Optimizing Energy Code Compliance for Concrete and Masonry

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ACI Technical Session (TAC)

Session Title:

How to Design and Construct Concrete and Masonry to Comply with the New Energy Codes

March 27, 2017, Detroit MI

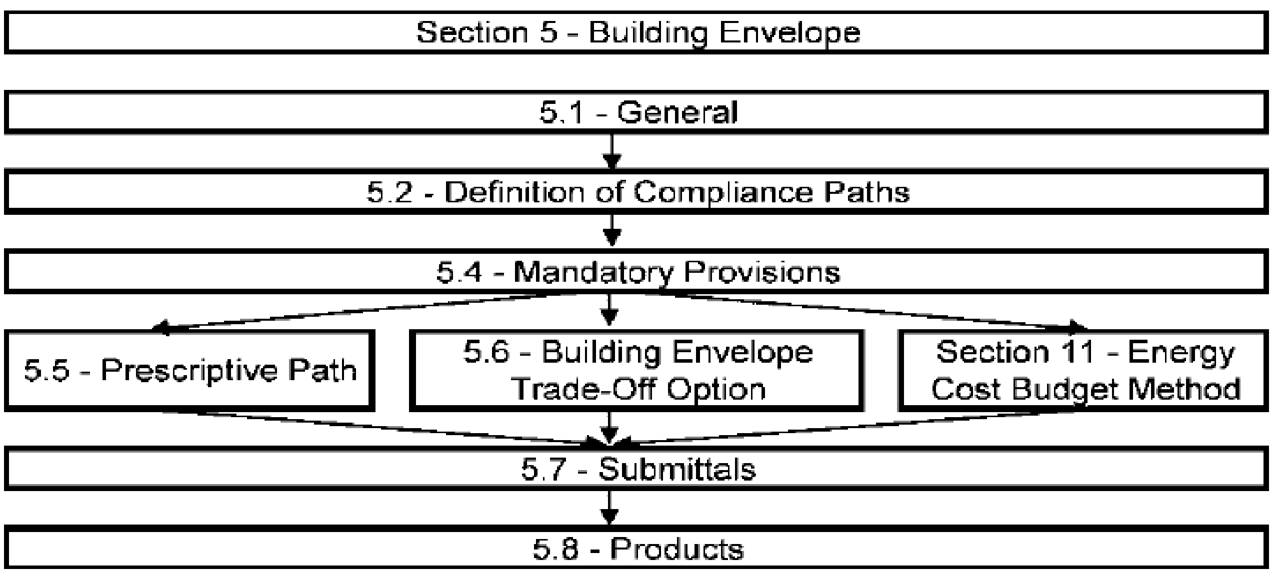
Overview of Presentation (Learning objectives)

- Discuss Code based energy design
- Discuss impacts of envelope thermal resistance of a few low rise buildings with external concrete masonry walls systems, both energy use and economics.
- Discuss design options for masonry walls system for optimum design.

Energy Code Design

Code generally allows 3 methods to be used for design of the various energy related building systems (IECC -ASHRAE 90.1) **Similar in other Systems**

5. BUILDING ENVELOPE



Energy Code Design

Prescriptive requirements – Envelope – Varies with Climate Zone

Climate Zone 4 B

TABLE 5.5-4 Building Envelope Requirements for Climate Zone 4 (A, B, C)*

Opaque Elements	Nonresidential Assembly Maximum	Nonresidential Insulation Min. R-Value	Residential Assembly Maximum	Residential Insulation Min. R-Value	Semiheated Assembly Maximum	Semiheated Insulation Min. R-Value
Roofs						
Insulation Entirely above Deck	U-0.048	R-20.0 c.i.	U-0.048	R-20.0 c.i.	U-0.173	R-5.0 c.i.
Metal Building[a]	U-0.055	R-13.0 + R-13.0	U-0.055	R-13.0 + R-13.0	U-0.097	R-10.0
Attic and Other	U-0.027	R-38.0	U-0.027	R-38.0	U-0.053	R-19.0
Walls, Above-Grade						
Mass	U-0.104	R-9.5 c.i.	U-0.090	R-11.4 c.i.	U-0.580	NR
Metal Building	U-0.084	R-19.0	U-0.084	R-19.0	U-0.113	R-13.0
Steel-Framed	U-0.064	R-13.0 + R-7.5 c.i.	U-0.064	R-13.0 + R-7.5 c.i.	U-0.124	R-13.0
Wood-Framed and Other	U-0.089	R-13.0	U-0.064	R-13.0 + R-3.8 c.i.	U-0.089	R-13.0
Walls, Below-Grade						
Below-Grade Wa						
Floors						
Mass						
Steel-Joist						
Wood-Framed an						
Slab-On-Grade Floors						
Unheated	F-0.730	NR	F-0.540	R-10 for 24 in.	F-0.730	NR
Heated	F-0.860	R-15 for 24 in.	F-0.860	R-15 for 24 in.	F-1.020	R-7.5 for 12 in.
Opaque Doors						
Swinging	U-0.700		U-0.700		U-0.700	
Nonswinging	U-0.500		U-0.500		U-1.450	

Fenestration	Nonresidential Assembly Max. U	Nonresidential Assembly Max. SHGC	Residential Assembly Max. U	Residential Assembly Max. SHGC	Semiheated Assembly Max. U	Semiheated Assembly Max. SHGC
Vertical Glazing, 0%–40% of Wall						
Nonmetal framing (all)[c]	U-0.40	SHGC-0.40 all	U-0.40	SHGC-0.40 all	U-1.20	SHGC-NR all
Metal framing (curtainwall/storefront)[d]	U-0.50		U-0.50		U-1.20	
Metal framing (entrance door)[d]	U-0.85		U-0.85		U-1.20	
Metal framing (all other)[d]	U-0.55		U-0.55		U-1.20	

Walls, Above-Grade

Mass U-0.104 R-9.5 c.i.

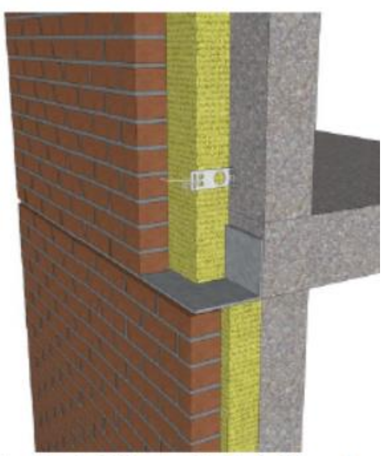
Energy codes have significantly increased R values (reduced U values) of the past few cycles

Also Thermal Bridging Becoming Important

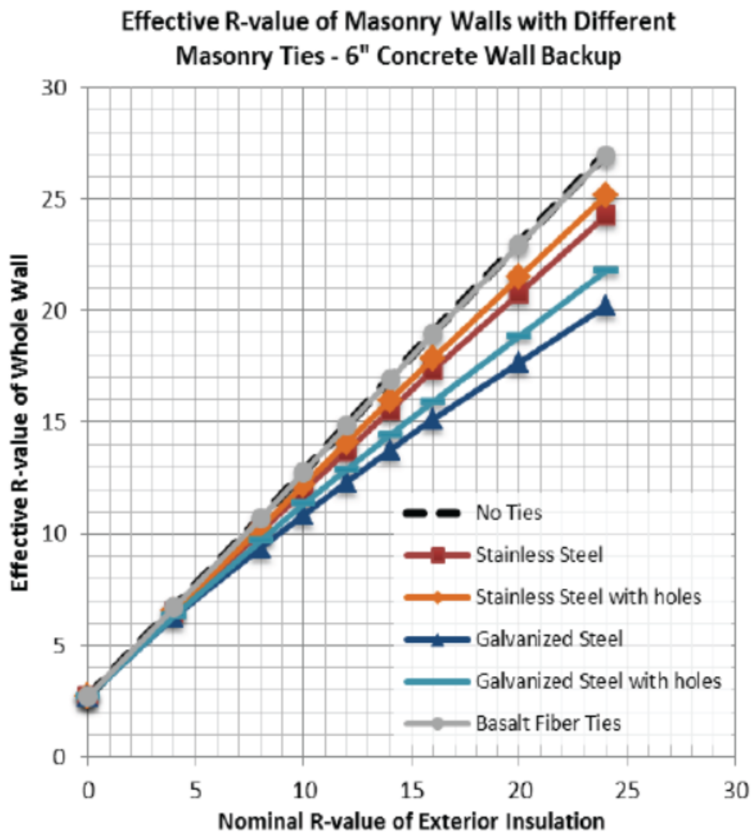
Thermal bridging can have a significant effect on Thermal resistance of the envelope – Thus the C_i requirement

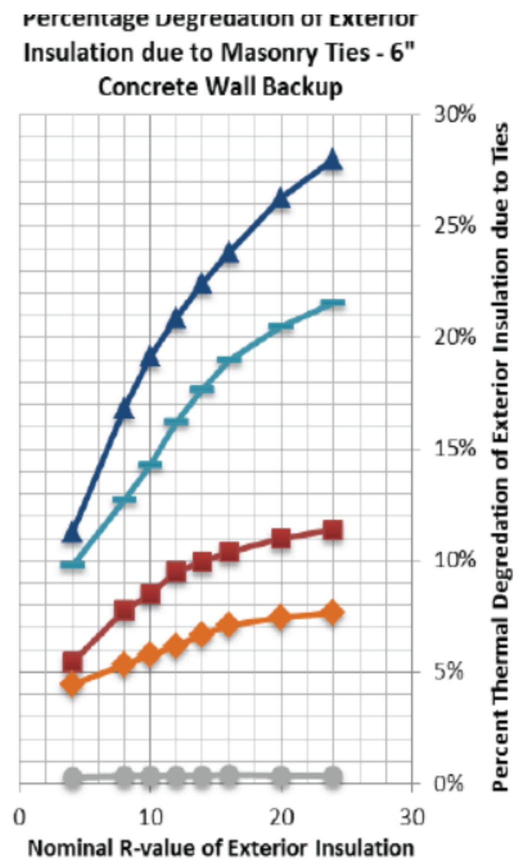
Ties(anchors) angles can reduce steady state thermal resistance significantly

16" x 24"



Standard slab attached shelf angle





THERMAL BRIDGING OF MASONRY VENEER CLADDINGS AND ENERGY CODE COMPLIANCE, 12th Canadian Masonry Symposium
Vancouver, British Columbia, June 2-5, 2013
Michael Wilson1, Graham Finch2 and James Higgins3

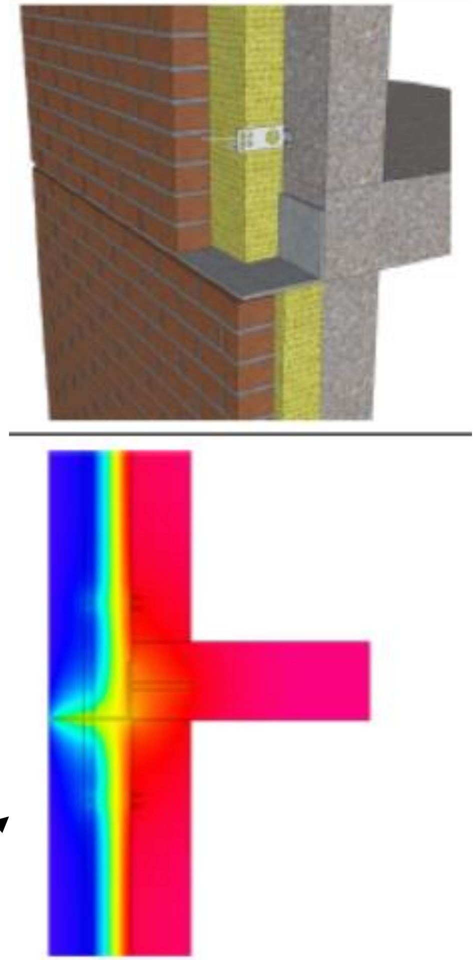
Thermal Bridging (cont.)

Thermal bridging can have a significant effect on Thermal resistance of the envelope – Thus the Ci requirement.

Shelf angles can reduce steady state thermal resistance significantly

~40% reduction

Poured Concrete Backup



R-16.8 (RSI 2.95)
U-0.060 (USI 0.339)

R-10.5 (RSI 1.84)
U-0.096 (USI 0.543)

MASONRY VENEER SUPPORT DETAILS: THERMAL BRIDGING, 12th Canadian Masonry Symposium
Vancouver, British Columbia, June 2-5, 2013
Michael Wilson1, Graham Finch2 and James Higgins3

Prescriptive Energy Code Requirements

- Becoming harder to meet with cost effective configurations
- Thermal bridging is becoming important (especially to code bodies) and is hard to address (especially shelf angles)
- Cost effectiveness of exterior mass concrete and masonry walls are being impacted

What to do ?

- What impacts do changes to exterior mass exterior walls actually have on the energy use of buildings ?

- Answer – It depends – Climate – interior use – configuration.

- These effects can be simply and conservatively addressed using COMCheck – ONLY Envelope Trade offs

COMcheck Results

- Using COMCheck allows slightly higher U-factor for mass wall than prescriptive
- Using trade-offs can change required efficiency for walls (or other components)

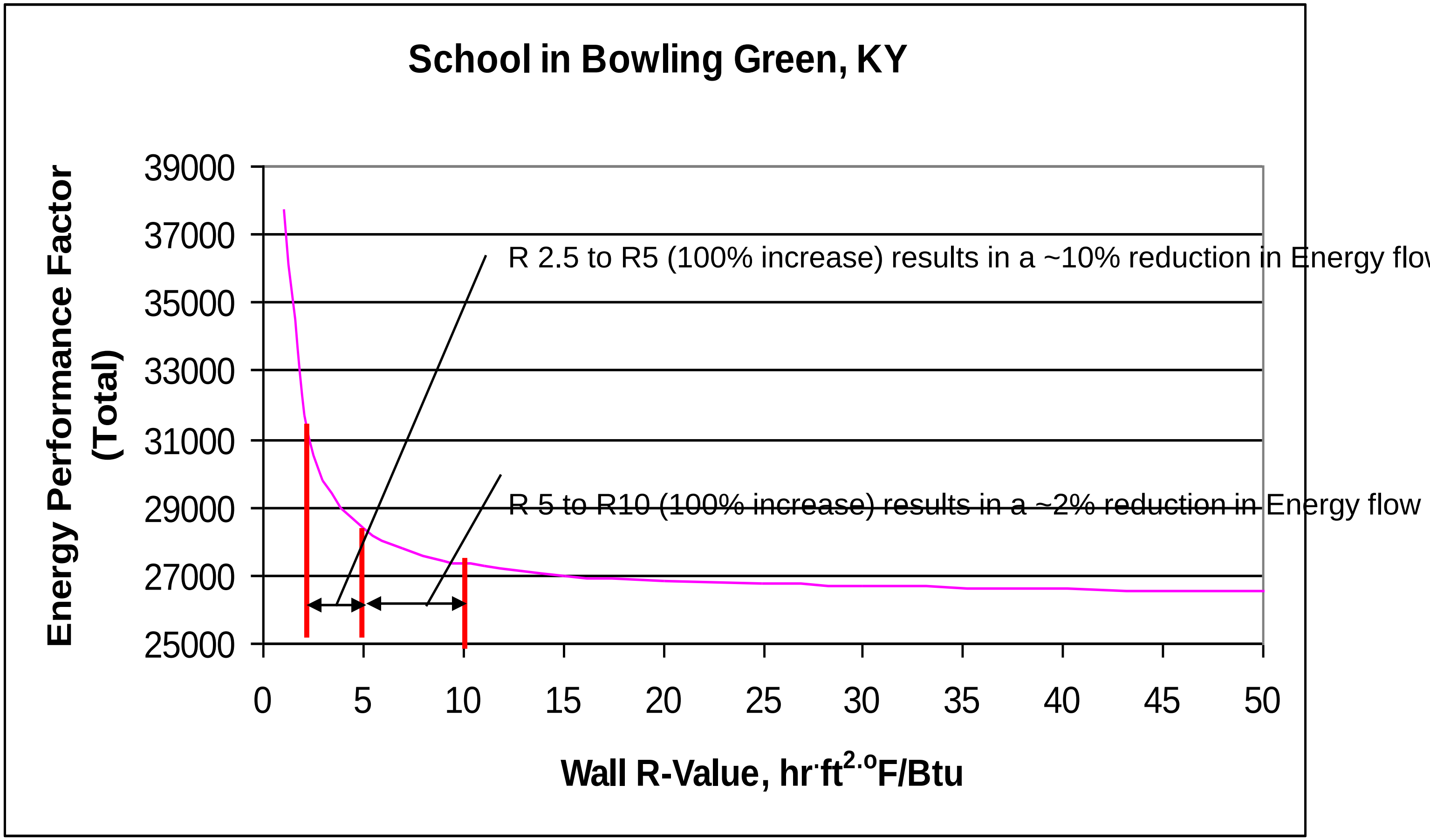
Method	Mass wall requirement
Prescriptive R-value	R9.5 ci
Prescriptive U-factor	U-0.104 (R9.6)
COMcheck code max U	U-0.109 (R9.2)
Trade-off: max roof R (R60)	U-0.164 (R6.1)

From NCMA Presentation

COMCheck Trade offs

- If close to prescriptive can help
- But prescriptive R/U values close to max effective values.
- Large increases in R have less impact at higher R values
- See following slide

Envelope Performance Factor (EPF) is a relative term that approximates the total heating and cooling energy associated with an average square foot of surface or square meter of building envelope



COMCheck accounts for this effect so adding a lot of R on roof only minimally effective if on flat part of curve

Holistic Analysis of Buildings

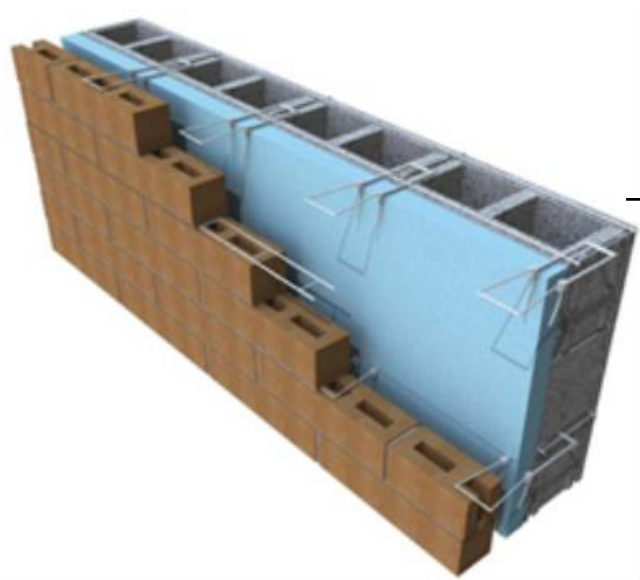
- To address effect of thermal mass and actual building performance holistic analysis needs to be conducted.
- At U o fL – Over the past few years we have been looking at the performance of structures that typically use exterior masonry walls.
- Two significant studies

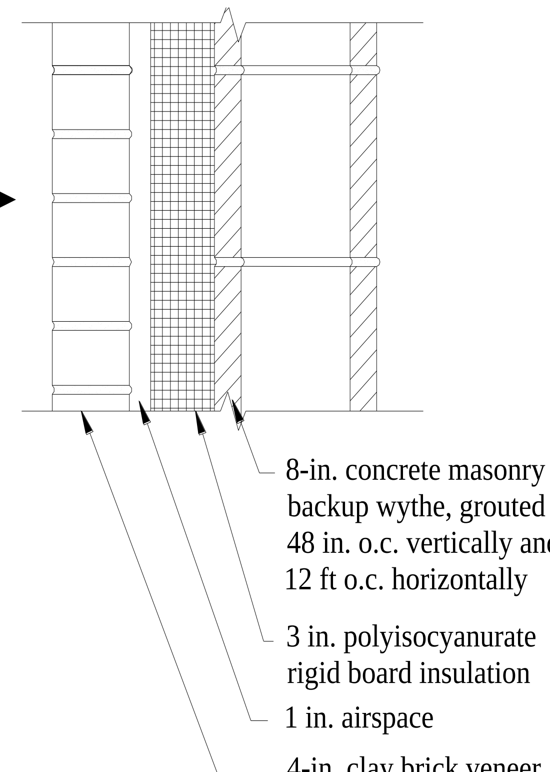
Designed a Base Prototype Middle School to Meet prescriptive provisions -4B

- Most Lights T 12- 2 and 4 lamp systems
- High bay halides
- HVAC VAV - Gas boilers and Chillers
- Typical school use schedules.
- Minimum Envelope U and R values ~ R 26 Roof, ~R 9.8 Walls
- Base EUI - ~132

www.schoolclearing house.org) ~158,000 ft^2 2 Story- Prototype

Evaluated Select Alternatives (ECM's):
•Variety of Building Envelopes - Walls & roofs





Vary the exterior masonry cavity wall insulation: 1 ¼" thick polystyrene, 1 ½" thick polystyrene, 2" thick polyisocyanurate foam board, 3" polyisocyanurate foam board. **Over 100% swing in insulation values.**

Also addressed ICF walls & Steel stud veneer walls.

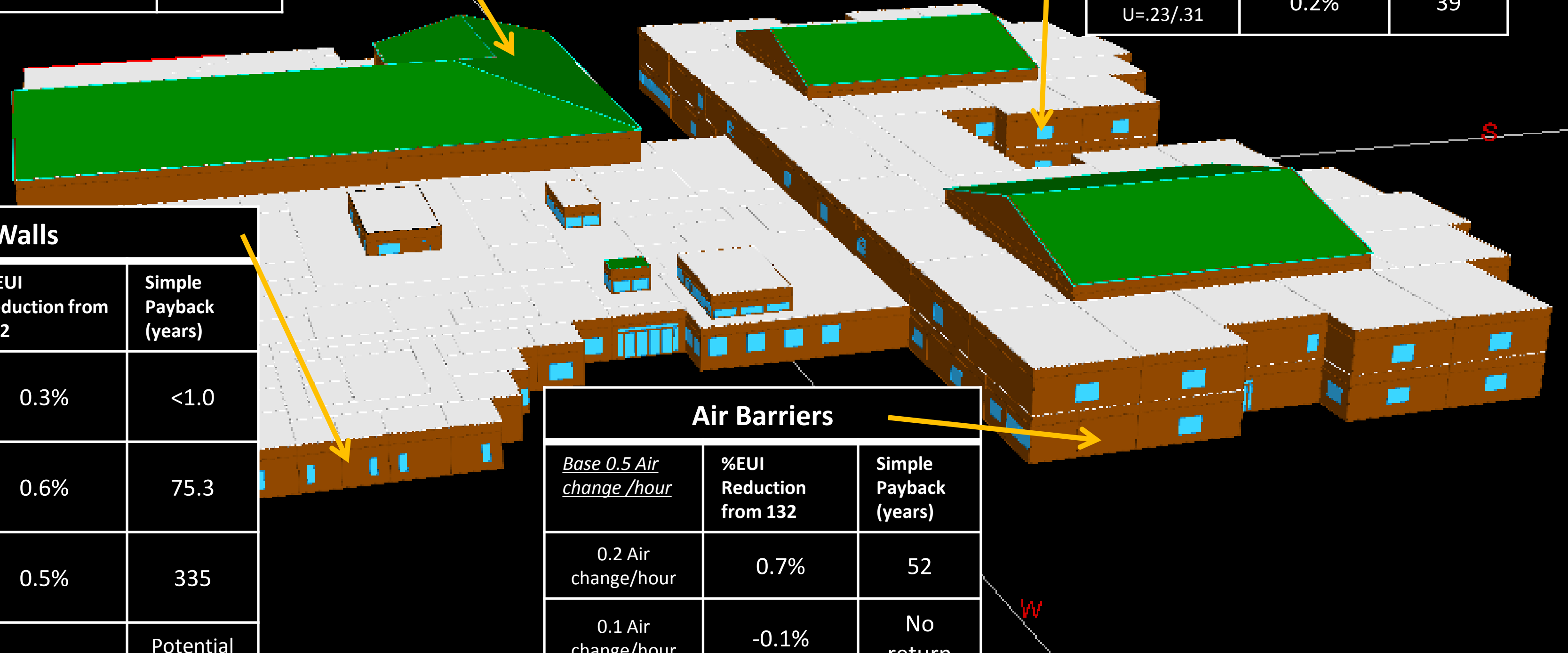
Investigated Energy Conservation Measures

- Each of the Mature alternative energy conservation measures (ECM's) technologies were incorporated into the building.
- Prototype building was re-analyzed using eQuest (DOE2) for each ECM singly and in groups - 5 KY cities. Holistic analysis – Energy Budget Method
- Conducted an economic differential cost analysis – Pay back and Self-funding

Energy Savings and Payback in Typical Middle School*

*Louisville, KY – other climates similar **(MEP changes affect energy 9- 80% - PB. 1 - 20 ys)**

EUI – Energy Use Index (kBtu/SF)



Roof

Base R = 22 pitched, R 26.3 flat	%EUI Reduction from 132	Simple Payback (years)
R = 29.4 pitched, R 33.3 flat BUR	0.3%	160
R = 37.0 pitched, R 40 flat BUR	0.6%	189

Windows

Base U = .54/.64 glass/frame	%EUI reduction from 132	Simple Payback (years)
Higher U=.67/.69	0.0%	Lower initial cost
Lower U=.23/.31	0.2%	39

Walls

Base R = 9.1 4" brick, 8" CMU	%EUI Reduction from 132	Simple Payback (years)
R = 13.3" 4" brick, 8" CMU	0.3%	<1.0
R = 25, 4" brick, 8" CMU	0.6%	75.3
ICF R = 22, 4" brick	0.5%	335
BVSS R = R37 , 4" brick, 6 " Steel Stud	0.6%	Potential lower initial cost**

Air Barriers

Base 0.5 Air change /hour	%EUI Reduction from 132	Simple Payback (years)
0.2 Air change/hour	0.7%	52
0.1 Air change/hour	-0.1%	No return

** lower initial cost ignores structural steel frame costs and probable condensation and maintenance issues

For more details See: *"Cost Effective Energy Efficient School Design" Report* (McGinley 2011)

ALTERNATIVE ENERGY EFFICIENT DESIGNS IN MEDIUM SIZED SINGLE WYTHE MASONRY BUILDINGS

- Looked at design alternatives to the simple prescriptive solutions offered by the energy code for three building archetypes that are typically constructed with single wythe masonry exterior wall systems.
- For each archetype, various code-compliant [ASHRAE 90.1 2010, NECB 2011] alternative construction configurations were examined for energy efficiencies, energy costs and construction costs (for various climate zones).
- Also conducted a differential capital cost and payback analysis

Archetype 1 – Warehouse - US

One of 16 reference buildings used for the evaluation of energy analysis software by the Department of Energy and developed to be representative of over 80% of typical warehouse configurations [Deru, et-al 2011], [NREL 2013].

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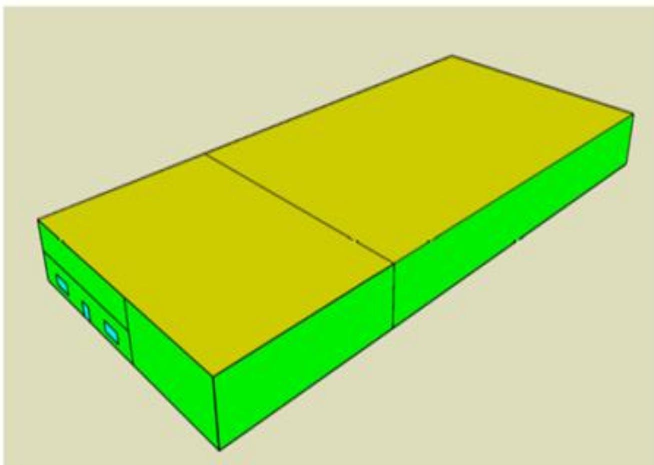
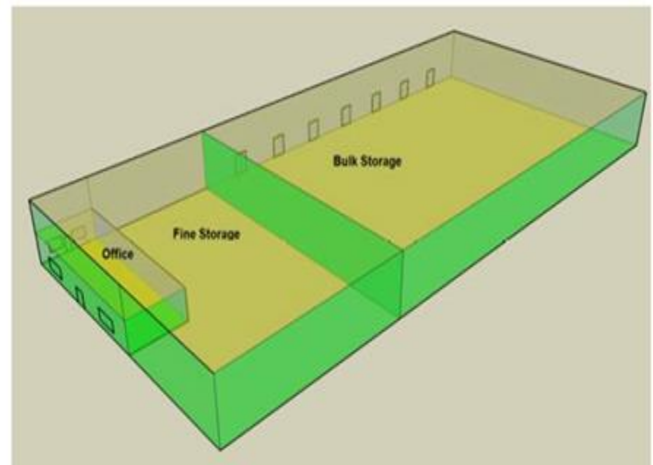
Prototype Warehouse for the Energy Modelling (≈50000 ft^2)

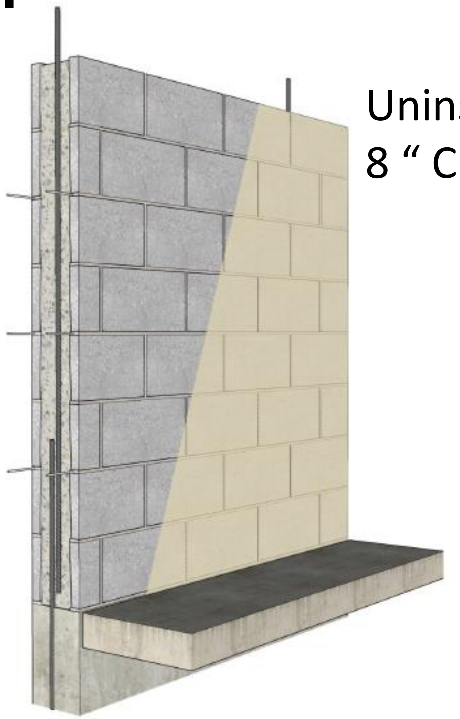




Evaluated Climate Zones and cities.

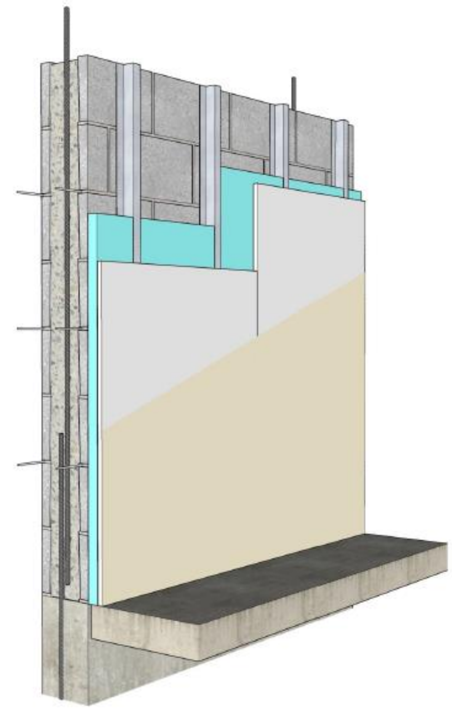
City	State	Climate Zone	City	State	Climate Zone
Atlanta	Georgia	3A	Chicago	Illinois	5A
Las Vegas	Nevada	3B	Boulder	Colorado	5B
San Francisco	California	3C	Minneapolis	Minnesota	6A
Baltimore	Maryland	4A	Helena	Montana	6B
Albuquerque	New Mexico	4B	Duluth	Minnesota	7
Seattle	Washington	4C			

Prototype Warehouse BASELINE DESIGNS - US Configured to Code Prescriptive levels and Analyzed using the Energyplus program for cities in Table 1 as required in the Energy Budget Code Compliance method



Uninsulated
8 “ CMU

Insulated
8 “ CMU
Z channels
½ Gypsum wall board



(Infiltration rate of 0.038 cfm/ft^2)

Some climate zone required the exterior walls of the bulk storage to be insulated, some did not. The office and fine storage areas were insulated with varying R values

Warehouse Sensitivity Analysis- US

8” CMU wall, partially grouted and reinforced at 48 inches OC -all other cores filled with foam insulation

By NCMA TEK Note 6B [14] U- and R-values = 0.287 Btu/ft^2-h-°F and 3.48 ft^2-h-°F/Btu

This is a significant decrease in thermal transmittance when compared to the bare masonry wall (with U-value of 0.580 Btu/ft^2-h-°F-partially grouted).

(8” CMU wall having a continuous insulation of R-7.2 ft^2-h-°F/ Btu (U-value of 0.125 Btu/ft^2-h-°F)).

Archetype 2 &3 Supermarket & Box Retail-US

One of 16 reference buildings used for the evaluation of energy analysis software by the Department of Energy [Deru, et-al 2011], [NREL 2013].

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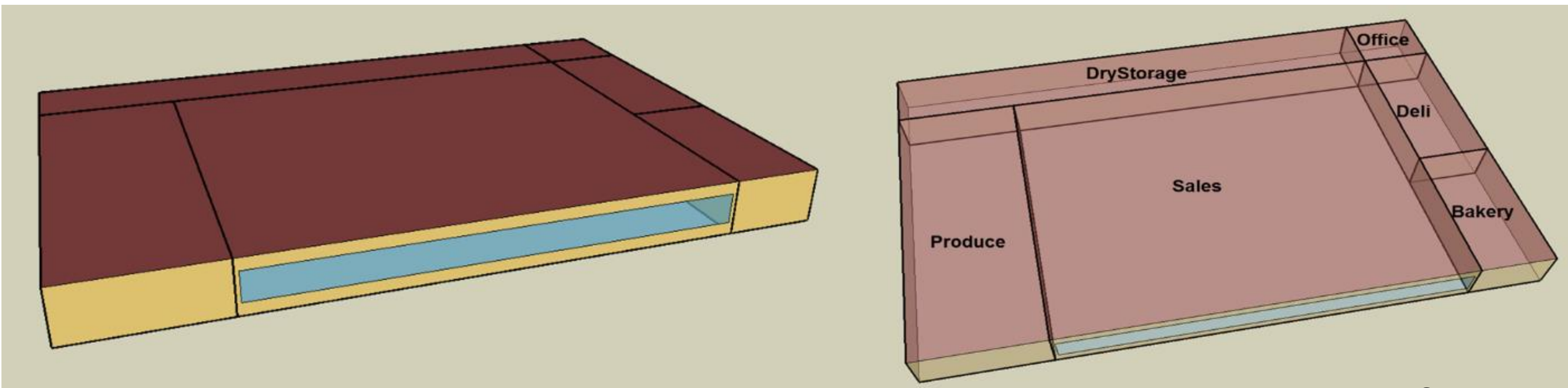
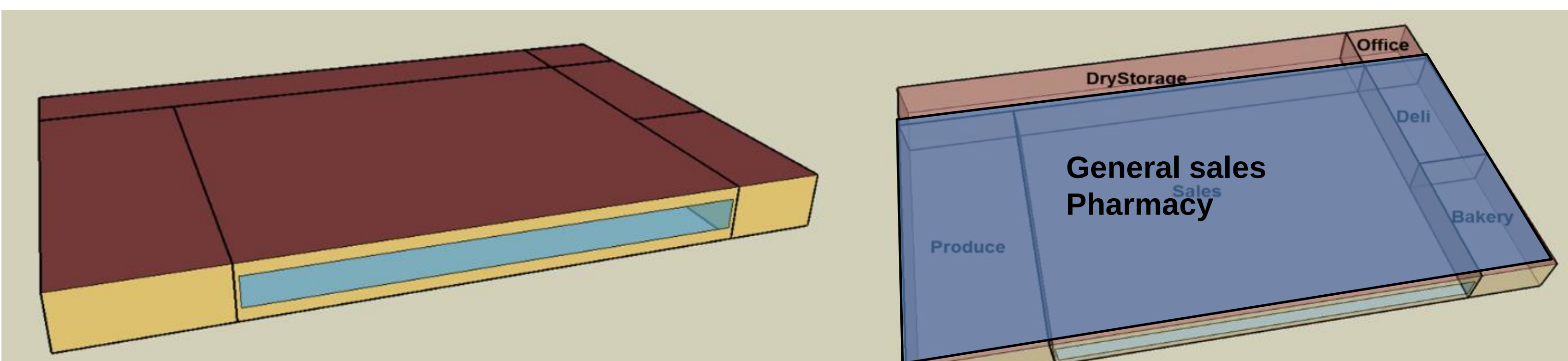
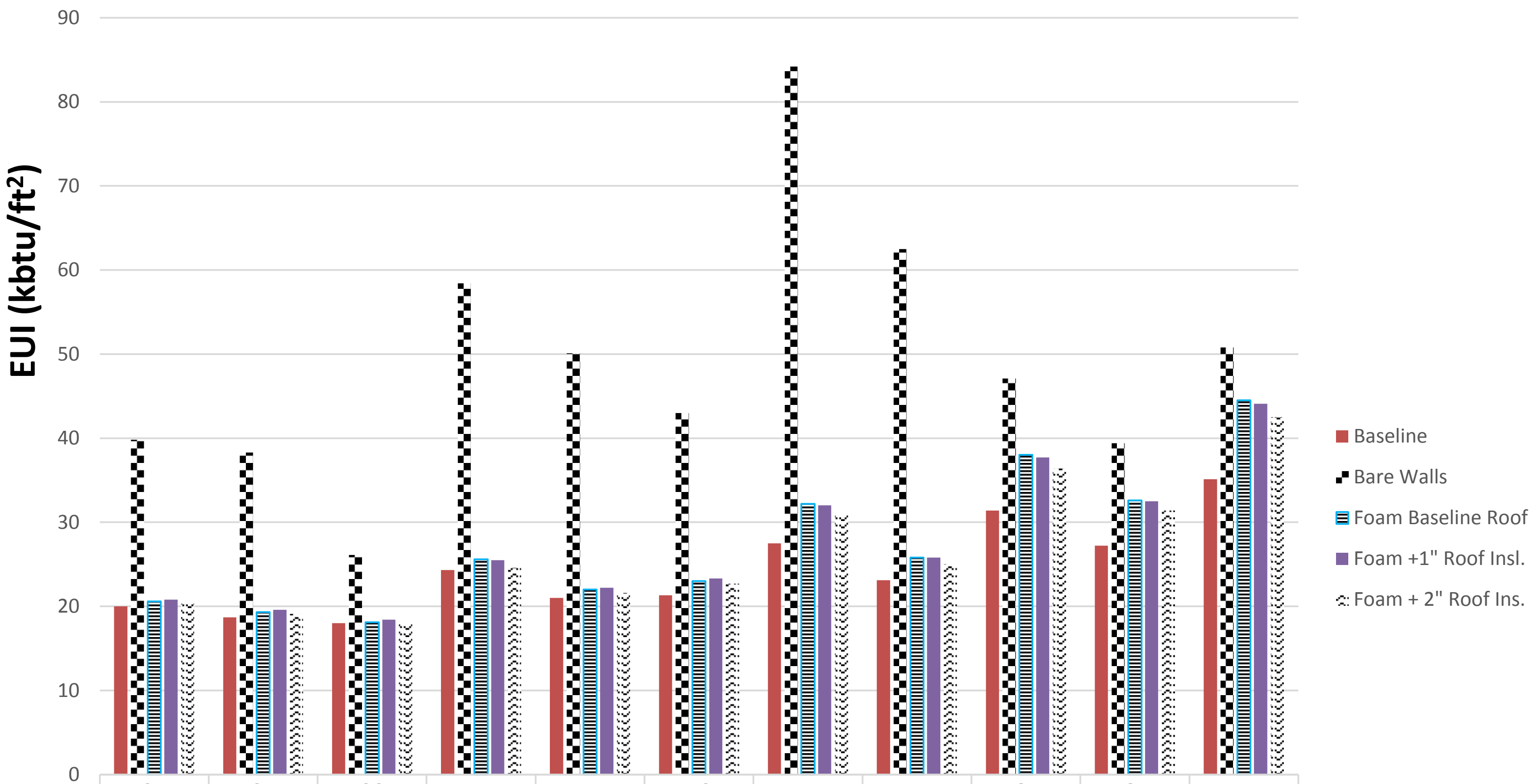


Prototype Supermarket for the Energy Modelling (≈45000 ft^2)



Prototype Box Retail for the Energy Modelling (≈45000 ft^2)

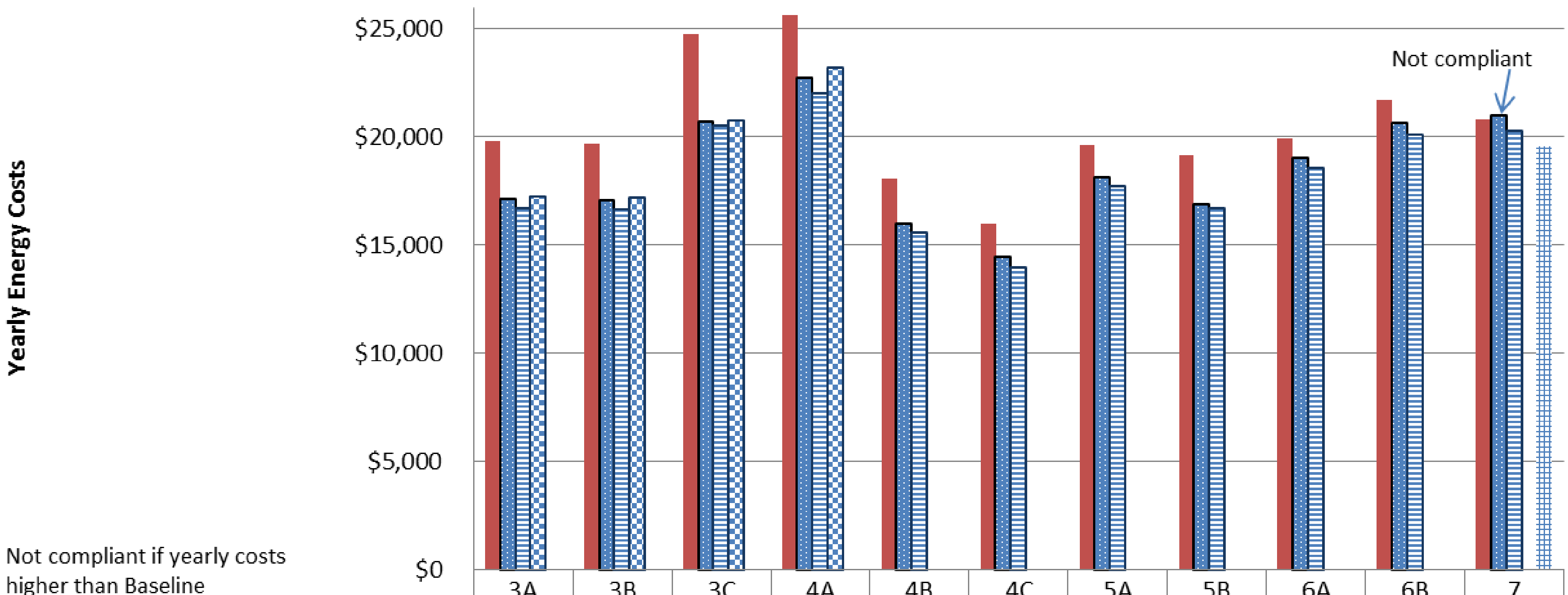
Warehouse Sensitivity Analysis- US



	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7
Baseline	20	18.7	18	24.3	21	21.3	27.5	23.1	31.4	27.2	35.1
Bare Walls	39.8	38.3	26.1	58.4	50.1	43	84.2	62.5	47.1	39.4	50.8
Foam Baseline Roof	20.6	19.3	18.1	25.6	22	23	32.2	25.8	38	32.6	44.5
Foam +1" Roof Insl.	20.8	19.6	18.4	25.5	22.2	23.3	32	25.8	37.7	32.5	44.1
Foam + 2" Roof Ins.	20.3	19.1	18	24.6	21.6	22.7	30.9	25	36.4	31.4	42.5

Climate Zone

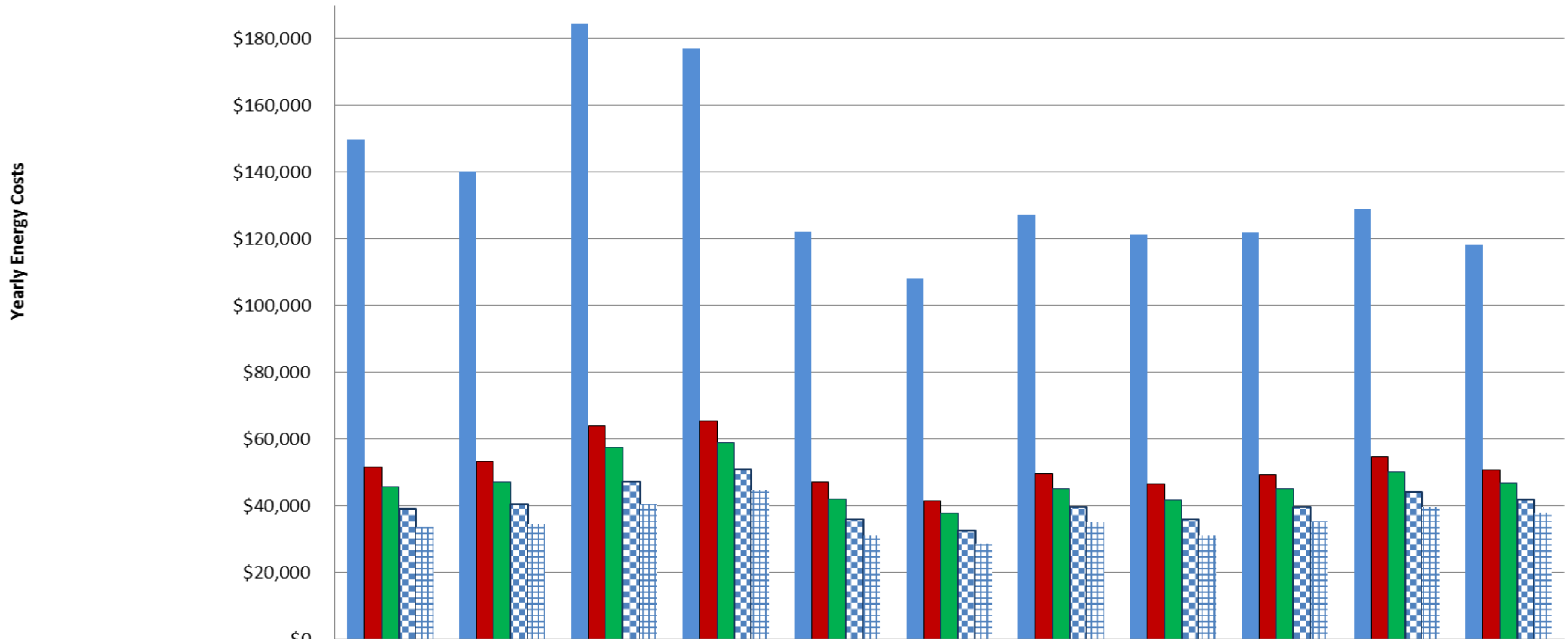
Alternative Designs US Code Compliance - Warehouse



	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7
Baseline	$19,792	$19,701	$24,728	$25,665	$18,076	$16,008	$19,616	$19,162	$19,915	$21,722	$20,833
8CMU 2roof Lower Ballast	$17,100	$17,059	$20,699	$22,737	$16,003	$14,424	$18,119	$16,863	$19,009	$20,663	
12CMU 2roof lower ballast	$16,708	$16,626	$20,540	$22,027	$15,603	$13,986	$17,699	$16,682	$18,530	$20,126	$20,284
8CMU Lower Ballast	$17,261	$17,197	$20,771	$23,176							
8CMU 2roof Lower Ballast Occ. Sensor											$19,546

Figure: Yearly Prototype Warehouse Energy Costs. (based on State Averages) Capital costs much lower for alternative designs except 12*

Alternative Designs US Code Compliance- Supermarket-Box Retail



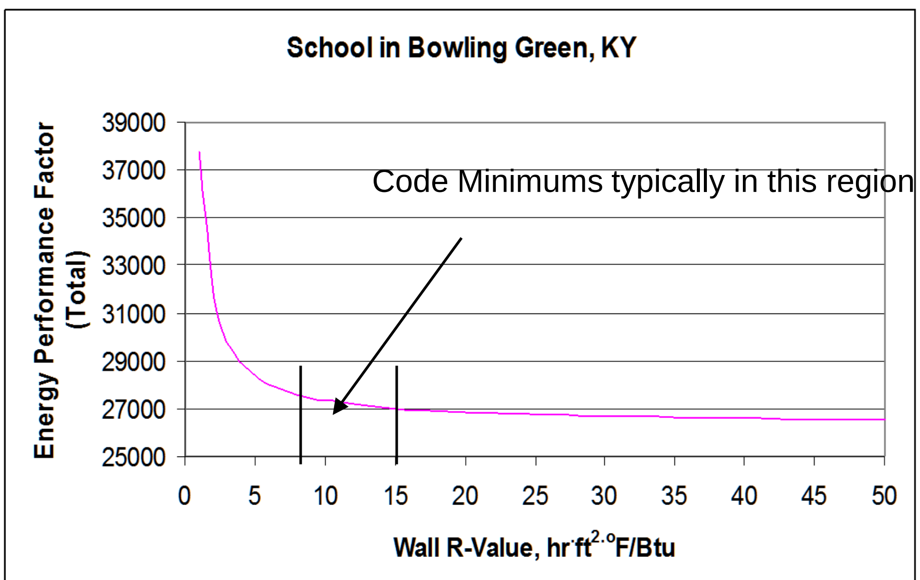
	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7
Supermarket Baseline (Refrig.)	$149,777	$140,225	$184,437	$177,234	$122,257	$108,122	$127,295	$121,389	$121,820	$128,828	$118,097
Supermarket Baseline (no Refrig.)	$51,461	$53,287	$63,925	$65,257	$46,958	$41,391	$49,524	$46,528	$49,231	$54,722	$50,770
Box Retail Baseline	$45,812	$47,091	$57,441	$58,869	$42,015	$37,706	$45,015	$41,857	$45,044	$50,137	$46,890
Supermarket No Refrig. 8CMU LED	$39,068	$40,483	$47,104	$50,992	$36,053	$32,490	$39,532	$35,896	$39,556	$44,162	$41,735
Box Retail 8CMU LED	$33,600	$34,455	$40,447	$44,658	$31,286	$28,760	$35,096	$31,303	$35,499	$39,686	$37,948

Yearly Prototype Energy Costs.

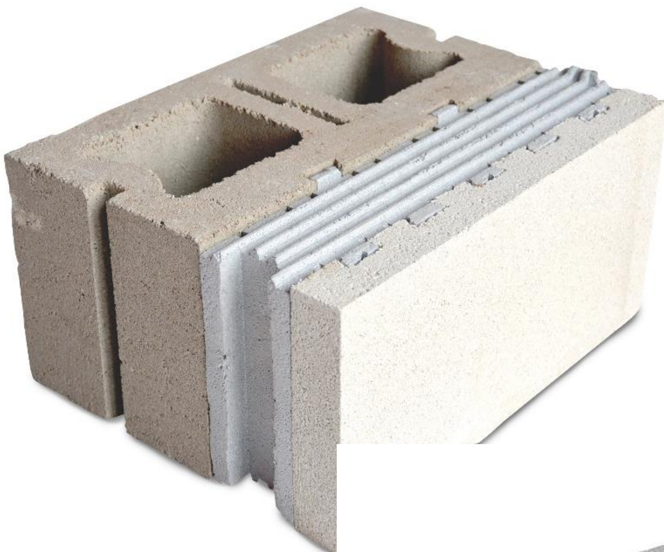
Capital costs lower or less than 1 year payback

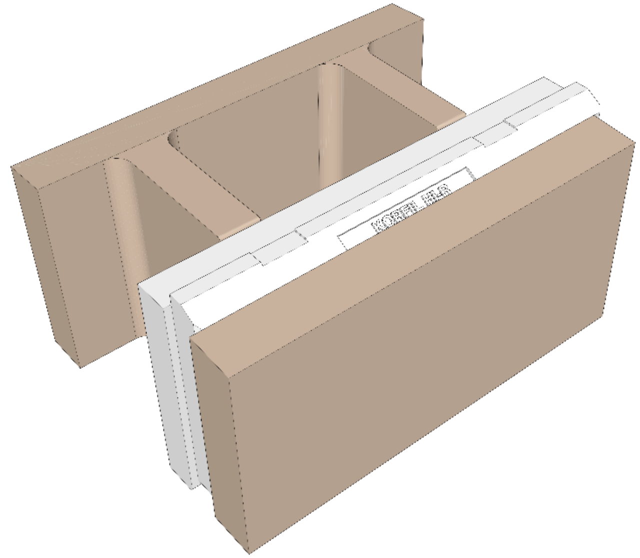
End results

- Holistic analyses shows indicates changes in U high levels (Low R) can have significant effect on performance up to a point but not much after this point
- You can back off code minimum insulation (max U values) with little impact on energy use.



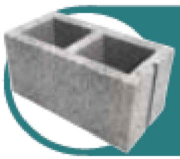
CMU Products for Energy Efficiency



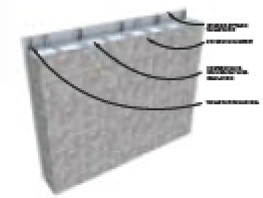


From NCMA
Presentation

Where Do I Find Masonry U-Factors?



SINGLE WYTHE CONCRETE MASONRY ASSEMBLIES
CELL INSULATION



Assembly 1-2: Polyurethane foamed-in-place insulation in ungrouted cells, exposed exterior masonry, 1/2 in. gypsum wallboard on furring on interior

Concrete Masonry Assembly R-Values (hr·ft²·°F/Btu) and U-Factors (Btu/hr·ft²·°F)

Density of CMU, PCF	6-in. Concrete Masonry				8-in. Concrete Masonry			
	Ungrouted	Lightly Reinforced	Heavily Reinforced	Fully Grouted	Ungrouted	Lightly Reinforced	Heavily Reinforced	Fully Grouted
85	7.48 (0.134)	5.55 (0.180)	4.39 (0.228)	2.90 (0.345)	9.68 (0.103)	6.73 (0.148)	5.11 (0.196)	3.21 (0.312)
95	6.64 (0.151)	5.11 (0.196)	4.13 (0.242)	2.81 (0.356)	8.50 (0.118)	6.17 (0.162)	4.80 (0.208)	3.10 (0.323)
105	5.90 (0.169)	4.71 (0.212)	3.90 (0.257)	2.73 (0.366)	7.48 (0.134)	5.65 (0.177)	4.50 (0.222)	3.00 (0.334)
115	5.27 (0.190)	4.35 (0.230)	3.68 (0.272)	2.66 (0.375)	6.59 (0.152)	5.18 (0.193)	4.23 (0.236)	2.91 (0.344)
125	4.73 (0.212)	4.02 (0.249)	3.48 (0.287)	2.60 (0.384)	5.83 (0.172)	4.75 (0.210)	3.98 (0.251)	2.83 (0.354)
135	4.26 (0.235)	3.73 (0.268)	3.30 (0.303)	2.55 (0.393)	5.18 (0.193)	4.37 (0.229)	3.75 (0.267)	2.76 (0.363)

Density of CMU, PCF	10-in. Concrete Masonry				12-in. Concrete Masonry			
	Ungrouted	Lightly Reinforced	Heavily Reinforced	Fully Grouted	Ungrouted	Lightly Reinforced	Heavily Reinforced	Fully Grouted
85	11.57 (0.086)	7.70 (0.130)	5.70 (0.176)	3.45 (0.290)	14.09 (0.071)	8.81 (0.113)	6.32 (0.158)	3.68 (0.271)
95	10.08 (0.099)	7.04 (0.142)	5.34 (0.187)	3.33 (0.300)	12.20 (0.082)	8.06 (0.124)	5.93 (0.168)	3.56 (0.281)
105	8.79 (0.114)	6.42 (0.156)	5.01 (0.200)	3.23 (0.310)	10.57 (0.095)	7.36 (0.136)	5.57 (0.179)	3.45 (0.289)
115	7.67 (0.130)	5.86 (0.171)	4.70 (0.213)	3.13 (0.319)	9.17 (0.109)	6.71 (0.149)	5.23 (0.191)	3.35 (0.298)
125	6.72 (0.149)	5.36 (0.187)	4.41 (0.227)	3.05 (0.328)	7.97 (0.125)	6.11 (0.164)	4.90 (0.204)	3.26 (0.307)
135	5.92 (0.169)	4.90 (0.204)	4.14 (0.242)	2.96 (0.337)	6.96 (0.144)	5.57 (0.180)	4.59 (0.218)	3.17 (0.315)

From NCMA Presentation

Where Do I Find Masonry U-Factors?

NATIONAL CONCRETE MASONRY ASSOCIATION
Sustainable Concrete Products for Structures and Hardscapes

NCMA R-Value / U-Factor / Heat Capacity Calculator
User Input Page (3 Layer Unit)

Please enter inputs below for the wall assembly

Step 2: CMU Description

Description:					

NOTE: Enter description of CMU to be included in calculation output

Step 3: CMU Nominal Dimesions

		Specified
Width (in.)		-0.375
Height (in.)		-0.375
Length (in.)		-0.375

Step 4: Face Shell Thickness

Face 1 Thickness (in.)	
Face 2 Thickness (in.)	

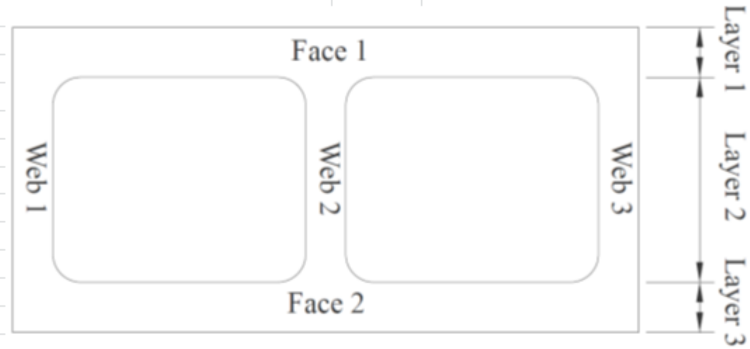
Step 4: Web Information

				Calculated Web Area
Web 1 Thickness (in.)		Web 1 Height (in.)		0
Web 2 Thickness (in.)		Web 2 Height (in.)		0
Web 3 Thickness (in.)		Web 3 Height (in.)		0
Web 4 Thickness (in.)		Web 4 Height (in.)		0
			Total	0

- Option - enter total web area for CMU

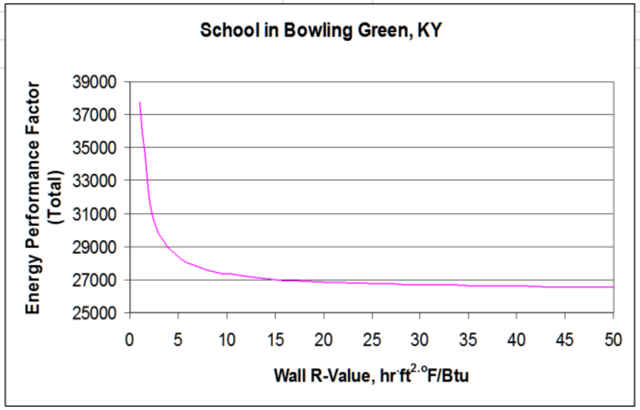
NOTE - Entering a total web area above will overide individial web entries.

3 Layer Unit



Steps 11 & 12: Surface Finishes

Inside Surface Finish	None
Outside Surface Finish	None



New – Changes to ASTM C 90 allow 2 web Blocks – will reduce block U

From NCMA Presentation

Conclusions

- Holistic analysis shows that small increases in low effective R values in Mass walls can have a significant effect in energy efficiency
- Past code minimum R values, increases in wall insulation has little effect.
- The significant relief of Ci and Maximum U values can be realized using holistic building analysis – Ultimately saving construction cost.
- Holistic design supports “doing more with less” - Sustainable design?

THANK YOU !

QUESTIONS?