Optimum Design of Masonry Passive Houses

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ABSTRACT

Studies by the U.S. Department of Energy (DOE) indicates that about 30% of the energy used in the US is being used by the housing sector. Thus, energy efficiency in residential structures is a significant focus of energy efficiency and environmental impact efforts.

Passive home design has grown in popularity as a good approach to reduce energy demand for heating and cooling. Passive design principles (superinsulation, airtight envelopes, elimination of thermal bridges, etc.) were pioneered in North America in the 1970s and 1980s and refined in Europe. These principles are thought to be universally effective in significantly reducing heating and cooling loads.

Due to the high thermal mass of concrete masonry walled homes, traditional passive house design methods were felt to underestimate the impact of these high mass walls have on the heating and cooling demand of the homes. Thus, an investigation was conducted to evaluate the energy performance of a typical residence that uses exterior concrete masonry wall systems using holistic energy analyses. Within this study, a typical home placed in the seven climate zones of the US was assessed using holistic energy modeling software and analyzed for their energy efficiency and costs. This paper presets the key findings of this investigation.

The study showed that prototype home could be modified to reach passive home performance with wood stud walls with high levels of insulation, in all climate zones. The analysis also showed that in most climates increasing wall insulation was needed to achieve the fixed 53.95 kJ/^{2} (4.75kbtu/ft^2) cooling and heating energy limits for passive house performance but more insulation had a decreasing impact on energy use, especially in warmer climates.

The study also showed that passive home designs can be achieved with CMU exterior walls and increasing wall insulation was needed to achieve the fixed cooling and heating energy limits for passive house performance but increasing values of insulation had a much lower impact on energy use than with the wood stud wall systems, especially in warmer climates.

KEYWORDS

Masonry walls, energy use, passive house, optimum design

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INTRODUCTION

Studies by the U.S. Department of Energy (DOE) shows that 50% and 60% of the total yearly energy cost of residential and commercial buildings is associated with heating and cooling, respectively [1]. These studies also show that about 30% of the energy used in the US is being used by this sector. Energy efficiency in residential structures is thus a significant focus of energy efficiency and environmental impact efforts.

As part of the increase in concern about energy use, the U.S. Department of Energy (DOE) joined with the Passive House Institute US (PHIUS) to promote this residential design approach for enhanced energy performance as it supports use of renewable energy in residential applications and "Zero Net Homes".

"Passive House" design is the use of energy saving standards to reduce the amount of heat that is gained and lost within a structure. This lowers the need for conditioning energy compared to more conventionally constructed residential buildings [2]. These design principles (superinsulation, airtight envelopes, elimination of thermal bridges, etc.) were pioneered in North America in the 1970's and 1980's and refined in Europe in the 1990s and were thought to be universally effective. However, the single rigid envelope performance metric developed in Germany has led to limited uptake of passive building principles in many regions of the United States. This fixed metric has also promoted design decisions that result in uneconomic designs and poor thermal comfort [3].

As residential structures in the United States are typically made of light wood framing, much of the energy efficiency research has been directed to these structures. As more energy efficient residential structures are developed, especially as they relate to the application of "Passive House" principals, the impact of exterior concrete masonry walls on residential energy efficiency and costs must be better understood. The commonly used prescriptive envelope provisions conservatively ignore much of the beneficial thermal mass effects of the masonry walls systems and often result in over insulated with little or no real energy efficiency gains [4,5].

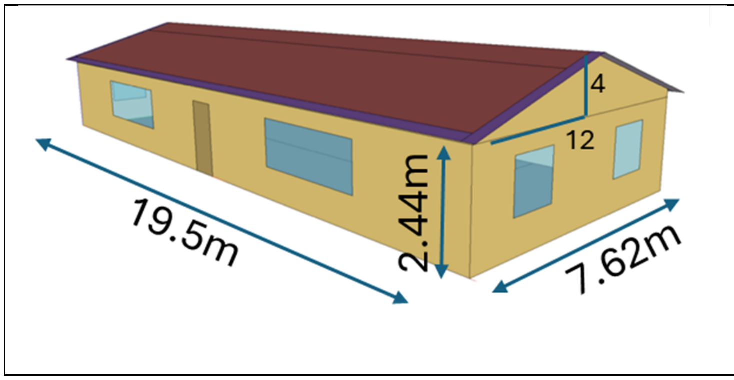
To investigate the used of exterior masonry walls in the passive design of homes, the following investigation evaluated the energy performance of a typical home with both wood stud walls and exterior concrete masonry walls. This was using holistic energy analyses [6] as this type of analysis has been shown to give a more exact assessment of the impacts of mass exterior wall energy efficiency (4,5]. Within this study, a typical one-story home was evaluated using holistic energy modeling software. These analyses were used to evaluate how concrete masonry walls can be configured to meet the passive house design criteria for energy efficiency in all 7 US climate Zones [7]. This following paper summarizes these analyses.

TYPICAL RESIDENCE AND ENERGY MODELLING

Base Home Model

To develop and assess the impact of mass exterior masonry walls systems on the energy use in typical residential applications in the US, an investigation of the energy used by typical single-story residential structures investigated. This study used the single-story residential prototype developed by NIST as the base model home [8]. This structure was chosen as it was specifically designed for US based energy studies and was specifically configured to represent the majority of single-family dwellings in the US. It was also suggested that this prototype can be used as a framework for developing additional prototype designs.

Figure 1 shows the one story residential NIST prototype building. This design was chosen to be representative of a simple one-story, 3-bedroom, 2-bathroom, slab-on-grade detached house with no garage. The prototype is a 2009 IECC compliant wood framed home, 19.5 m x 7.62 m (64 ft. x 25 ft.), with 148.6 m^2 (1,600 $ft.^2$) of conditioned floor area (CFA). In this study, the house was assumed oriented with long dimension east to west, and the short dimension north to south. The first floor has 2.44 m (8 ft.) high ceilings. The roof slope was assumed to be 4:12 with .3 m (1 ft) overhangs on the north and south sides. Additional characteristics of the home are listed elsewhere [8]



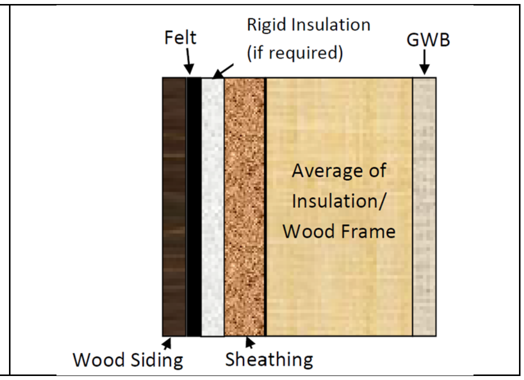


Figure 1 Single Story Residential Protype by NIST (Kneifel, 2011).

Energy Models

The investigation used an EnergyPlus holistic energy analysis in the form of the BEopt program to predict the energy used by of residential structures. This program was developed by the Department of Energy specifically for the wholistic analysis of typical single family residential structures and has been shown to accurately simulate performance of single-family homes with a variety of configurations [6,7]. Furthermore, this type of analysis has been shown to give more exact assessment of the impacts of mass exterior wall energy efficiency [4,5].

The prototype home was modelled using the BEopt program and the characteristics consistent with those listed for the NIST prototype [9]. The thermal resistance of the exterior envelope (excluding the roof) was determined using an average transmittance with the surface-weighted path fractions. The exterior wall construction was assumed to have 5 or 6 layers, depending on the energy code prescriptive requirements for the climate zone under consideration. The wall systems generally had wood siding, a felt air barrier, rigid insulation (if required by code), plywood sheathing, 38 mm x 89 mm (1.5 in. x 3.5 in.) framing with batt insulation in the wall cavities, and 13 mm (½ in.) gypsum wall board (GWB). Initially, the exterior walls were assumed to be 38 x 89 mm (1.5 in. x 3.5 in. wood-studs), 406 mm (16 in. on center) (OC) with cavity fiberglass batts with R 21.58 watt/m^2 K (3.8 ft^2·ºF·h/Btu) per 25 mm (1 in.) This was consistent with the IECC and the NIST prototype description.

The ceilings were assumed to have 38 x 140 mm (1.5 in. x 5.5 in.) ceiling joists 406 mm (16 inches on center) with blown-in cellulose insulation in the open cavities. Additional blown-in insulation was added on top of the cavity insulation as required by the IECC for the various climate zones. The average material U-factor was determined in the same manner as the exterior wall for the wood frame/cavity layers. Note that the wood framing accounts for 11 % of the ceiling surface.

The roof construction is assumed to be 38 x 140 mm (1.5 in. x 5.5 in.) wood rafters with 13 mm (1/2 in.) plywood sheathing, felt paper, and asphalt shingles. The roof is split into two surfaces for the energy simulation, one with framing (23 % of roof area) and one without framing (77 % of roof area).

The foundation/floor of the prototype home was a 101 mm (4 in.) concrete slab. Some climate zones require rigid insulation to be placed on the slab edge.

The window glazing area was taken as 15 % of the conditioned floor area and split between the four exterior walls based on wall area. Two, 1.22 m (4 ft.) high windows were modelled on each side of the house (8 in total) equal distanced from the wall edges. There were assumed to be two, 914 x 1830 x 203 mm, 32 mm (3 ft. x 6 ft., 1.75 in.) thick solid pine wood doors, located in the center of the exterior walls on the north and south walls. Windows and door U values are varied with climate zone as directed by code prescriptive maximums.

The exterior wall insulation R values were varied from R 73.8 watt/m^2/K (13 ft^2·ºF·h/Btu) to 119.2 watt/m^2/K (21 ft^2·ºF·h/Btu), depending on climate zone as directed by the prescriptive code tables. Typical HVAC systems, domestic hot water and lighting systems, along with typical use schedules were based on the energy analysis program default settings. Further details of the home configurations are described in the NIST report [9].

The appliances were taken as defined in the NIST document or were assumed to be consistent with those commonly used. All appliances, including the refrigerator, cooking range, dishwasher, clothes washer, clothes dryer, hot water fixtures, and plug loads were not varied in the base models, until passive house designs were attempted.

To validate the energy models of the prototype home, the predicted site energy from the BEopt model of NIST home, the results of the BEopt analyses were compared to typical residential energy use. Typical residential yearly energy use was taken from the 2015 Residential Energy Consumption data provided by U.S. Energy Information Administration [1]. The 2015 data is currently the most up to date information available they provide, and the use of this data allows the comparison of different energy sources. For a typical residence in an urban area, mixed humid climate region with the 148.6 m^2 (1600 ft^2) (same as the prototype) a range of approximately 65 kJ/year (62 MMBtu/year) to 76 kJ/year (72 MMBtu/year) was calculated for the city of Louisville, KY. Fig. 2 shows the predicted prototype home energy use using NIST home characteristics, falls within this range. The model was thus deemed to be reasonably accurate.

Table 1 shows comparisons of the yearly site energy predicted by the BEopt model for the prototype home configured to the 2021 International Residential Code (IRC) minimum insulation and efficiency requirements with variable heating sources for a range of different climate zones.

Table 1: Prototype Home Energy Site Energy Use by Climate Zone for Given Heat Source

		Electric Furnace		Gas Furnace		Air Source Heat Pump	
City	Zone	(KJ/year)	(MMBtu/year)	(KJ/year)	(MMBtu/year)	(KJ/year)	(MMBtu/year)
Miami, FL	1A	55.4	52.5	55.5	52.6	54.8	51.9
Houston, TX	2A	57.8	54.8	60.3	57.2	52.1	49.4
Las Vegas, NV	3B	57.6	54.6	59.9	56.8	52.3	49.6
Louisville, KY	4A	64.5	61.1	69.8	66.2	54.0	51.2
Seattle, WA	4C	69.0	65.4	76.7	72.7	52.1	49.4
Chicago, IL	5A	84.1	79.7	95.2	90.2	63.6	60.3
Minneapolis, MN	6A	103.4	98	119.6	113.4	78.8	74.7
Duluth, MN	7	118.7	112.5	138.8	131.6	91.4	86.6

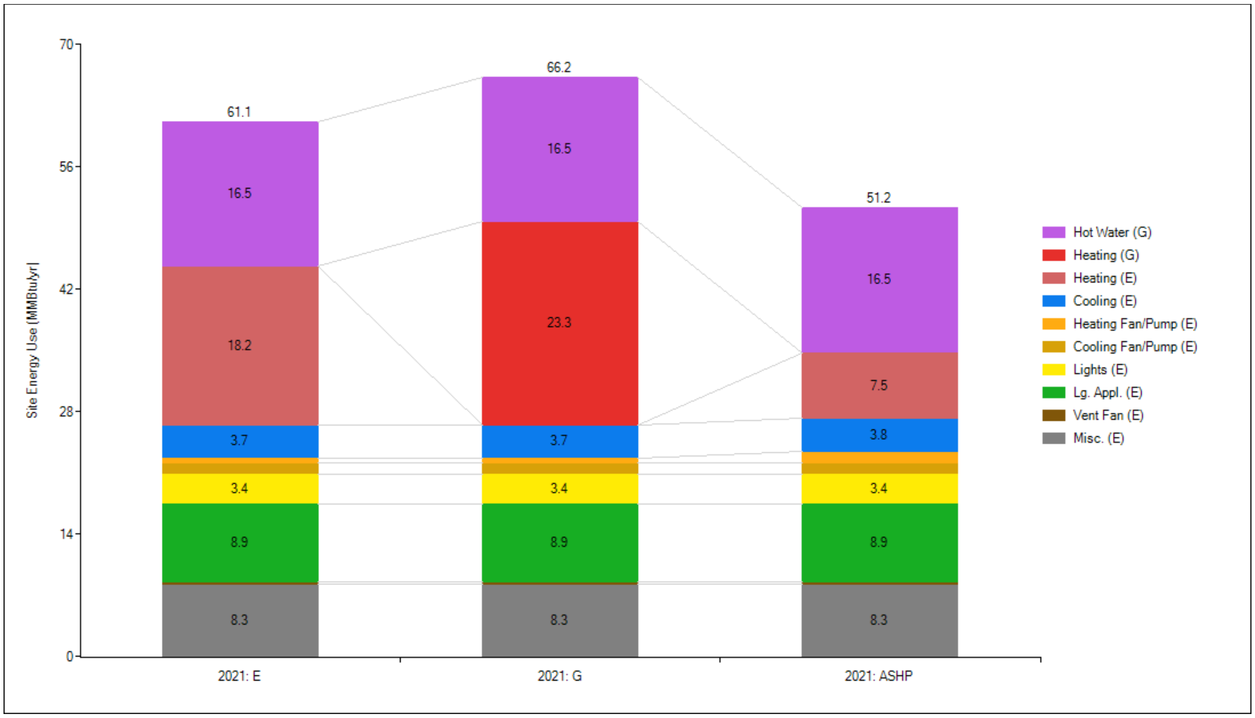


Figure 2: BEopt 2.8 Predicted Yearly Energy Use (NIST Home Configuration in Louisville) (Btu = 1.055 KJ)

Passive House Design

Passive house standards are not a singular set of prescriptive provisions that can be applied to produce a passive house design. Passive House design is a design methodology that is intended to reduce the amount of heat that is gained and lost within a structure in order to significantly lower the need for space conditioning [2]. For this investigation the goal of the passive designs was initially intended to meet the 53.94 KJ/m^2 (4.75kbtu/ft^2) heating and cooling energy limit required by this standard design methodology. Note that this limit is based on source limits and will vary significantly depending on the location of the home and the make-up of the grid electrical generation sources. It should also be noted that work by others suggest that this one size fits all energy limit may not be the most cost-effective way of applying passive house design in the US and they suggest climate zone variations on these limits [10,11]. These variable limits will be discussed later.

As “passive house” design requires a reduction of heating and cooling energy demand, it will result in different designs in each climate zone.

To allow easier comparisons, changes in prototype design were minimized during the passive house designs. In addition, the source limits on heating and cooling energy that are part of the passive house design were taken as site energy limits. We then assumed that PV panels would be sized to provide the energy needed by cooling and heating thus making site energy used for heating the same as source energy. This change made it simpler to compare similar residential designs using wood exterior walls and concrete masonry walls and evaluate the impact of exterior masonry walls. This methodology was also consistent with a passive home design study by LeBeau et al [10].

The prototype home was then modelled with exterior wood stud walls, and changes were made in the prototype base model home for each climate zone based on guidance from prior investigations [12, 10].

These changes are summarized in Table 2 for each climate zone. Modification of the 2021 IRC [13] compliant prototype home models were made until the heating and cooling yearly energy use were less than or equal to 53.94 KJ/m^2 ($4.75kbtu/ft^2$). In all analyses it was assumed that the ducts were in the conditioned space. The analyses also assumed:

- set points were 77 F in summer and 70 F in winter
- there was a gas hot water UEF=0.83 – 52 C (125 F)
- 100 % LEED lights
- freezer/refrigerator EF 21.9
- 80% usage electric range
- dishwasher 270 KWh 80% usage
- clothes washer IMEF=2.06 - 80% usage
- 0.6ACH50 air changes
- energy recovery ventilation – 70%
- natural ventilation in cooling months 3 days per week
- ceiling and interior walls, 13 mm (½ in.) drywall, asphalt shingles, wood doors - 40 ft^2 and 0.088 m^2K/W (0.5 btu/h-R-ft^2)
- interior shading = 0.7

Table 3 shows a summary of the prototype house (with Table 2 configurations) yearly site energy use broken down into total energy use, cooling energy, and heating energy, with changes intended to meet the passive house design criteria. This table also shows that the prototype home would meet the maximum cooling or heating energy limits in all climate zones (assuming this energy was provided on site by PV) and thus are compliant with the passive house standards.

Table 2: Passive House Applications (US Standard Units)

BEopt Input Categories	1A: Miami Florida	2A: Houston Texas	3B: Las Vegas Nevada	4A: Louisville Kentucky	4C: Seattle Washington	5A: Chicago Illinois	6A: Minneapolis Minnesota	7: Duluth Minnesota
Wood Stud	Uninsulated, 2x4, 16" o.c: R-21 Fiberglass Batt, 2x4, 16" o.c.	Uninsulated, 2x4, 16" o.c: R-21 Fiberglass Batt, 2x4, 16" o.c.	R-13 Batt, 2x4, 16" o.c.: R-21 Fiberglass Batt, 2x4, 16" o.c.	R-20 Batt, 2x4, 16" o.c.: R-21 Fiberglass Batt, 2x4, 16" o.c.	R-20 Batt, 2x4, 16" o.c.: R-21 Fiberglass Batt, 2x4, 16" o.c.	R-20 Batt, 2x4, 16" o.c.: R-21 Fiberglass Batt, 2x4, 16" o.c.	R-20 Batt, 2x4, 16" o.c.: R-21 Fiberglass Batt, 2x4, 16" o.c.	R-20 Batt, 2x4, 16" o.c.: R-21 Fiberglass Batt, 2x4, 16" o.c.
Exterior Insulation	R-60	R-60	R-60	R-5: R-60	R-5: R-60	R-5: R-60	R-5: R-60	R-5: R-60
Unfinished Attic	Ceiling R-38 Fiberglass, Vented	Ceiling R-60 Fiberglass, Vented	Ceiling R-60 Fiberglass, Vented	Ceiling R-60 Fiberglass, Vented	Ceiling R-60 Fiberglass, Vented	Ceiling R-60 Fiberglass, Vented	Ceiling R-60 Fiberglass, Vented	Ceiling R-60 Fiberglass, Vented
Slab	Under Slab 2' R5 XPS	Under Slab 2' R5 XPS	Under Slab 4' R10- XPS	Under Slab 4' R10- XPS	Under Slab 4' R10- XPS	Under Slab 4' R10 XPS	Whole Slab, R10 XPS	Whole Slab, R20 XPS
Windows 15% of wall area	ll Clear, double, thermal-break (U-value: 0.40; SHGC: 0.25)	Clear, double, thermal-break (U-value: 0.40; SHGC: 0.25)	Clear, double, thermal-break (U-value: 0.30; SHGC: 0.25)	Clear, double, thermal-break (U-value: 0.18; SHGC: 0.40)	Clear, double, thermal-break (U-value: 0.23; SHGC: 0.40)	Clear, double, thermal-break (U-value: 0.16; SHGC: 0.60)	Clear, double, thermal-break (U-value: 0.13; SHGC: 0.60)	Clear, double, thermal-break (U-value: 0.12; SHGC: 0.60)
Doors	Wood, U-value: 0.5 btu/h-R-ft^2	Wood, U-value: 0.5 btu/h-R-ft^2	Wood, U-value: 0.5 btu/h-R-ft^2	Wood, U-value: 0.5 btu/h-R-ft^2	Wood, U-value: 0.5 btu/h-R-ft^2	Wood, U-value: 0.5 btu/h-R-ft^2	Wood, U-value: 0.5 btu/h-R-ft^2	Wood, U-value: 0.5 btu/h-R-ft^2
Air Source Heat Pump	SEER 18.1, 8.4 HSPF2	SEER 16.2, 7.7 HSPF2	SEER 16.2, 7.7 HSPF2	SEER 16.2, 7.7 HSPF2	SEER 16.2, 7.7 HSPF2	SEER 20.9, 8.9 HSPF2	SEER 20.9, 8.9 HSPF2	SEER 20.9, 8.9 HSPF2

During this analysis, it was clear that some changes in the building characteristics did not have a significant impact on yearly energy use. For example, the interior shade characteristics did not change the overall energy use significantly. In addition, wall insulation above code minimums did not always have a significant impact on the building energy performance. Changes in exterior wall insulation also produced little change in yearly energy use in climates that predominantly require cooling. The prototype model in Miami Florida showed that there is almost no variation in yearly energy use with relatively large changes in exterior insulation exterior insulation levels (up to a sixfold increase from code minimums). This result was also observed colder climate zones, were increasing the exterior wall insulation levels significantly above code minimum levels had at most a 7% reduction in yearly energy use (note this is with over a 100% increase in insulation levels). It is clear that the current building code provisions in regards to exterior envelope characteristics provide close to passive design performance in the home in many climates.

Table 3: Passive House Energy Compliance (MMBtu = 1.055 kJ)

City	Zone	Base Model Energy Use		Passive Model Yearly Energy Use		Passive Model Cooling Energy Use		Passive Model Heating Energy Use		Passive Model Cooling/heating Energy Use		Passive Maximum Cooling/Heating Energy Use	
		MMBtu /yr	KJ/yr	MMBtu/ yr	KJ/yr	MMBtu/ yr	KJ/yr	MMBtu /yr	KJ/yr	kBtu/ft^2	x10^3 KJ/m^2	kBtu/ft^2	x10^3 KJ/m^2
Miami	1A	51.3	54.1	29.8	31.4	7.1	7.5	0.0	0.0	4.43	50.3	4.75	53.9
Houston	2A	48.2	50.9	29.3	30.9	5.1	5.4	0.6	0.6	3.19	36.2	4.75	53.9
Las Vegas	3B	49.8	52.5	30.4	32.1	5.5	5.8	1.1	1.2	3.43	39.0	4.75	53.9
Louisville	4A	55.1	58.1	32.0	33.8	2.9	3.1	3.4	3.6	2.13	24.2	4.75	53.9
Seattle	4C	48.2	50.9	30.1	31.8	0.72	0.8	3.7	3.9	2.31	26.2	4.75	53.9
Chicago	5A	63.9	67.4	33.2	35.0	1.9	2.0	4.9	5.2	3.06	34.8	4.75	53.9
Minneapolis	6A	79.1	83.5	36.2	38.2	1.3	1.4	7.0	7.4	4.38	49.7	4.75	53.9
Duluth	7	88.8	93.7	37.7	39.8	0.9	0.9	7.0	7.4	4.38	49.7	4.75	53.9

CMU Wall Systems

To evaluate use of exterior concrete masonry wall in passive house design, the exterior walls on the compliant prototype home BEopt models were replaced with masonry walls, as shown in Fig. 3. Initially, the exterior masonry walls were assumed to be uninsulated 8”, fully grouted hollow concrete masonry with an effective insulation value of R of 0.35 m^2K/W (2 $ft^2\cdot°F\cdot h/BTU$), [15]. This masonry wall configuration was chosen because it is one of the most common configurations used. A density of 1522 kg/m^3 (95 lb/ft^3) was assumed for the fully grouted wall. The R values of the CMU wall will vary with grouting percentage and density, but a uniform value was assumed. Additional exterior insulation and a finish system was assumed to be used to add thermal resistivity to the walls to determine its impact. Fig. 4 shows the yearly energy use of the prototype home with exterior CMU walls and varying levels of insulation for the Miami Florida climate. There is very little variation in yearly energy use even when significant amounts of insulation are added, up to 10.6 m^2K/W (R-60 $ft^2\cdot°F\cdot h/Btu$). Agan, it is clear that significantly increasing thermal insulation on exterior walls have little impact on energy use in cooling climates beyond code minimum values.

Fig. 5 shows the energy use of the protype home with CMU exterior walls in Duluth Minnesota (Climate Zone 7). Due to the extreme climate in this zone, larger variations in energy use are shown with increasing exterior wall insulation. A decrease of approximately 38% in yearly energy use was observed with an increase of exterior insulation to R of 0.88 m^2K/W (5 $ft^2\cdot°F\cdot h/Btu$). However, while these changes are larger than the other climate zones, the changes significantly reduce with increasing levels of insulation. After an R of 3.52 m^2K/W (20 $ft^2\cdot°F\cdot h/Btu$) of exterior insulation, increasing the external insulation over three-fold only reduced the yearly energy use of the prototype home by 2.11 kJ (2 MMBtu’s) per year.

For the exterior concrete masonry walls, the amount of insulation needed for CMU wall systems to achieve low energy losses through the envelope is much lower than that needed to wood stud walls. This is the impact of the thermal mass of the masonry wall, which reduces the heat movement in cyclic temperature swings.

Fig. 6 shows the total energy use for the passive home prototype for Louisville KY (Climate Zone 4 - mixed climate). The red dashed line shows the code (ICC 2021) minimum prescriptive insulation requirements for the CMU wall systems. It is clear that this level of thermal insulation shows prototype home yearly energy use very close to that for homes with much higher insulation values. It appears that use of mass exterior walls would allow for much less insulation than wood stud exterior wall systems for passive design. This lower insulation need for exterior CMU walls was seen in all climate zones.

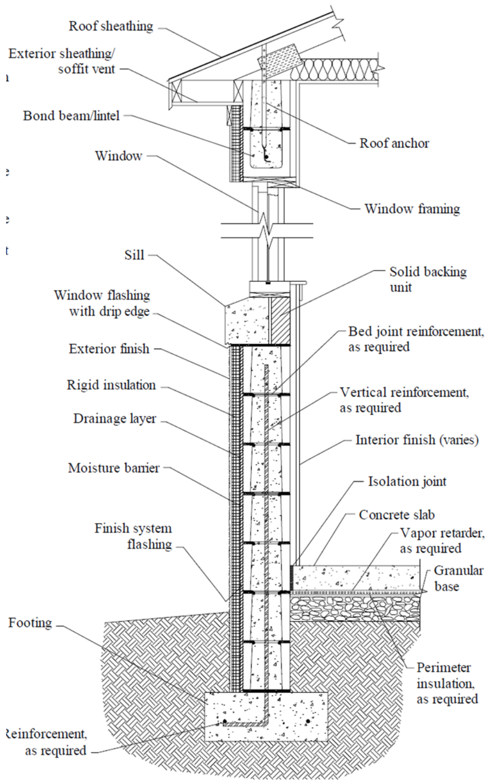


Figure 3: CMU Wall Configuration [14]

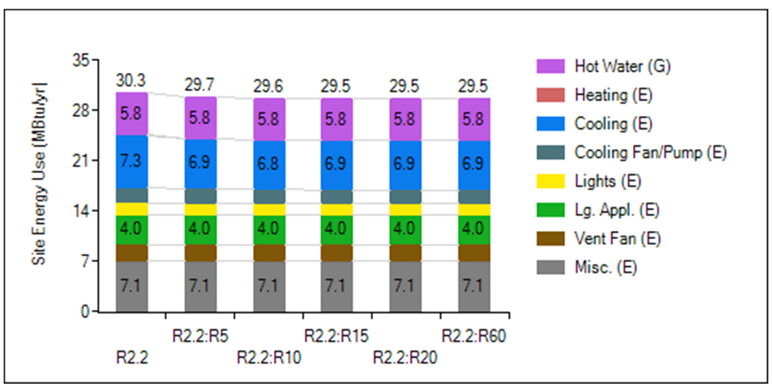


Figure 4: CMU Wall Varying Insulation, Miami Florida 1 (MMBtu = 1.055 kJ)

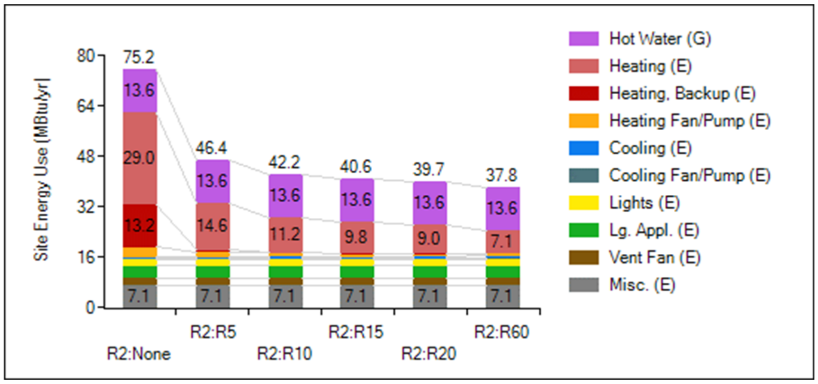


Figure 5: CMU Wall Varying Insulation, Duluth Minnesota (MMBtu = 1.055 kJ)

Again, using the prototype home configurations with exterior wood stud walls that were passive home design compliant, the exterior walls were replaced by CMU walls with exterior insulation. The exterior insulation levels were set to 10.6 m^2K/W (R 60 ft^2·°F·h/Btu). The prototype home yearly energy use for heating and cooling were found to be less than 53.95 kJ/^{2} (4.75kbtu/ft^2) and were thus passive house design compliant in all climate zones, assuming that PV site energy is provided to meet heating or cooling loads with CMU exterior walls. In addition, Klingenberg (2016) suggest that having one limit for heating and cooling energy for all climate zones is not an effective way to design homes over the range of climates typical in North America. They established passive home design limits for heating and cooling energy for each zone. Using these limits, the prototype home with CMU walls were analyzed with close to code minimum insulation. Table 4 shows the prototype homes that showed yearly heating and cooling energy use that meets passive home design standards.

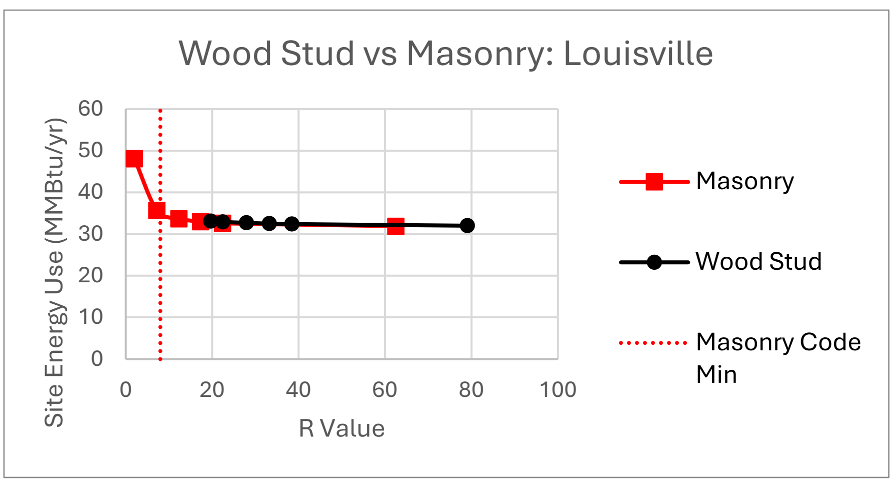


Figure 6: CMU and Wood stud Walls with Varying Insulation, Louisville KY (MMBtu = 1.055 kJ)

A similar performance was obtained for Masonry walls in a severe heating climate like Deluth MN, as shown in Figure 7.

A significant difference in the passive prototype home configurations with the CMU exterior walls is the lower amounts of insulation needed in many of the climates to achieve passive home performance, compared to wood stud wall configurations. For the homes that use CMU walls with R 0.88 m^2K/W (5 ft^2·°F·h/Btu) insulation, only 1in. of XPS insulation is needed, for an R of 1.76 ^{2}· m^2K/W (10 °F·ft^2h/BTU only 2 in. of XPS insulation is needed, and for the R 2.64 m^2K/W (15 $ft^2·°F·h/Btu$) insulation, 76 mm (3 in.) of XPS insulation is needed. This compares to R 10.4 m^2K/W (60 $ft^2·°F·h/Btu$) walls where 305 mm (12 in) of insulation is required.

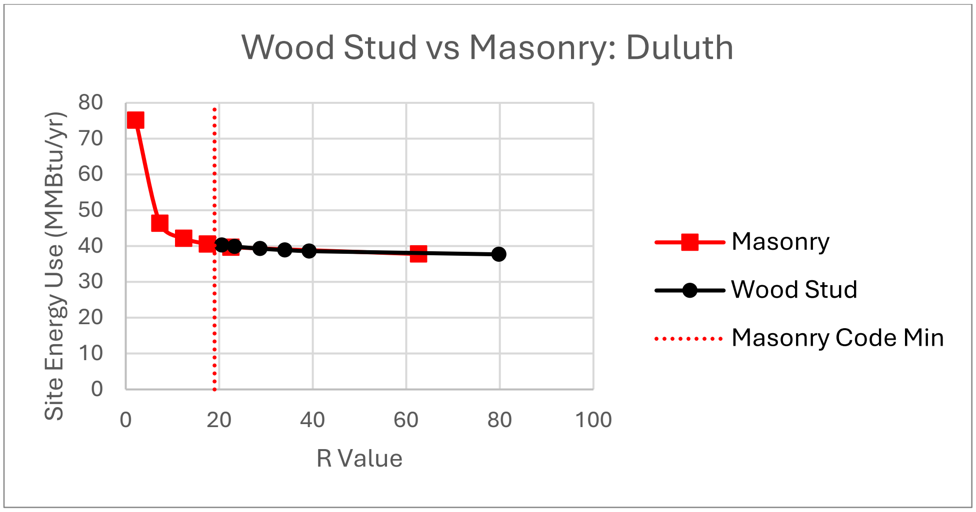


Figure 7: Wood Stud VS CMU, Duluth Minnesota (MMBtu = 1.055 kJ)

Table 4: Prototype Homes Meets Passive Climate Specific Home Design Standards. With Near Code Minimum Insulation Levels and CMU Walls.

City	Zone	Insulation Level		Passive Model Yearly Energy Use		Passive Model Cooling Energy Use		Passive Model Heating Energy Use	
		(m^2K/W)	($ft^2·°F·h/BTU$)	KJ/m^2	$Kbtu/ft^2$	KJ/m^2	$Kbtu/ft^2$	KJ/m^2	$Kbtu/ft^2$
Miami	1A	0.88	5	211.2	18.6	48.8	4.3	0.0	0
Houston	2A	0.88	5	213.5	18.8	35.2	3.1	0.0	0
Louisville	4A	1.76	10	239.6	21.1	18.2	1.6	36.3	3.2
Seattle	4C	1.76	10	224.9	19.8	3.4	0.3	36.3	3.2
Chicago	5A	2.64	15	243.0	21.4	12.5	1.1	43.2	3.8
Minneapolis	6A	2.64	15	271.4	23.9	9.1	0.8	63.6	5.6

Conclusions

This investigation evaluated the energy performance of a home with exterior concrete masonry walls using holistic energy analyses. Specifically, a review of the literature related to passive house design, energy efficiency, CMU wall systems, residential homes, and energy programs was conducted. Holistic building energy models were then created for a typical residence using exterior walls formed from wood stud. These holistic energy models were created for all seven climate zones in the United States and used to establish baseline energy performance based on existing energy related prescriptive building code provisions. This analysis was also used to identify what building systems impact energy use. Passive house principles and standards were then applied to the base-line residential model with wood stud exterior walls and changes were made in the building to achieve passive house energy performance in each climate zone. Exterior concrete masonry wall systems were then incorporated in the residential home as replacements for the exterior wood stud walls. Modifications of these models were made with the goal of meeting passive house performance limits. Changes in the exterior masonry wall systems were made to determine the differences in energy use that these changes produced. Specifically, the exterior wall insulation was varied to see what impacts this had on the building energy use.

The NIST home protype residential home design was chosen to be representative of a simple one-story, 3-bedroom, 2-bathroom, slab-on-grade detached house with no garage.

The study showed that prototype home could be modified to reach passive home performance with wood stud walls with high levels of insulation, in all climate zones. The analysis also showed that in most climates increasing wall insulation was needed to achieve the fixed 53.95 kJ/^{2} (4.75kbtu/ft^2) cooling and heating energy limits for passive house performance but more insulation had a decreasing impact on energy use, especially in warmer climates.

The study also showed that passive home designs can be achieved with CMU exterior walls in all climates. The analysis showed that in most climates increasing wall insulation was needed to achieve the fixed cooling and heating energy limits for passive house performance but increasing values of insulation had a much lower impact on energy use than with the wood stud wall systems, especially in warmer climates. This effect of the wall thermal mass was significant enough to allow insulation levels near building code minimums to achieve passive house performance in most climates, if the climate specific passive house limits are used.

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