tucson | Wood Frame | 60.0 | 16,659 | 83.6 | 793 | 143.6 | $1,777 |
| | CMU | 60.4 | 16,772 | 84.5 | 801 | 144.9 | $1,790 |
| | Code Matching | 65.6 | 18,221 | 92.8 | 880 | 158.4 | $1,951 |
| St Louis | Wood Frame | 47.8 | 13,273 | 176.3 | 1,672 | 224.1 | $1,998 |
| | CMU | 46.4 | 12,902 | 171.9 | 1,630 | 218.3 | $1,945 |
| | Code Matching | 49.6 | 13,775 | 189.5 | 1,797 | 239.1 | $2,108 |
| Denver | Wood Frame | 40.9 | 11,368 | 187.5 | 1,778 | 228.5 | $1,905 |
| | CMU | 39.2 | 10,883 | 177.9 | 1,687 | 217.1 | $1,815 |
| | Code Matching | 41.3 | 11,478 | 190.3 | 1,805 | 231.7 | $1,929 |
| Minneapolis | Wood Frame | 40.9 | 11,363 | 241.0 | 2,285 | 281.9 | $2,189 |
| | CMU | 39.9 | 11,093 | 235.4 | 2,232 | 275.3 | $2,137 |
| | Code Matching | 41.1 | 11,421 | 242.3 | 2,297 | 283.4 | $2,200 |

In these comparisons, both the 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 walls in Lake Charles and Tucson were significantly over-insulated. As shown in Table 5, these walls had insulation levels of 90 to 93% greater than required by code, based on U-factors.

For Lake Charles and Tucson, comparisons of total energy use revealed that the houses with wood frame and CMU walls had similar energy use, within 2%, even though the wood frame walls had insulation levels that were approximately 55% greater than the CMU walls, based on U-factor. This shows the benefits of thermal mass walls in warm climates. In moderate and cold climates, comparison of total energy use for houses with CMU and wood frame walls showed energy savings of 2 to 5% for houses with CMU walls. In these climates CMU walls had insulation levels that ranged from 1 to 5% above that of the wood frame walls, based on U-factors. These results show that thermal mass effects are less predominant in cold climates.

**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 |
|---|---|---|---|
| Lake Charles | Wood Frame | 10% | 93% |
| | CMU | 8% | 5% |
| Tucson | Wood Frame | 9% | 90% |
| | CMU | 9% | 4% |
| St. Louis | Wood Frame | 6% | 37% |
| | CMU | 9% | 44% |
| Denver | Wood Frame | 1% | 7% |
| | CMU | 6% | 13% |
| Minneapolis | Wood Frame | 1% | 1% |
| | CMU | 3% | 1% |

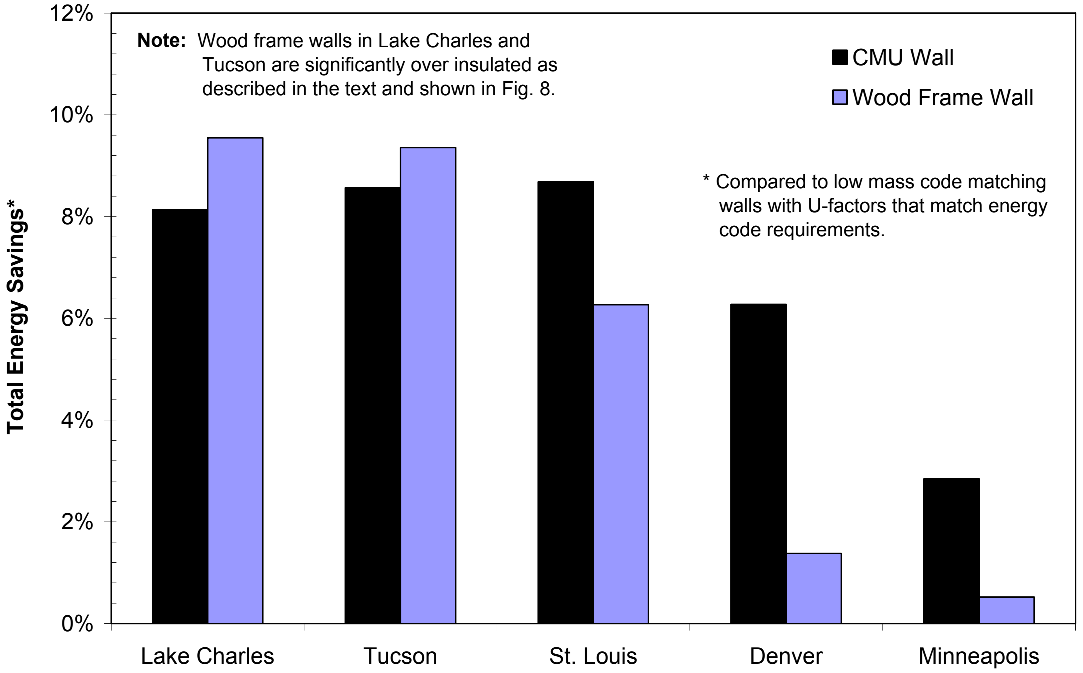

Figure 7 – Comparison of Total Energy Savings

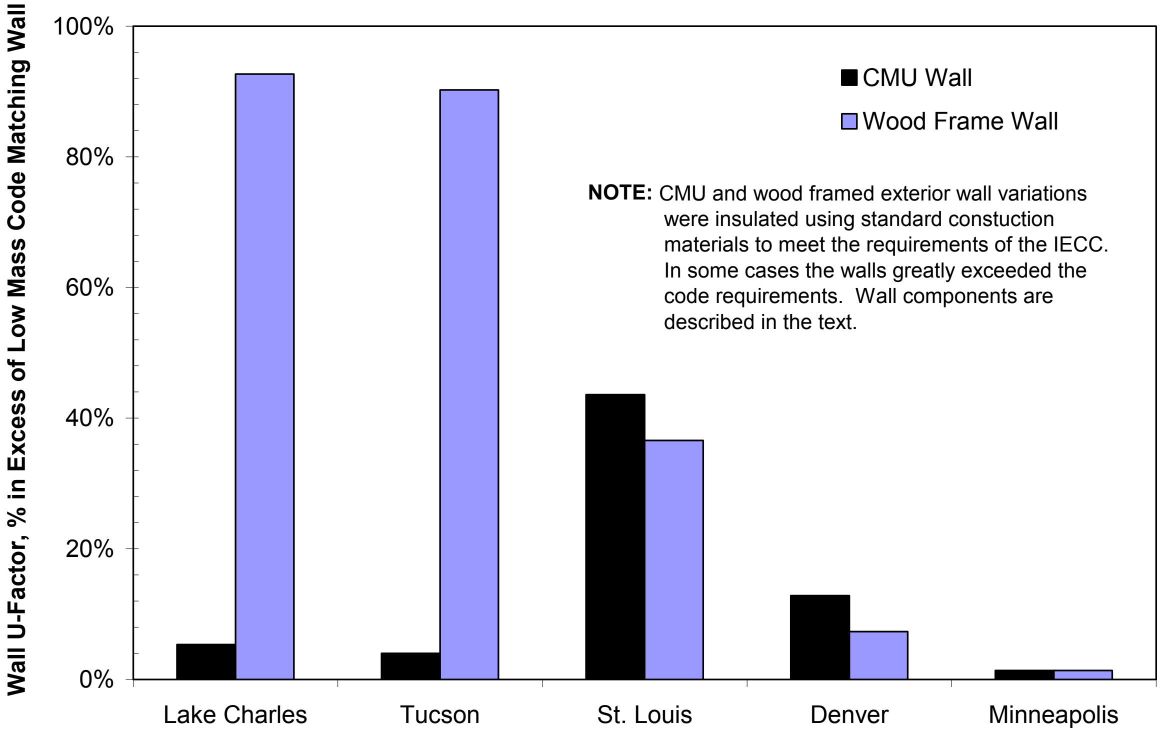

Figure 8 – Comparison of Wall U-Factors

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 9 combines data from Figs. 7 and 8 to show the effects of thermal mass and over-insulating exterior walls on total energy savings. Data are presented for the 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 increase by approximately 1%. Figure 9 also shows that this relationship is not applicable to the CMU walls. Because of thermal mass, CMU walls have more energy savings than frame walls with identical levels of insulation (U-factors). The energy savings due to thermal mass are not linear because the effects of thermal mass are climate dependent.

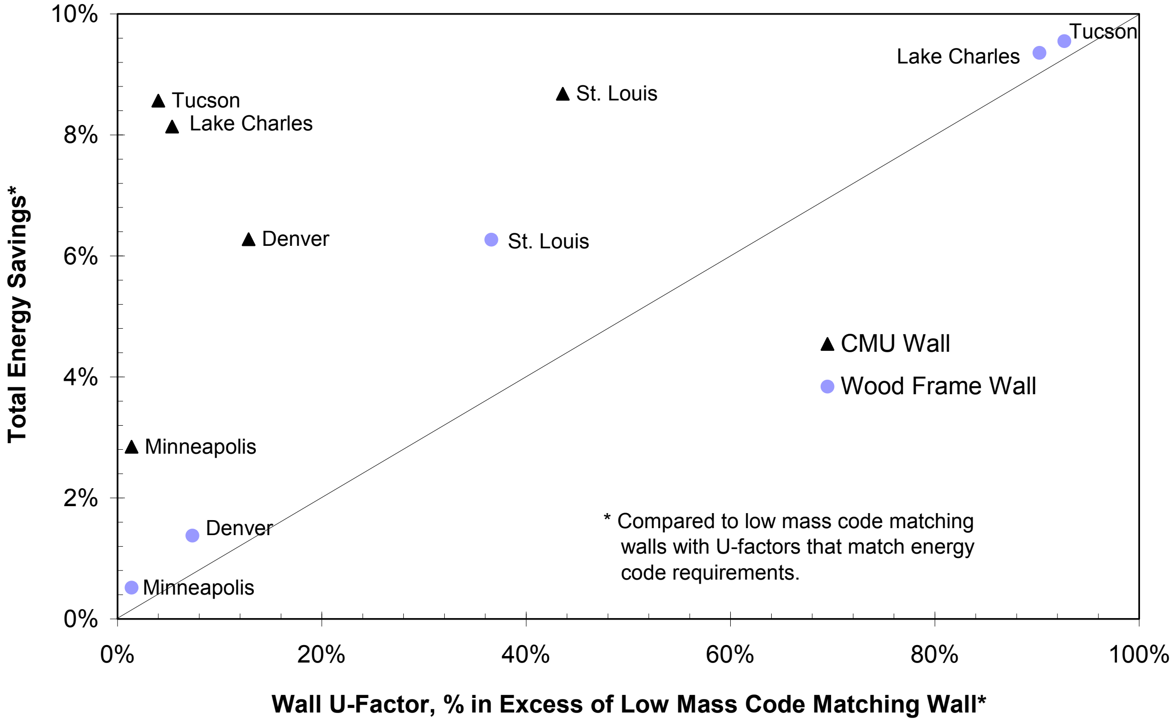

**Figure 9 – Effects of Over-Insulation on Total Energy Savings in CMU and Wood Frame Walls**

### *HVAC System Capacity*

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 CMU walls moderates indoor daily temperature swings and peak loads. This results in a smaller required HVAC system capacity for a house with CMU walls.

Figure 10 presents the reduction in total HVAC system capacity in the CMU and wood frame house variations in comparison to the code matching house variation. Since all 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 the required system capacity in Minneapolis for the CMU and wood frame variations shows the effects of thermal mass. In this location, where walls were insulated to the same level above the low mass code matching wall (1% in excess), the calculated HVAC system capacity was approximately 10% less for the CMU variation. Comparison of calculated system capacities for all locations revealed that the HVAC capacities for the CMU variations ranged from 3 to 16% less than that of the wood frame house variations and 11 to 24% less than that of the low mass code matching house variations. Discounting locations where the wood frame walls are significantly over-insulated (in comparison to the code matching and CMU walls), HVAC capacities for the CMU variations ranged from 10 to 16% less than that of the wood frame house variations. For locations where wood framed walls were significantly over-insulated, the calculated HVAC system capacity of houses with CMU walls was still less than that of the houses with the over-insulated wood framed 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** |
| Lake Charles | Wood Frame | 25 | 87 | 13 | 45 |
| | CMU | 23 | 78 | 12 | 41 |
| | Code Matching | 30 | 104 | 15 | 53 |
| Tucson | Wood Frame | 30 | 102 | 16 | 55 |
| | CMU | 29 | 98 | 16 | 54 |
| | Code Matching | 35 | 119 | 19 | 65 |
| | Wood Frame | 29 | 99 | 15 | 53 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| St. Louis | CMU | 26 | 89 | 14 | 48 |
|  | Code Matching | 32 | 109 | 17 | 58 |
| Denver | Wood Frame | 27 | 92 | 14 | 47 |
|  | CMU | 23 | 78 | 12 | 39 |
|  | Code Matching | 28 | 95 | 14 | 48 |
| Minneapolis | Wood Frame | 25 | 87 | 13 | 45 |
|  | CMU | 23 | 79 | 12 | 41 |
|  | Code Matching | 26 | 88 | 13 | 46 |

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.

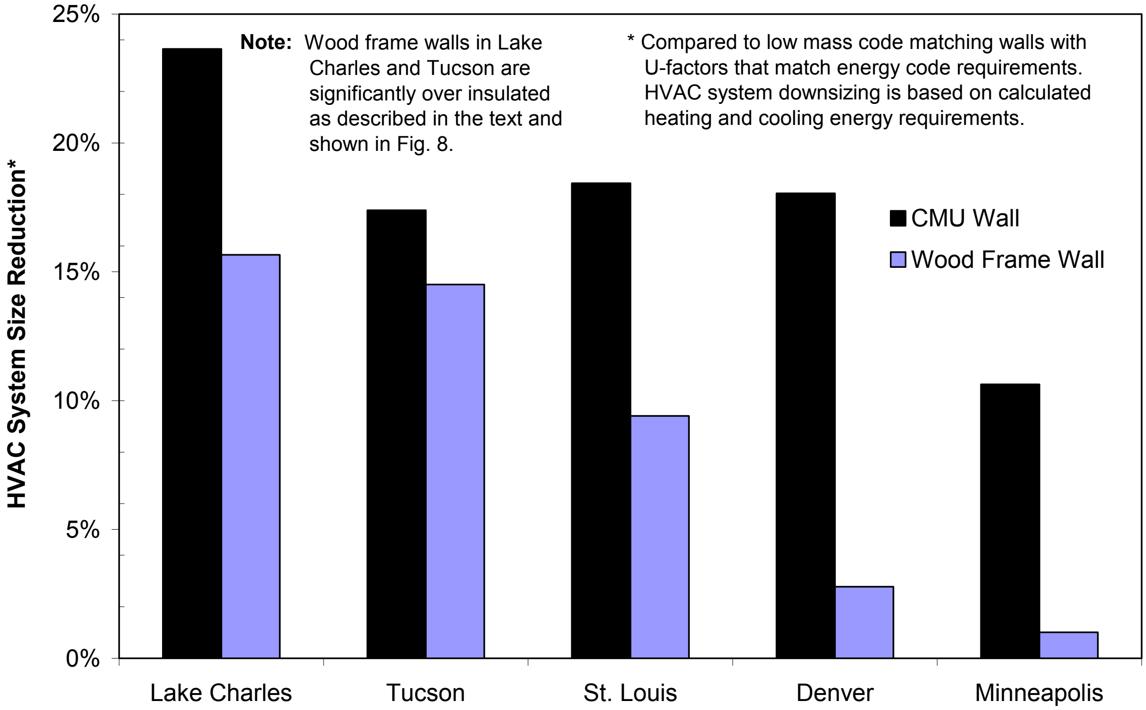

**Figure 10 – Comparison of HVAC System Capacities**

## 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, medium-weight concrete masonry unit (CMU) walls, and a fictitious non-mass exterior wall that met prescribed minimum IECC requirements. All walls were assumed to have wood furring and gypsum wallboard on the interior surface.

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, wood frame walls in Lake Charles and Tucson were significantly over-insulated in comparison to CMU and low-mass code matching walls. For these locations, comparisons of total energy use revealed that the houses with wood frame and CMU walls had similar energy use, within 2%, even though the wood frame walls had insulation levels approximately 55% greater that of the CMU walls. This shows the benefits of thermal mass walls in warm climates. In moderate and cold climates, comparison of total energy use for houses with CMU and wood frame walls showed energy savings of 2 to 5% for houses with CMU walls. In these climates CMU walls had insulation levels that ranged from 1 to 5% above that of the wood frame walls.

A linear relationship was noted between over-insulating and energy savings of wood frame walls. This relationship shows that for every 10% increase in the wood frame wall insulation level, total energy savings increase by approximately 1%. Because of the inherent thermal mass of CMU, this relationship is not applicable to houses with CMU walls. These houses have total energy savings greater than 1% for every 10% in increase in the insulation level, and this relationship was found to be climate dependent.

Houses with CMU walls also showed additional savings from a reduction in the required HVAC system capacity. Total system capacity for houses with CMU walls ranged from 11 to 24% less than that of the houses with code matching walls and 10 to 16% less than that of the houses with wood frame walls in locations where wood frame walls were not significantly over-insulated.

## ACKNOWLEDGEMENT

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