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THERMAL MASS WORKS CMU VS WOOD

Investigating effectiveness of thermal mass with insulation

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Photo by Rocky Jenkins, CEMEX

CMU structural walls provide thermal mass to reduce the amount of insulation needed in comparison to wood-frame walls.

Concrete masonry assemblies have many attributes, including being a versatile material choice for energy efficiency in building envelopes and providing thermal mass.

Recently completed simulations of realistic single-family houses show that thermal mass walls outperform wood-framed walls whether the insulation is on the inside or outside of the thermal mass in climate zones 3 and 4 in the midsection and western portions of the US.

EnergyPlus simulations were performed on 607 walls in 15 climate zones (CZ) and for a typical one- and two-story house for an analysis period of one year. Most of the walls were constructed of concrete masonry units (CMU) of different unit weights, various grout spacings in the CMU cores, and different amounts of insulation on the inside, outside and in the CMU cores.

Windows in the homes were equally distributed on all four cardinal directions and were 15% of the conditioned floor area, which is 2200 sf for the two-story house. Windows and energy criteria other than insulation in opaque walls are equal to the 2012 International Energy Conservation Code (IECC) for each CZ.

The research held all factors, other than the opaque sections of exterior walls, equal for each climate zone for simulations.

Note that results would most likely be even more favorable had passive solar techniques been employed, such as shifting more windows to the south side of the house and allowing a larger range in thermostat set points (they are quite narrow in this study). But even in these typical houses, results are favorable.

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Three Wall Comparisons

This article focuses on two-story homes compared in CZ 3A, 3B, 3C, 4A, 4B and 4C – from Baltimore MD to Memphis TN to El Paso TX to Albuquerque NM to San Francisco CA to Salem OR. An R13 wood-framed wall is compared to a 115 pcf partly grouted CMU wall with R8 **interior** insulation and a 115 pcf partly grouted CMU wall with R8 continuous **exterior** insulation.

Walls have similar overall R-values and U-factors, although the overall R-value for the wood-framed wall is 9% greater. **Wood-framed wall** has R13 batt insulation between wood studs at 16" on center (oc), with gypsum wallboard on the interior and 7/16" OSB on

Walls were constructed of CMU of different unit weights, various grout spacings in CMU cores and different amounts of insulation on the inside, outside and in CMU cores

the exterior. The U-factor is 0.092 and the overall R-value is 10.87.

CMU wall with interior insulation is 115 pcf CMU with grout every 48" oc. R3 reflective insulation is between the wood furring. R5 continuous insulation is inside of the wood furring, with gypsum wallboard on the interior and cementitious stucco on the exterior. The U-factor is 0.10 and the overall R-value is 10.0.

CMU wall with exterior insulation is 115 pcf CMU with grout every 48" oc. R8 continuous insulation is on the exterior, with gypsum wallboard on the interior and with a synthetic stucco on the exterior. U-factor is 0.10 and the overall R-value is 10.0.

Thermostat settings were relatively narrow – 75°F for cooling and 72°F in the winter. This means that the temperature is never allowed to go above 75°F without the air conditioner turning on and never allowed to go below 72°F without the furnace turning on. It is likely, typical houses have a wider range of temperature and therefore the beneficial results for thermal mass are conservative.

Cities were previously determined by Department of Energy (DOE) to be representative of CZ 3 and 4. This means that performing an analysis for these cities provides results that are generally accepted to extend to the entire CZ. Therefore, these results can be assumed to generally apply to all locations in CZ 3 and 4 as shown in **Figure 1** (p. 20), although the actual results will vary depending on the actual location in the CZ. This CZ map has been used in all versions of the IECC and ASHRAE 90.1 since 2004.

Cities and results are presented in **Tables 1 and 2**. Results were generated from project data. The PNNL report[1] on the methodology can be found at *floridamasonry.com/pnnl-energy-research.html*

The Energy Use Index (EUI) is the HVAC energy usage for heating and cooling, including fan, furnace and air-conditioning. Heating is from a natural gas furnace. Energy is kBTU per sf of house area for one year. In this case, it is for a two-story, 2200 sf house. **The Energy Cost Index (ECI) is the EUI multiplied by energy costs.** National average energy rates were used with electricity at $0.11 per kWh and natural gas at $1.05 per therm. Project data allows the energy prices to be changed to different national or local prices. Default values were used in the study. Costs are in US$/ sf of house for one year.

Energy Usage Results

Table 1 shows energy usage results when the wood-framed wall is compared to CMU walls with interior and exterior insulation. **Results show that the house with CMU walls with insulation on the interior uses 3 to 23% less HVAC energy than the house with wood-framed walls.**

Mass walls not only perform well in hot climates, as is commonly known, but also perform well in more mild climates with cooler winter temperatures. **Results also**

Table 1 – *HVAC Energy Usage* Results for House with Wood-Framed Walls with R13 Insulation Compared to House with Similarly Insulated CMU Walls with Interior or Exterior Insulation

	Energy Use Index (EUI), kBTU/sf/year			% Improvement	
City, Climate Zone	Wood R-13[1]	CMU int. ins., R-3+R-5[2]	CMU ext. ins., R8[3]	CMU int. ins. vs. Wood, % less	CMU ext. ins. vs. Wood, % less
Memphis, 3A	20.58	19.57	18.84	4.9	8.5
El Paso, 3B	16.17	13.89	13.00	14.1	19.6
San Francisco, 3C	11.85	9.10	7.74	23.2	34.7
Baltimore, 4A	25.46	24.67	24.10	3.1	5.3
Albuquerque, 4B	20.40	18.02	17.20	11.7	15.7
Salem, OR, 4C	22.27	20.47	19.84	8.1	10.9

1Wood-frame wall has R13 batt insulation between wood studs at 16" oc, with gypsum wallboard on the interior and 7/16" OSB on the exterior. U-factor is 0.092. Overall R-value is 10.87.

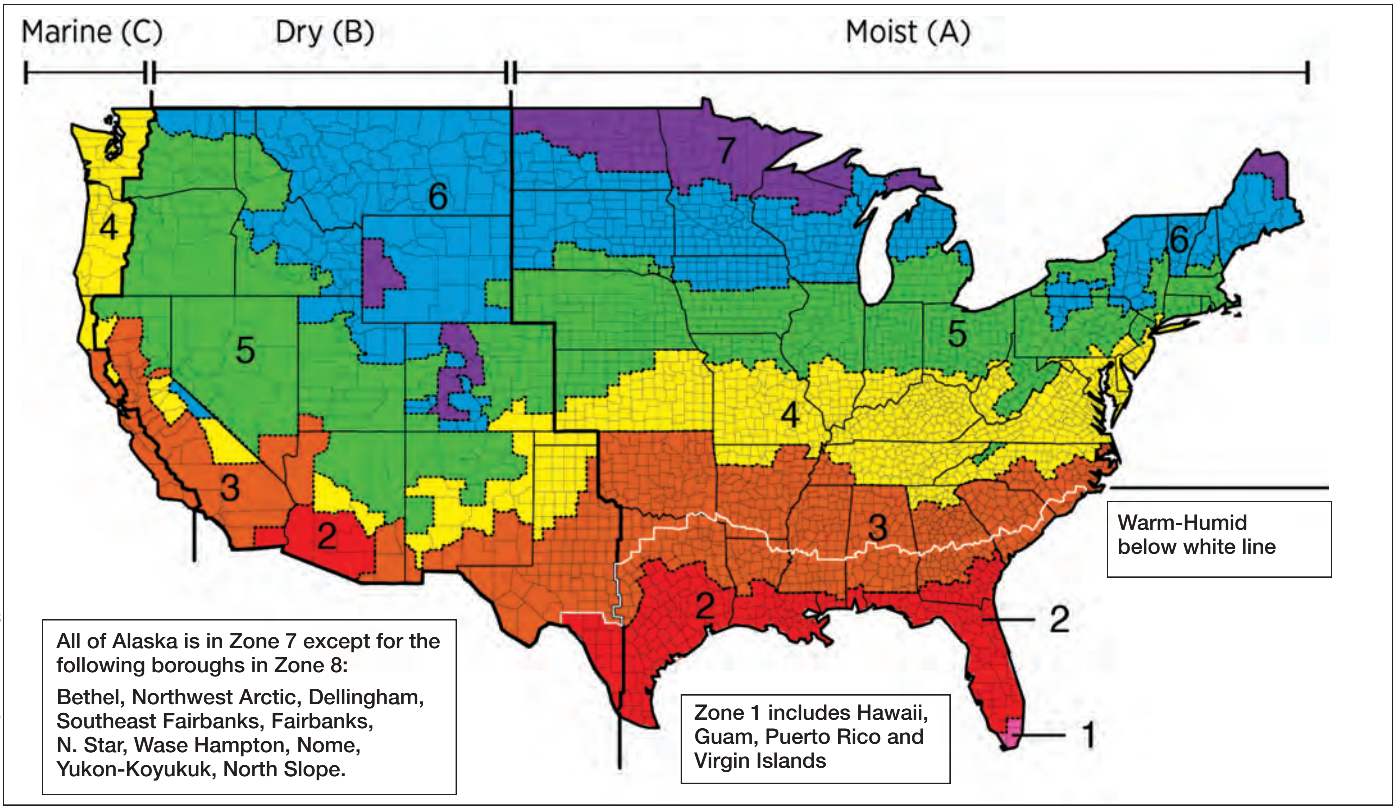
2CMU wall with interior insulation is 115 pcf CMU with grout every 48" oc. R3 reflective insulation is between the wood furring. R5 continuous insulation is inside of the wood furring, with gypsum wallboard on the interior and cementitious stucco on the exterior. The U-factor is 0.10 and the overall R-value is 10.00.

3CMU wall with exterior insulation is 115 pcf CMU with grout every 48" oc. R8 continuous insulation is on the exterior, with gypsum wallboard on the interior and with a synthetic stucco on the exterior. The U-factor is 0.10 and the overall R-value is 10.00.

Table 2 – *HVAC Energy Cost* Results for House with Wood-Framed Walls with R13 Insulation Compared to House with Similarly Insulated CMU Walls with Interior or Exterior Insulation

	Energy Cost Index (ECI), $/sf/year			% Improvement	
City, Climate Zone	Wood R-13	CMU int. ins., R-3+R-5	CMU ext. ins., R8	CMU int. ins. vs. Wood, % less	CMU ext. ins. vs. Wood, % less
Memphis, 3A	0.378	0.361	0.346	4.5	8.4
El Paso, 3B	0.341	0.303	0.286	11.0	16.0
San Francisco, 3C	0.177	0.130	0.107	26.3	39.3
Baltimore, 4A	0.392	0.376	0.364	3.9	7.1
Albuquerque, 4B	0.355	0.314	0.298	11.5	16.1
Salem, OR, 4C	0.322	0.288	0.273	10.4	15.0

[1]Hart, R., Mendon, V., Taylor, T., Residential Wall Type Energy Impact Analysis, PNNL-22867, Pacific Northwest National Laboratory, Richland WA, January 2014.



PNNL for US Department of Energy

Figure 1 Climate Zones recognized by ASHRAE 90.1 and the IECC

show that the house with CMU walls with exterior insulation uses 5 to 35% less HVAC energy than the same house with wood-framed walls.

Table 1 shows that mass not only works well when insulation is on the outside of the mass, but also works well (although not quite as well) when insulation is on the inside of the mass. **The inside surface of the mass does not need to be exposed to the indoor air in order for the mass wall to save energy.**

Energy Costs

Table 2 shows similar results for energy costs when the wood-framed wall is compared to CMU walls with interior or exterior insulation. **Results show that the house with CMU walls with exterior insulation costs 7 to 39% less to heat and cool than the same house with wood-framed walls. Results also show that the house with CMU walls with interior insulation costs 4 to 26% less to heat and cool than the house with wood-framed walls.**

Energy and cost-saving results for mass walls are more significant for CZ 3 compared to CZ 4. They are also more significant for the drier western portion of the US – the ***B*** and ***C*** CZ compared to the moist eastern portion – the **A** CZ. (Divisor is generally on a line drawn up through the center of Texas.) This is due to greater outdoor daily temperature swings in the western part of the US.

Effects of Thermal Mass

Thermal mass has two distinct energy saving methods. First, thermal mass performs best when heat flow is reversed in the wall at any point during the day. In these cases, rather than flowing through the wall, heat flow in one direction cancels out heat flow in the other, resulting in very low heat flow through the wall for many hours.

The balance point of a building is that temperature at which the building does not need either heating or cooling. For houses, the balance point tends to be between 60 to 65°F. Thermal mass works best in climates where the temperature fluctuates above and below the balance point during the day.

> **Mass not only works well when insulation is outside the mass but also works well when insulation is inside the mass**

In these cases, the thermal mass will have the outer side cooler during the nighttime (heat loss) and warmer during the daytime (heat gain) than the balance point of the building – resulting in reversals in heat flow through the wall – and therefore resulting in periods of very low heat flow through the mass wall. For CZ 3 and 4, the outdoor temperature fluctuates above and below the balance point for most days of the year, resulting in beneficial thermal mass effects.

Second, thermal mass also performs well when the mass is exposed on the inside of the wall. This inside mass helps prevent the inside air temperature from readily changing, and therefore delays and moderates times when the HVAC system requires heating and air-conditioning. This effect is generally separate and distinct from the reversals in heat flow through the wall described above.

Therefore, as further shown in this study, the inside surface of the walls are not required to be exposed thermal mass – there are still thermal mass effects when insulation and gypsum wallboard are on the inside surface of the mass wall.

In summary, thermal mass in walls performs well in CZ 3 and 4 and it:

Results show house with CMU walls with exterior insulation uses 5 to 35% less HVAC energy than the same house with wood-framed walls

- Doesn't have to be in a passive solar house with south facing glass and large indoor temperature swings. It performs well in a standard house.
- Doesn't have to be in a hot climate.
- Doesn't have to have concrete or CMU exposed on the inside surface (insulation can be on the inside surface).
- Performs well from Baltimore to Memphis to El Paso to Albuquerque to San Francisco to Salem.

The intent is that other aspects of thermal mass in masonry walls from this study, including benefits in other climate zones, will be covered in future articles.

Martha G VanGeem, PE, LEED AP BD+C, FACI is a self-employed consulting engineer in the Chicago area with over 35 years experience. She serves as a project principal investigator and specialized consultant in the areas of green buildings and infrastructure, energy use in buildings, energy codes, thermal mass and moisture mitigation. In the area of green technologies, VanGeem provides expertise on LEED and other green rating systems, product category rules (PCR), environmental product declarations (EPD) and life-cycle assessment (LCA). She is a member of many energy and green building standards committees including those within ASHRAE, ACI and ASTM. She is the recipient of ASHRAE's 2013 Standards Achievement Award and has authored more than 100 publications. VanGeem received her bachelor's degree of civil engineering from the University of Illinois (Urbana) and her MBA from the University of Chicago.
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