J.B. SPEED SCHOOL OF ENGINEERING

Concrete Masonry Passive House Design

W. Mark McGinley, Ph. D., PE FASTM, FTMS
Briana Kozlowski, M.Sc.

The Masonry Society
Fall Meetings Nov 2023

1

1

Introduction

- DOE indicates that 50% and 60% of the total yearly energy cost of residential and commercial buildings, a significant energy use sector (30%). Is used to cool and heat.
- Passive House design is intended to reduce the amount of heat that is gained and lost within a structure.
- Although residential structures in the United States are typically constructed from light wood framing, many areas use residences with exterior wall systems assembled out of concrete masonry units (CMU's).
- Application of "Passive House" principals to the design homes with exterior concrete masonry walls on residential energy efficiency was investigated.

2

2

Introduction

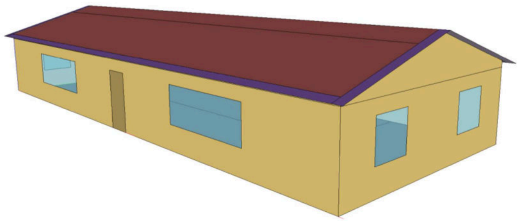
- Used Holistic Energy Analysis – Beopt 2.8 and 3.0Beta to investigate passive house design of homes.
- Used a prototype home to remove the home configuration variabilities from the analyses.
- NIST Prototype used as it was designed to be representative of typical one-story residences and was specifically intended for energy studies.

3

3

Introduction

The one story residential NIST prototype building:
is 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, 64 ft. x 25 ft., with 1,600 ft.^{2} of conditioned floor area (CFA). In this study, the house was assumed oriented with the 64 ft. dimension east to west, and the 25 ft. dimension north to south. The first floor has 8 ft. high ceilings. The roof slope was assumed to be 4:12 with1 ft overhangs on the north and south sides.

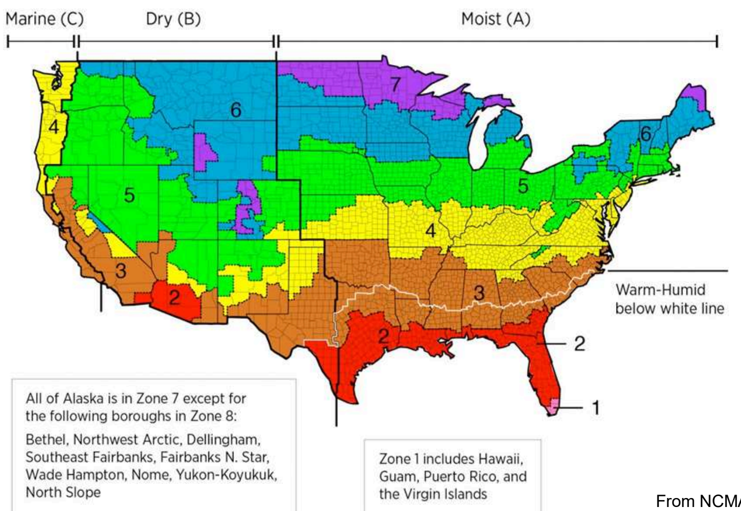


Single Story Residential Protype by NIST (Kneifel, 2011).

4

4

All 7 Climate Zones in US were Addressed

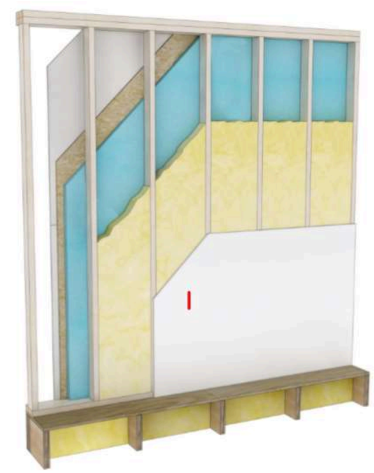


From NCMA Presentation

5

Modelling

- Calibrated models against published results of the NIST home and ensured that the predicted yearly energy use was in typical ranges (DOE).
- Upgraded prototype with code prescriptive requirement - IRC 2009, 2018 and 2021.
- Started with wood exterior walls.



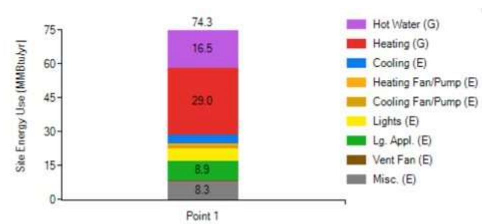
6

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" OC	Uninsulated, 2x4, 16" OC	R-13 Fiberglass Batt, 2x4, 16" OC	R-20 Fiberglass Batt, 2x4, 16" OC	R-20 Fiberglass Batt, 2x4, 16" OC	R-20 Fiberglass Batt, 2x4, 16" OC	R-20 Fiberglass Batt, 2x4, 16" OC	R-20 Fiberglass Batt, 2x4, 16" OC
Wall Sheathing	R-10 XPS	R-10 XPS	R-10 XPS	R-5 XPS	R-5 XPS	R-5 XPS	R-5 XPS	R-5 XPS
Unfinished Attic	R-30 Fiberglass, Vented	R-49 Fiberglass, Vented	R-49 Fiberglass, Vented	R-60 Fiberglass, Vented	R-60 Fiberglass, Vented	R-60 Fiberglass, Vented	R-60 Fiberglass, Vented	R-60 Fiberglass, Vented
Slab	Uninsulated	Uninsulated	2' R-10 XPS (Horizontal Insulation)	4' R-10 XPS (Horizontal Insulation)	4' R-10 XPS (Horizontal Insulation)	4' R-10 XPS (Horizontal Insulation)	4' R-10 XPS (Horizontal Insulation)	4' R-10 XPS (Horizontal Insulation)
Window	Clear, double, thermal-break (U-value: .40; SHGC: .25)	Clear, double, thermal-break (U-value: .40; SHGC: .25)	Clear, double, thermal-break (U-value: .30; SHGC: .25)	Clear, double, thermal-break (U-value: .30; SHGC: .40)	Clear, double, thermal-break (U-value: .30; SHGC: .40)	Clear, double, thermal-break (U-value: .30; SHGC: .40)	Clear, double, thermal-break (U-value: .30; SHGC: .40)	Clear, double, thermal-break (U-value: .30; SHGC: .40)
Air Leakage	5ACH50	5ACH50	3ACH50	3ACH50	3ACH50	3ACH50	3ACH50	3ACH50

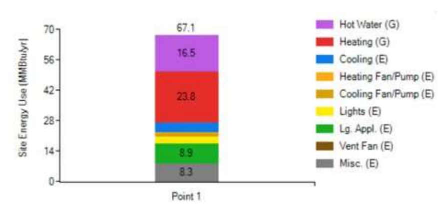
7

7

Some Results



Increments in Code has a small decrease in energy use from NIST 2009 Mixed climates Louisville

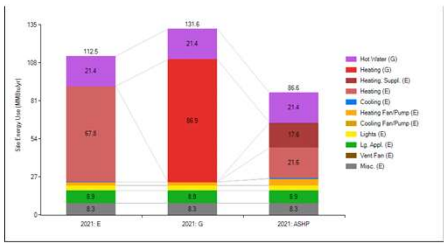


Increments in Code has a small Mixed climates Louisville (2021)

8

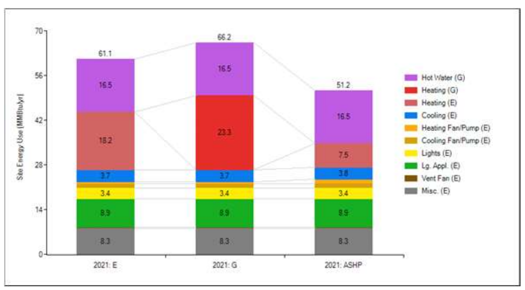
8

Some Results



Heating Systems has significant impact in cold climates Duluth Minnesota

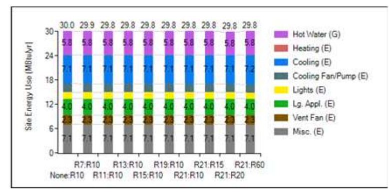
Heating Systems has significant impact in Mixed climates Louisville



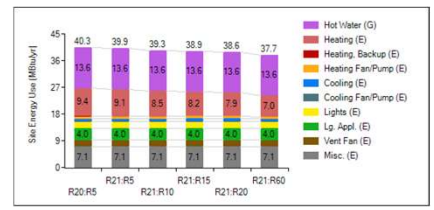
9

Some Results

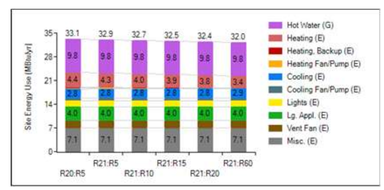
Varying wall insultation



Miami Florida



Duluth



Louisville

10

Some Results

Prototype Home Energy Site Energy Use by Climate Zone (2021 code) and Heat Source

City	State	Zone	Electric Furnace (MMBtu/yr)	Gas Furnace (MMBtu/yr)	Air Source Heat Pump (MMBtu/yr)
Miami	Florida	1A	52.5	52.6	51.9
Houston	Texas	2A	54.8	57.2	49.4
Las Vegas	Nevada	3B	54.6	56.8	49.6
Louisville	Kentucky	4A	61.1	66.2	51.2
Seattle	Wash.	4C	65.4	72.7	49.4
Chicago	Illinois	5A	79.7	90.2	60.3
Minneapolis	Minnesota	6A	98	113.4	74.7
Duluth	Minnesota	7	112.5	131.6	86.6

11

11

Passive House Design

- Starting with 2021IRC design and Holistic energy Analysis – investigated home characteristics that had significant impact on yearly energy use both in lit search and holistic analysis for the various climates.
- Adjusted 2021 compliant prototype home models until the heating and cooling yearly energy use were less than or equal to 4.75kbtu/ft^2 per year (7.6 MMBtu heating or cooling energy for our prototype model).

12

12

Passive House Design- Wood

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 Fiberglass Batt, 2x4, 16” o.c.: R-21 Fiberglass Batt, 2x4, 16” o.c.	R-20 Fiberglass Batt, 2x4, 16” o.c.: R-21 Fiberglass Batt, 2x4, 16” o.c.	R-20 Fiberglass Batt, 2x4, 16” o.c.: R-21 Fiberglass Batt, 2x4, 16” o.c.	R-20 Fiberglass Batt, 2x4, 16” o.c.: R-21 Fiberglass Batt, 2x4, 16” o.c.	R-20 Fiberglass Batt, 2x4, 16” o.c.: R-21 Fiberglass Batt, 2x4, 16” o.c.	R-20 Fiberglass Batt, 2x4, 16” o.c.: R-21 Fiberglass Batt, 2x4, 16” o.c.
Wall Sheathing	R-10: R-60	R-10: R-60	R-10: R-60	R-5: R-60	R-5: R-60	R-5: R-60	R-5: R-60	R-5: R-60
Exterior Finish	Vinyl, light	Vinyl, light	Vinyl, light	Vinyl, light	Vinyl, light	Vinyl, medium/dark	Vinyl, medium/dark	Vinyl, medium/dark
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
Roof Material	Asphalt Shingles, light	Asphalt Shingles, light	Asphalt Shingles, light	Asphalt Shingles, light	Asphalt Shingles, light	Asphalt Shingles, medium	Asphalt Shingles, medium	Asphalt Shingles, Dark
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
Exterior Wall Mass	½” Drywall	½” Drywall	½” Drywall	5/8” Drywall	5/8” Drywall	5/8” Drywall	5/8” Drywall	2 x ½” Drywall
Partition Wall Mass	½” Drywall	½” Drywall	½” Drywall	5/8” Drywall	5/8” Drywall	5/8” Drywall	5/8” Drywall	2 x ½” Drywall
Ceiling Mass	½” Drywall	½” Drywall	½” Drywall	5/8” Drywall	5/8” Drywall	5/8” Drywall	5/8” Drywall	2 x ½” Drywall
Window Areas	15% of wall area	15% of wall area	15% of wall area	15% of wall area	15% of wall area	15% of wall area	15% of wall area	15% of wall area
Windows	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)
Interior Shading	Summer = 0.7, Winter = 0.7	Summer = 0.7, Winter = 0.7	Summer = 0.7, Winter = 0.7	Summer = 0.7, Winter = 0.7	Summer = 0.7, Winter = 0.7	Summer = 0.7, Winter = 0.7	Summer = 0.7, Winter = 0.7	Summer = 0.7, Winter = 0.7
Door Area	40 ft^2	40 ft^2	40 ft^2	40 ft^2	40 ft^2	40 ft^2	40 ft^2	40 ft^2
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 Leakage	0.6ACH50	.6ACH50	.6ACH50	.6ACH50	.6ACH50	.6ACH50	.6ACH50	.6ACH50

13

13

Passive House Design – Wood

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
Mechanical Ventilation	ERV, 70%	ERV, 70%	ERV, 70%	ERV, 70%	ERV, 70%	ERV, 70%	ERV, 70%	ERV, 70%
Natural Ventilation	Cooling Months only, 3 days/week	Cooling Months only, 3 days/week	Cooling Months only, 3 days/week	Cooling Months only, 3 days/week	Cooling Months only, 3 days/week	Cooling Months only, 3 days/week	Cooling Months only, 3 days/week	Cooling Months only, 3 days/week
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
Ducts	In Finished Space	In Finished Space	In Finished Space	In Finished Space	In Finished Space	In Finished Space	In Finished Space	In Finished Space
Cooling Set Point	77 F	77 F	77 F	77 F	77 F	77 F	77 F	77 F
Heating Set Point	70 F	70 F	70 F	70 F	70 F	70 F	70 F	70 F
Water Heater	Gas, tank, UEF=0.83	Gas, tank, UEF=0.83	Gas, tank, UEF=0.83	Gas, tank, UEF=0.83	Gas, tank, UEF=0.83	Gas, tank, UEF=0.83	Gas, tank, UEF=0.83	Gas, tank, UEF=0.83
Distribution	Insulated, PEX	Insulated, PEX	Insulated, PEX	Insulated, PEX	Insulated, PEX	Insulated, PEX	Insulated, PEX	Insulated, PEX
Water Heater Set Point	125 F	125 F	125 F	125 F	125 F	125 F	125 F	125 F
Lighting	100% LED	100% LED	100% LED	100% LED	100% LED	100% LED	100% LED	100% CFL
Refrigerator	Top freezer, EF = 21.9	Top freezer, EF = 21.9	Top freezer, EF = 21.9	Top freezer, EF = 21.9	Top freezer, EF = 21.9	Top freezer, EF = 21.9	Top freezer, EF = 21.9	Top freezer, EF = 21.9
Cooking Range	Electric, 80% usage	Electric, 80% usage	Electric, 80% usage	Electric, 80% usage	Electric, 80% usage	Electric, 80% usage	Electric, 80% usage	Electric, 80% usage
Dishwasher	270 Rated kWh, 80% usage	270 Rated kWh, 80% usage	270 Rated kWh, 80% usage	270 Rated kWh, 80% usage	270 Rated kWh, 80% usage	270 Rated kWh, 80% usage	270 Rated kWh, 80% usage	270 Rated kWh, 80% usage
Clothes Washer	IMEF=2.06, 80% Usage	IMEF=2.06, 80% Usage	IMEF=2.06, 80% Usage	IMEF=2.06, 80% Usage	IMEF=2.06, 80% Usage	IMEF=2.06, 80% Usage	IMEF=2.06, 80% Usage	IMEF=2.06, 80% Usage
Clothes Dryer	Electric, CEF=3.73, 80% Usage	Electric, CEF=3.73, 80% Usage	Electric, CEF=3.73, 80% Usage	Electric, CEF=3.73, 80% Usage	Electric, CEF=3.73, 80% Usage	Electric, CEF=3.73, 80% Usage	Electric, CEF=3.73, 80% Usage	Electric, CEF=3.73, 80% Usage
Hot Water Fixtures	Multiplier of 1	Multiplier of 1	Multiplier of 1	Multiplier of 1	Multiplier of 1	Multiplier of 1	Multiplier of 1	Multiplier of 1
Plug Loads	Multiplier of 1	Multiplier of 1	Multiplier of 1	Multiplier of 1	Multiplier of 1	Multiplier of 1	Multiplier of 1	Multiplier of 1

14

14

Some Results

Were able to achieve Passive House designs in all Climate Zones

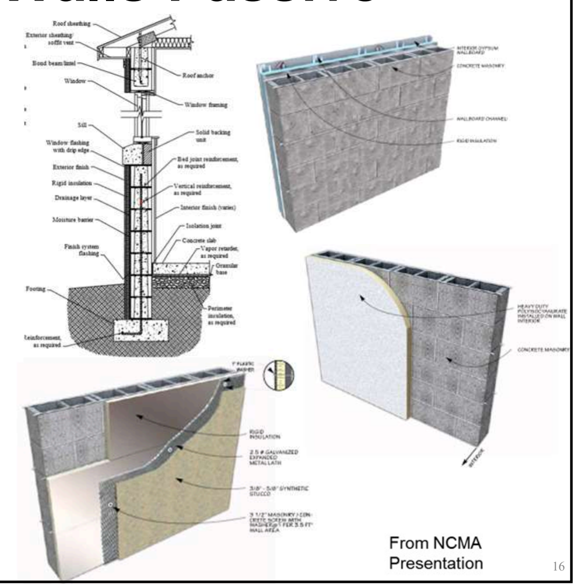
City	State	Zone	Base Model Energy Use (MMbtu/year)	Passive Model Energy Use (MMbtu/yr)	Passive Model cooling Energy Use (MMbtu/yr)	Passive Model heating Energy Use (MMbtu/yr)	Passive Maximum heating/cooling energy (Kbtu/ft^2)	Passive House Principal Standard MAXIMUM (Kbtu/ft^2)
Miami	FL	1A	51.3	29.8	7.1	0	4.43	4.75
Houston	TX	2A	48.2	29.3	5.1	.6	3.19	4.75
Las Vegas	Nevada	3B	49.8	30.4	5.5	1.09	3.43	4.75
Louisville	Kentucky	4A	55.1	32.0	2.9	3.4	2.13	4.75
Seattle	Washington	4C	48.2	30.1	.72	3.7	2.31	4.75
Chicago	Illinois	5A	63.9	33.2	1.9	4.9	3.06	4.75
Minneapolis	Minnesota	6A	79.1	36.2	1.3	7.0	4.38	4.75
Duluth	Minnesota	7	88.8	37.7	.9	7.0	4.38	4.75

15

15

Masonry Walls Passive Designs

- Using the Prototype Home 2021 configurations we replace the exterior walls with masonry walls
- Started with bare Masonry walls and then added external insulation until
- Then started changes like wood system until passive home performance obtained

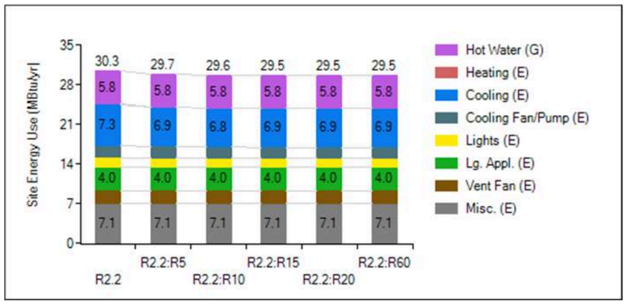


From NCMA Presentation

16

16

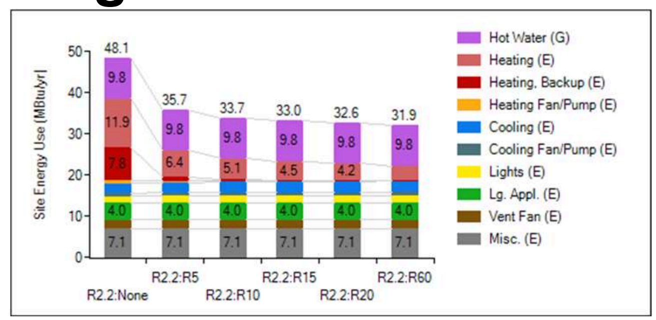
Masonry Walls Passive Designs



Maimi – Variation in wall insulation almost no impact and bare walls can meet passive home performance

17

Masonry Walls Passive Designs

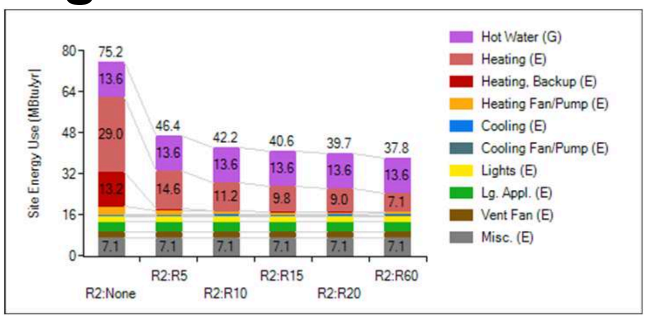


Louisville – Variation in wall insulation has an impact initially but tails off quite quickly. R 10 insulation gives maximum impact , beyond this there is little impact.

Note typical yearly energy cost savings are less than $50 per year – Cost of 2in. of additional rigid insulation over $1.5 SQFT or a total increase of $1,400, a simple payback of 28 years+

18

Masonry Walls Passive Designs

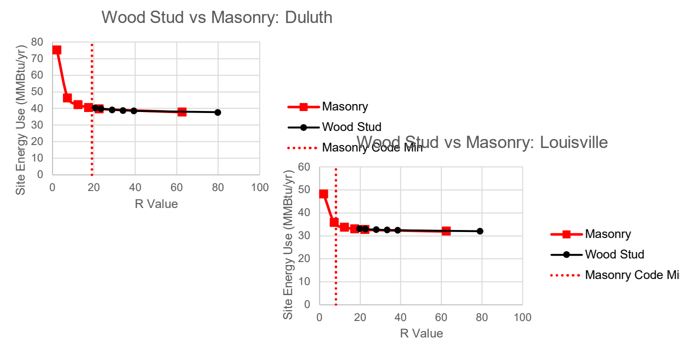


Duluth – Variation in wall insulation has an impact initially but tails off quite quickly. R 10 insulation gives close to maximum impact, beyond this there is little impact.

19

19

Masonry Walls Passive Designs



The prescriptive Code limits can be used to set insulation limits in passive house design. Note the Duluth prototype does not quite meet the 4.75 limit but gets close and does meet the climate limited

20

20

Passive House Design

- All prototype homes met passive home limits of 4.75kbtu/ft^2 per year (7.6 MMBtu heating or cooling energy for our prototype model) , in every climate using essentially the same configurations as the wood wall systems, except Climate Zone 7
- Study by Klingenberg at al (2016) suggest climate based limits for passive house more appropriate
- For Climate Zone they suggest a 7.9 kbtu/ft^2 per year. The CMU exterior wall configuration was well below this value

21

21

Conclusions

- Exterior Masonry Walls can be used with passive home designs with code prescritpive levels of insulation if place on the exterior face.
- This engages the thermal mass of exterior walls to help regulate the interior temperatures and store thermal energy
- Adding large amounts of insulation on the exterior masonry wall does not significantly impact energy use in the home and thus is not cost effective.

22

22

J.B. SPEED SCHOOL
OF ENGINEERING

THANK YOU !

QUESTIONS?

23

23