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Analysis of the Concrete Masonry Unit (CMU) Mass Wall Effectiveness of the 2015 International Energy Conservation Code (IECC) for a Single-Family Residence in Illinois State, USA

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ABSTRACT

Purpose: Illinois State accepted the 2015 International Energy Conservation Code (IECC) with amendments as State Energy Code to establish minimum design and construction requirements for energy efficiency of the buildings. In the 2015 IECC, mass wall credits are allowed to use to maintain the thermal performance of building's exterior walls while reducing the R-value based on the insulation strategies of mass walls. This paper investigates the effectiveness of mass wall according to the 2015 IECC for a single-family residence in Illinois State, USA. **Method:** Three climate locations (northern, central and southern locations) in Illinois were selected. Next, the general characteristics of the house including the floor area, construction type, thermal characteristics of the building envelope, an efficiency of the HVAC and DHW system were decided and modeled based on the survey data. Then, different wall types as specified in the IECC 2015 were incorporated into the simulation models. Next, simulations were performed to study the effects resulted by the wall types and different climates using the BEopt building energy simulation program. Lastly, the electricity (kWh/year) and gas consumptions (MBtu/year and kWh/year) of each simulation were converted to energy costs. **Results:** The following observations are found: 1) cooling and heating energy use were almost the same owing to the thermal mass effect of the code-specified envelope characteristics; 2) CMU walls with integral insulation strategies, which are not compatible with the 2015 IECC, show the highest heating, cooling energy and annualized utility bills ; 3) there are larger variations in heating energy use than cooling energy use; 4) utility bills are increased as moving from southern to northern region.

KEYWORD

축열벽
IECC 건물 코드
냉난방 에너지

Mass Walls
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1. Introduction

It has been known that the use of thermal mass wall is one of the effective ways to reduce building's heating and cooling loads. In addition, mass wall can be efficiently used to maintain a stable room temperature in areas where it has large swings of daily temperature because mass wall can absorb heat from the sun and release it over time.

According to Zhu et al. [1], proper applications of mass walls in buildings can reduce building heating and cooling loads more than buildings made with lightweight materials. In addition, the proper combinations of location and numbers of layers of insulation shows different thermal performance [2], and Kosny et al. [3] found that three layers of insulation had the best thermal performance if one of three insulation layers was located in the outside of wall, the second layer of insulation was in the middle of wall and third piece of insulation was in the interior face of wall.

One research found that the steady-state R-value used for measuring the thermal performance of the insulation does not reflect the dynamic thermal performance of massive walls. Therefore, dynamic thermal performance analysis using detailed simulation should be incorporated to evaluate the benefit of mass walls [4].

IECC (International Energy Conservation Code) is the building code that was enacted in 2000 by the International Code Council (ICC). Many states and municipal governments in the United States adopted the IECC to establish minimum design and construction requirements for the energy efficiency of the buildings. Illinois State adopted the 2015 IECC with amendments as the State Energy Code [5].

In the 2015 IECC, use of mass wall as the building envelope allows less R-value than wood frame wall based on the TABLE R402.1.2 in the 2015 IECC (Table 1) for each climate zone. As written in the 2015 IECC [6], mass walls are above-grade walls of concrete block, concrete, insulated concrete form (ICF), masonry cavity brick (other than brick veneer), earth (adobe, compressed earth block, rammed earth) and solid timber/logs, or any other walls having a heat capacity greater than or equal to 6 Btu/ft^2•°F (37.9 kJ/m^2•°C).

Table 1 shows that the IECC 2015 allows reducing insulation level (R-value) if exterior walls are constructed with mass materials based on the climate zone that will be explained in the next section.

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Table 1. Insulation requirements by component (partial excerpt from the 2015 IECC)

Climate Zone (Illinois)	**Wood Frame Wall R-value (hr • ft^2 • °F/Btu) (m^2 • °C/w)**	**Mass Wall R-value (hr • ft^2 • °F/Btu) (m^2 • °C/w)**
4	20 (3.52) or 13+5[1)] (2.29 + .88)	8/13[2)] (1.41/2.29)
5	20 (3.52) or 13+5 (2.29 + .88)	13/17 (2.29/2.99)

Although many previous studies have evaluated the thermal performance of various types of walls, there were not enough research to compare the thermal performance of the mass walls with the typical wood frame walls as changing the location of insulation layers as specified in the IECC code.

This paper presents detailed comparison results of the electricity and gas energy consumptions among different wall types including typical wood frame walls and various CMU (Concrete Masonry Unit) mass walls as specified in the 2015 IECC in Illinois State. For the analysis, BEopt simulation program ver. 2.7 was used. BEopt stands for Building Energy Optimization, and has been developed by the National Renewable Energy Laboratory (NREL) in support of the U. S. Department of Energy (DOE). BEopt software is graphical user interface (GUI) to utilize EnergyPlus simulation engine, and provides detailed simulation analysis to evaluate residential building energy consumptions and identify cost-optimal efficiency packages [7].

2. Methodology

The purpose of this study is to investigate the effectiveness of the CMU mass walls comparing with typical wood frame walls in Illinois State based on the 2015 IECC. To accomplish this, three climate locations (northern, central and southern locations) in Illinois were selected. Next, the general characteristics of the house including the floor area, construction type, thermal characteristics of the building envelope, an efficiency of the HVAC and DHW system were decided and modeled based on the U.S. Census Bureau [8], the 2015 IECC [6] and NREL [9]. Then, different wall types as specified in the IECC 2015 were incorporated into the simulation models as other variables remain the same. Next, simulations were performed at the three locations to investigate the effects resulted by the wall types and different climates. Lastly, the electricity (kWh/year) and gas consumptions (MBtu/year and kWh/year) of each simulation were converted to energy costs ($/year and ₩/year).

2.1. IECC Climate Zone

IECC uses the 17 zone classification scheme which was developed by Briggs et al. [10] using temperature, radiation, wind and humidity (Figure 1, left). Climate zones are numbered from 1 to 8, with higher zone numbers representing colder climates, and are further divided into moist (A), dry (B), and marine (C) regions. State of Illinois belongs to Climate Zone 4A and 5A.

In order to investigate CMU mass wall effects occurred by different weather in Illinois State, three TMY3 weather files were selected based on the geographical location; 1) Northern Region: Chicago TMY3 weather file (Climate Zone 5A), 2) Central Region: Springfield TMY3 weather file (Climate Zone 5A), and 3) Southern Region: Carbondale TMY3 weather file (Climate Zone 4A) (Figure 1, right). The summary of the climate characteristics is shown in Table 2.

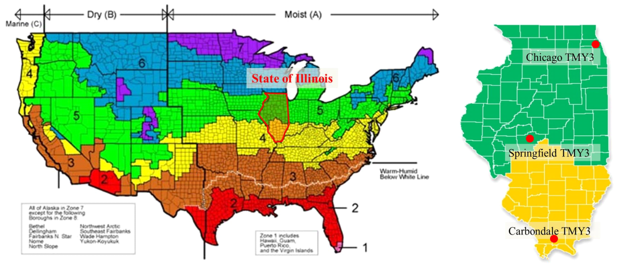


Figure 1. 2015 IECC Climate Zones (left) and Illinois Climate Zones with TMY3 weather files for simulations (right)[10]

Table 2. Climate characteristic of the three selected locations

Location	HDD65[3)]	CDD65[4)]	Annual Avg. Dry-bulb Temp.	RH (%)
Carbondale, IL	3983	1553	57°F (14°C)	72
Springfield, IL	5596	1165	53°F (12°C)	69
Chicago, IL	6493	835	49°F (9°C)	70

2.2. Base-Case Simulation Model

According to U.S. Census Bureau [8], the median size of a completed single-family house in 2016 was 2,422 ft^2 (225 m^2). In order to simplify the base-case simulation model, 2,500ft^2 (232 m^2) single-family detached residence with a square-shape plan was considered as the basis for the simulations. Building envelope and system properties such as R-value, SHGC and HVAC equipment efficiencies were modeled as specified by the 2015 IECC [6]. Other building characteristics which were not specified by the 2015 IECC were modeled based on the Building America Housing Simulation Protocols developed by National Renewable Energy Laboratory [9]. The Building America Housing Simulation Protocols (HSP) document was sponsored by the U.S. Department of Energy (DOE), and it provides guidance to the simulation model.

The base-case model for the simulations is a single story residence with 9 ft (2.7m) wall height, slab-on-grade and an unconditioned-vented attic. Base-case model has a 15% window-to wall ratio and fraction of this window area has been equally distributed on each façade (i.e. 25% window area on each front, back, left and right facade). For consistency of the simulations, the same building and system

1) The first value is cavity insulation, the second value is continuous insulation, so "13+5" means R-13 cavity insulation plus R-5 continuous insulation.

2) The second R-value applies when more than half the insulation is on the interior of the mass wall.

3) Heating Degree Days at 65° F (18.3° C) base temperature

4) Cooling Degree Days at 65° F (18.3° C) base temperature

configurations were assumed for all buildings and locations conforming to the 2015 IECC [6] and NREL [9] while changing only the wall type. Table 3 shows the model specifications of simulations except wall types. Wall types have been explained in Table 4.

Table 3. Base-case simulation model specifications

	Category	IECC Zones	Option	Ref.
Building	Orientation	All	North	[9]
Operation	Heating Set Point	All	71°F (21.7°C)	
	Cooling Set Point	All	76°F (24.4°C)	
Ceiling / Roof	Unfinished attic	4 and 5	R-49 (8.63 m^2 • °C/w)5) cellulose, vented	[6]
	Roof material	All	Asphalt shingles, medium	[9]
Foundation/ Floors	Slab	4 and 5	2-ft (0.61 m) R-10 (1.76 m^2 • °C/w) perimeter, R-5 (0.88 m^2 • °C/w) gap	[6]
Windows	Window	4	Double-pane, medium-gain low-e, nonmetal frame, argon fill (U = 0.35 Btu/hr•°F•ft^2 (1.97 W/°C•m^2), SHGC = 0.40)	
		5	Double-pane, medium-gain low-e, nonmetal frame, argon fill (U = 0.32 (1.80 W/°C•m^2), SHGC = NR)	
Space Conditioning	Heating	All	Gas, 78% AFUE6) furnace	
	Cooling	All	SEER7) 13 central air conditioner	

2.3. Selected Wall Types

In order to investigate the mass wall effectiveness, CMU mass walls were compared with typical wood frame walls. Typical wood frame walls consist of vinyl siding, OSB (Oriented Strand Board), insulation, stud and gypsum board. As specified in the 2015 IECC (Table 1), two wood frame walls were modeled; 1) R-20 (3.52 m^2 • °C/w) with 2"x6" (5cmx10cm) @ 24" (61cm) O.C. (On Center) stud (Figure 2, left), 2) R-5 XPS (0.88 m^2 • °C/w) as continuous insulation and R-13 (2.29 m^2 • °C/w) with 2x4 @ 16" (41cm) O.C stud (Figure2, right).

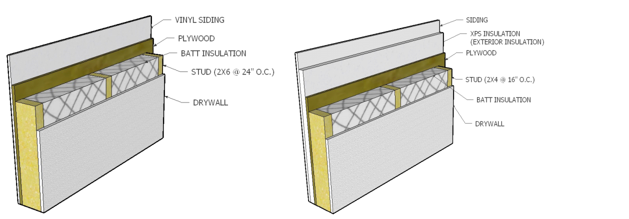


Figure 2. Wood frame wall wth R-20 insulation (left) and R-13+5 insulation (right) as specified in the IECC 2015

In order to find the general CMU wall types for a residence, CMU wall configurations from Concrete Masonry Association [11] were referred. According to Concrete Masonry Association, there are three CMU wall types; interior insulation, integral, and exterior insulation. The interior insulation is used to separate the interior from the mass wall as decreasing the ability of the mass walls in maintaining room temperature (Figure 3, top, left). Integral insulation is a method of filling insulation materials such as perlite in the cell of CMU (Figure 3, top, right), and exterior insulation is that insulation is installed outside of CMU wall as the mass wall is exposed to inside (bottom). It has been known that exterior insulation is the least affected by the outdoor conditions among the three insulation strategies. Since the 2015 IECC did not specify the integral insulation, CMU wall with integral insulation does not comply with the IECC. However, the study included this wall type for comparison because integral insulation is also one of the popular insulation strategies in the industry. In addition, three different sizes of CMU (6" (15cm), 8"(20cm) and 12" (30cm)) were used for the analysis to investigate the effect of CMU wall thickness.

Eleven wall types with different insulation level were modeled for comparison as shown in Table 4. Wall type #1 and # 2 indicate the typical wood frame wall, wall type #3 to #5 indicate CMU walls with exterior insulation, wall type #6 to #7 indicate the integral insulation and wall type #9 to #11 indicate CMU walls with interior insulation. Each wall type shows each layer from exterior to interior. R-value of each wall was selected to comply with the 2015 IECC (Table 1) except the wall type #6, 7, and 8 (integral insulation strategy) because insulations were not installed on these wall types.

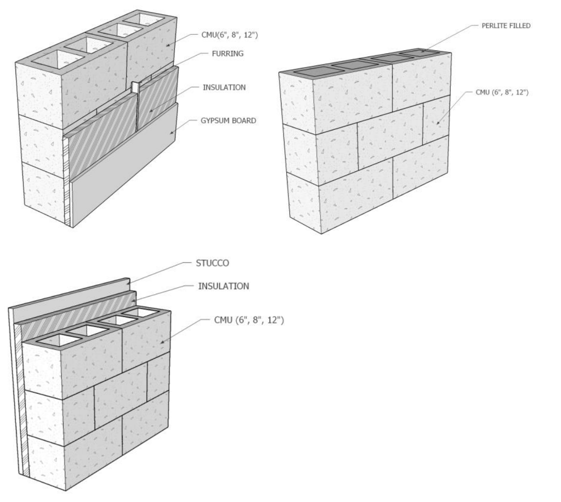


Figure 3. Three CMU wall insulation strategies: interior (top, left), integral (top, right), and exterior (bottom).

2.4. Fuel Prices

The electricity and gas consumption of the simulation results are converted to energy costs using the most recent state-specific residential fuel price of DOE's energy information management [12 and 13]. Fuel price of electricity was \$0.121/kWh and gas price was \$0.788/therm plus \$8.00 monthly service charge.

5) Numbers in the parenthesis indicate the SI unit
6) Annual fuel utilization efficiency
7) Seasonal Energy Efficiency Ratio

Table 4. Wall types for simulations.

Wall Type	Wall Layers (from exterior to interior)	U-value 8)	Climate Zone
#1	Vinyl Siding (3/8") (95mm) + OSB (1/2") (12.7mm) + R-20 (3.52) Batt Insulation with 2x6, 24 in o.c. + Gypsum board (1/2") (12.7mm)	0.054 (0.304)	4 & 5
#2	Vinyl Siding (3/8") (95mm) + OSB (1/2") (12.7mm) + R-5 (0.88) XPS + R-13 (2.29) Batt Insulation with 2x4, 16 in o.c. + Gypsum board (1/2") (12.7mm)	0.056 (0.316)	
#3	EIFS stucco (1") (25.4mm) + R-8 (1.41) XPS + 6-in. (150mm) Hollow CMU	0.073 (0.415)	4
	EIFS stucco (1") (25.4mm) + R-13 (2.29) XPS + 6-in. (150mm) Hollow CMU	0.053 (0.304)	5
#4	EIFS stucco (1") (25.4mm) + R-8 (1.41) XPS + 8-in. (200mm) Hollow CMU	0.070 (0.398)	4
	EIFS stucco (1") (25.4mm) + R-13 (2.29) XPS + 8-in. (200mm) Hollow CMU	0.052 (0.295)	5
#5	EIFS stucco (1") (25.4mm) + R-8 (1.41) XPS + 12-in. (300mm) Hollow CMU	0.069 (0.390)	4
	EIFS stucco (1") (25.4mm) + R-13 (2.29) XPS + 12-in. (300mm) Hollow CMU	0.051 (0.290)	5
#6	6-in. (150mm) Perlite CMU	0.156 (0.884)	4 & 5
#7	8-in. (200mm) Perlite CMU	0.127 (0.718)	
#8	12-in. (300mm) Perlite CMU	0.093 (0.525)	
#9	6-in. (150mm) Hollow CMU + R-13 (2.29) XPS + Gypsum Board (1/2") (12.7mm)	0.053 (0.300)	4
	6-in. (150mm) Hollow CMU + R-17 (2.99) XPS + Gypsum Board (1/2") (12.7mm)	0.044 (0.248)	5
#10	8-in. (200mm) Hollow CMU + R-13 (2.29) XPS + Gypsum Board (1/2") (12.7mm)	0.051 (0.291)	4
	8-in. Hollow (200mm) CMU + R-17 (2.99) XPS + Gypsum Board (1/2") (12.7mm)	0.043 (0.241)	5
#11	12-in. (300mm) Hollow CMU + R-13 (2.29) XPS + Gypsum Board (1/2") (12.7mm)	0.050 (0.286)	4
	12-in. (300mm) Hollow CMU + R-17 (2.99) XPS + Gypsum Board (1/2") (12.7mm)	0.042 (0.238)	5

3. Results

Simulation results identify the major end-use components of the electricity use and thermal energy use including cooling, heating, cooling fan, heating fan, lights, appliances, and domestic hot water for each simulation. In order to confirm the validity of the simulation results, simulation results of the wood frame walls from each location were compared to the survey data of energy consumption per household from U.S. EIA (Energy Information Administration)[14].

As shown in Table 5, there seems to be no significant difference between the simulation results and the survey data.

Table 5. Simulation results vs. U.S. EIA Survey Data.9)

Location	Simulations	Simulation Average	U.S. EIA
Chicago, IL	145.1 (42.5)	126.5 (37.1)	128.8 (37.7)
Springfield, IL	127.9 (37.5)		
Carbondale, IL	106.6 (31.2)		

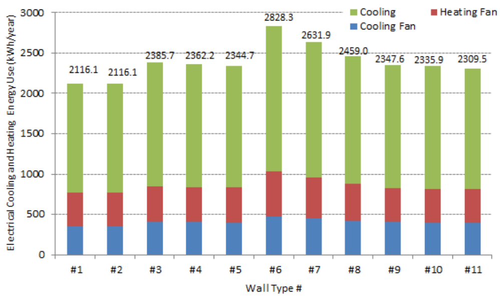
8) First number indicates U-value in IP unit (Btu/hr•° F•ft2) and second number in parenthesis indicates U-value in SI unit (W/° C•m2)

9) First number indicates MMBtu/year and and second number in parenthesis indicates MWh/year

Simulations were performed using eleven wall types on three different locations in Illinois. Since simulation results from cooling and heating energy showed the variation while other results remained the same, results were analyzed using data from only cooling, heating, cooling fan and heating fan. Figures 4 to 6 show the annual electricity (kWh/year) and gas (MBtu/year and kWh/year) consumptions, and annualized utility bills ($/year and ₩/year). Wall Type # in each figure matches the numbers listed in Table 4.

3.1. Southern Region (Climate Zone 4A)

Carbondale TMY3 weather file was used for the simulations of the southern region. The analysis showed that the cooling energy use of wall types #1 and #2 (wood frame walls) was the same at 2116.1 kWh/year, and heating energy use was 58.4 MBtu/year (17,111 kWh/year) and 58.3 MBtu/year (17,088 kWh/year) respectively. This means that R-20 (3.52 m^2 • °C/w) cavity insulation has very similar thermal performance with R-5 (0.88 m^2 • °C/w) continuous and R-13 (2.29 m^2 • °C/w) cavity insulation. After changing the wall type from wood frame walls to CMU mass walls, cooling energy increased by 10.9% on average. Heating energy use increased by 2.7% for exterior insulation, and decreased by 1.6% for interior insulation. When comparing the results from exterior insulation and interior insulation of the same thickness of CMU wall (i.e. wall type #3 vs. #9, #4 vs. #10, and #5 vs. #11), interior insulations showed less cooling and heating energy consumptions. It is because the requirement of interior insulation (R-13) (2.29 m^2 • °C/w) was higher than exterior (R-8) (1.41 m^2 • °C/w) on the 2015 IECC even though the exterior insulation has been known to be better efficient than interior insulation. As expected, the integral CMU walls (wall types #6, #7 and #8), which were not compatible with the 2015 IECC, showed higher cooling and heating energy use than the other wall types. For annualized utility bills, #1 and #2 wood frame wall types showed the lowest utility bills ($1875.8 (₩2,065,000) and $1876.5 (₩2,066,000)respectively) than the other wall types. Among the CMU walls, #5 and #11 wall types, which used 12" (30cm) CMU, showed the lowest utility bills than the other CMU walls.



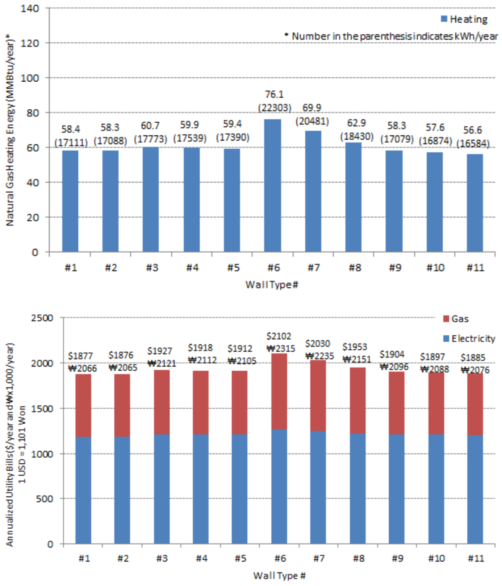


Figure 4. Cooling energy use (top), Heating energy use (center) and annualized utility bills (bottom) (Southern Region)

3.2. Central Region (Climate Zone 5A)

Springfield TMY3 weather file was used for the simulations of the central region. Cooling energy use decreased and heating energy use increased compared to the southern region. These variations in the cooling and heating energy use simply reflected the colder climate condition of this location. The electrical energy use of wall types #1 and #2 (wood frame wall) showed the same at 1623.7 kWh/year, which decreased by 23.3% from the southern region. Heating energy use was 80.1 MBtu/year (23,481 kWh/year), which increased by 37.2% from the southern region. The wood frame wall types showed lower cooling energy use than the CMU wall types, while CMU wall types with insulations showed lower heating energy use than the wood frame wall. Cooling energy use increased by 5.6% average and heating energy use decreased by 4.0% after changing wall types from the wood frame walls to CMU mass walls.

The comparison of annual cooling energy use of CMU wall types showed that exterior insulation strategy (wall types #3, #4 & #5) reduced cooling energy slightly than the interior insulation strategy (wall types #9, #10 & #11). Exterior insulation strategy resulted in slight increase of heating energy than the interior insulation strategy.

For annualized utility bills, #11 and #5 wall types using 12” (30cm) CMU showed the lowest utility bills than the other wall types because of heating energy reduction. A large variation in the heating energy use for space heating was observed in this location than the southern region. It indicated higher savings in heating energy use due to the thermal mass properties of CMU walls. The integral CMU walls (wall types #6, #7 and #8), which were not compatible with the 2015 IECC, showed the most electrical and thermal energy use.

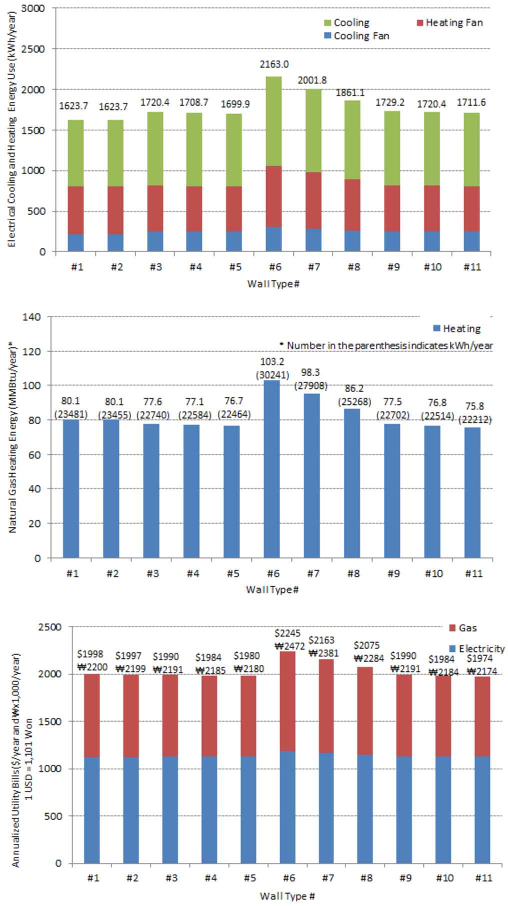


Figure 5. Cooling energy use (top), Heating energy use (center) and annualized utility bills (bottom) (Central Region)

3.3. Northern Region (Climate Zone 5A)

Chicago TMY3 weather file was used for the simulations of the northern region. The patterns of simulation results from the northern region were similar to that of the central region as cooling energy use decreased and heating energy increased. When wall types were changed from wood frame walls to CMU mass walls, cooling energy use increased and the heating energy use decreased. Cooling energy use and heating energy use of the wood frame walls (wall type #1 and #2) showed 1304.2 kWh/year (38.4% lower compared to the southern region) and 97.5 MBtu/year (28,556 kWh/year) and 97.4 MBtu/year (28,529 kWh/year) (67.0% higher compared to the southern region) respectively. It was also found that the wood frame walls (#1 and #2) showed less cooling energy use (4.5% average difference) and higher heating energy use (3.5% average difference) than the CMU walls.

For CMU wall comparisons of the same thickness, exterior insulation strategy (wall type #3, #4 and #5) provided more benefit in saving cooling energy use, and interior insulation strategy (wall type #9, #10 and #11) yields better contribution to saving heating energy use. For annual utility bills, wall types #11 and #5 showed the lowest utility bills over the year.

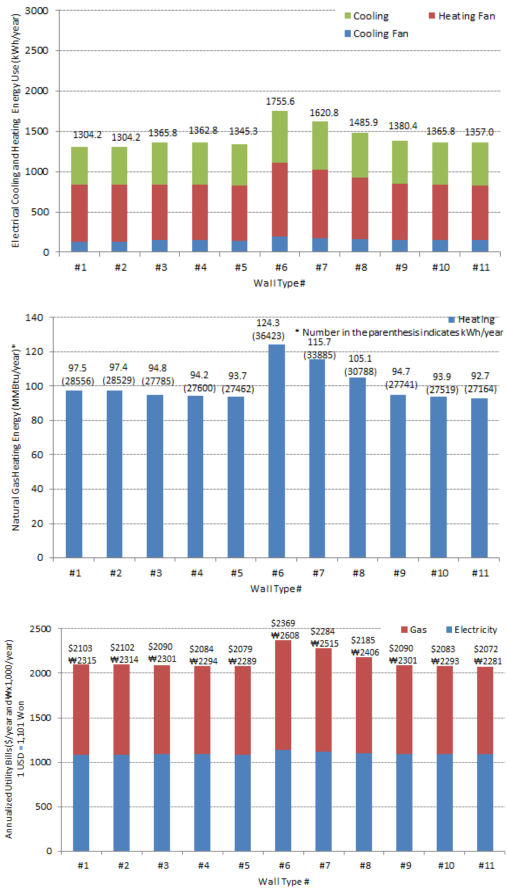


Figure 6. Cooling energy use (top), Heating energy use (center) and annualized utility bills (bottom) (Northern Region)

4. Conclusion

This paper explored the effectiveness of CMU mass walls according to the 2015 IECC in the State of Illinois. Based on the simulation results, the following observations are found: 1) even though insulation levels of CMU walls were lower than the wood frame wall, cooling and heating energy use were similar owing to the thermal mass effect of the code-specified envelope characteristics in all the three locations; 2) integral insulation strategies (wall type # 6, #7, and #8) were not compatible with the 2015 IECC, and showed the highest heating, cooling energy and annualized utility bills; 3) It was also found that there were larger variations in heating energy use than cooling energy use when locations are changed from southern to northern region; 4) Increased utility bills were found as moving from southern to northern region, because of the increased heating energy demand. It means that the rate of the heating energy increment is greater than the cooling energy reduction. Annualized utility bills increased by 6.4% as changing the location from the southern to the central region and 12.1% from the southern to the northern region in the case of the wood frame wall. For CMU wall types, annualized utility bills increased by 4.0% as changing the location from the southern to the central and 9.2% from the southern to the northern region. It implied that CMU mass walls can contribute more to the utility bill savings than wood frame wall because of the less variation.

5. Future Work

This study used only one residence type which was the slab-on-grade using electricity for cooling and gas for heating in Illinois State (Climate Zone 4A and 5A). Different case studies can be evaluated including different foundation systems such as finished basement, unfinished basement and crawl spaces, other climate zones, and different fuel types for HVAC systems. In addition, this study did not investigate other mass wall types such as concrete, insulated concrete form (ICF), masonry cavity, brick, earth, etc., so the benefits of other mass wall types can be further investigated. Lastly, analysis of mass walls with cost effectiveness can be more realistic in comparing different mass wall options.

Reference

[1] Zhu, S., Hurt, D., Correia, R., Boehm, R., “Detailed energy saving performance analyses on thermal mass walls demonstrated in a zero energy house”. Energy and Building, Vol.41, 303–310, 2009

[2] Al-Sanea, S.A., Zedan, M.F., "Improving thermal performance of building walls by optimizing insulation layer distribution and thickness for same thermal mass". Applied Energy, Vol.88(9), 3113-3124, 2011

[3] Ozel, M., Pihtili, K., "Optimum location and distribution of insulation layers on building walls with various orientations". Building and Environment, Vol.42(8), 3051-3059, 2007

[4] Kosny, J., J.E. Christian, A.O. Desjarlais., E. Kossecka, and L. Berrenberg., “The performance check between whole building thermal performance criteria and exterior wall measured clear wall R-value, thermal bridging, thermal mass, and air-tightness”. ASHRAE Transactions, Vol 104(2), 1379-1389, 1998

[5] U.S. Department of Energy (US DOE), “Building Energy Codes Program”, Available at https://www.energycodes.gov/adoption/states/illinois (accessed Sep 25, 2017), 2015

[6] International Code Council (ICC), “2015 International Energy Conservation Code”, Country Club Hills, IL: International Code Council, Inc,. 2014

[7] NREL (National Renewable Energy Laboratory), “BEopt”, Available at https://beopt.nrel.gov/ (accessed Nov 15, 2017), 2017

[8] U.S. Census Beaureu, “Highlights of Annual 2016 Characteristics of New Housing”, Available at https://www.census.gov/construction/chars/highlights.html (accessed Sep 1, 2017), 2016

[9] NREL(National Renewable Energy Laboratory), “2016 Building America Housing Simulation Protocols (Report Number: NREL/TP-5500-60988)”, Golden, CO: U.S. Department of Energy, 2016

[10] Briggs, R.S., R.G. Lucas, Z.T. Taylor., “ASHRAE 4610/4611 – Climate Classification for Building Energy Codes and Standards”, Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 2003

[11] Concrete Masonry Association. “CMU Insulation Methods”, Available at http://www.cmacn.org/energy/basics/cmu.htm (accessed Aug 7, 2017), 2017

[12] EIA (U.S. Energy Information Administration), “Electric Power Monthly”. Available at https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a (accessed Sep 27, 2017), 2017

[13] EIA (U.S. Energy Information Administration), “Natural Gas Prices”, Available at https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PRS_DMcf_a.htm (accessed Sep 27, 2017), 2017

[14] U.S. Energy Information Administration (EIA), “Residential Energy Consumption Survey”, Available at https://www.eia.gov/consumption/residential/data/2009/index.php?view=consumption#summary (accessed Nov 16, 2017), 2009