J.B. SPEED SCHOOL
OF ENGINEERING

# Masonry Walls and Energy Codes - Effective Compliance Methods
# Session 1

W. Mark McGinley, Ph. D., PE FASTM, FTMS

MASONRY SEMINAR
Masonry Institute of Hawaii
**March 2020**

1

## Introduction

- The prescriptive energy code requirements for building envelopes have increased significantly over the past several years.
- Compliance with these code provisions is becoming increasingly more difficult, and new solutions are necessary.
- This presentation will provide an overview of energy code provisions and energy related analysis.

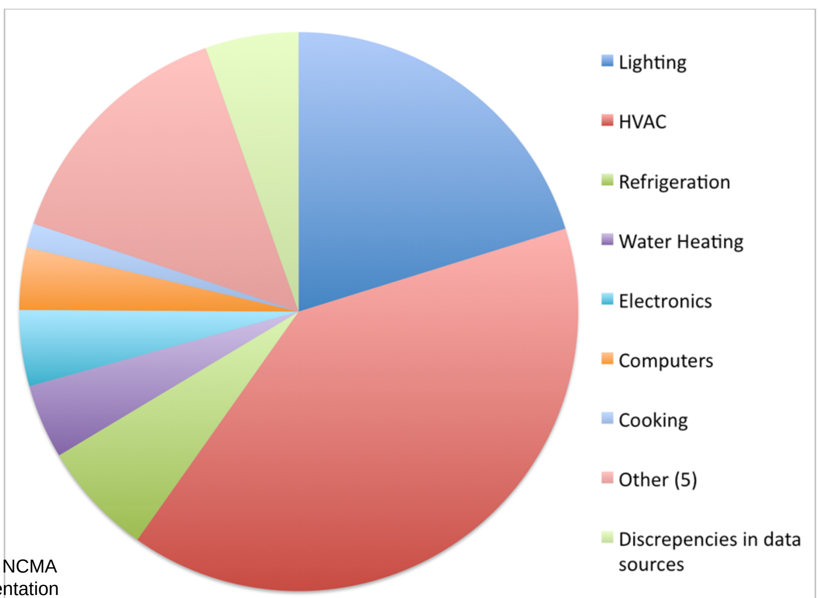
2

# Introduction

- Look at thermal bridging, U and R values, and payback costs analysis for energy improvements using whole building analysis
- Throughout discuss resources available for designers, such as ACI/TMS 122.
- Summarize a series of energy studies conducted on mass masonry wall buildings in a variety of climates



# Commercial Building Energy Use

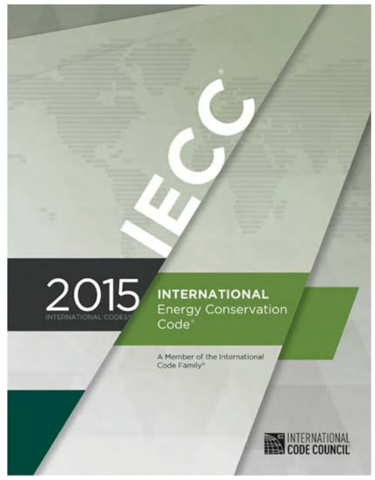



From NCMA Presentation

# International Energy Conservation Code

Energy codes continue to become more stringent…

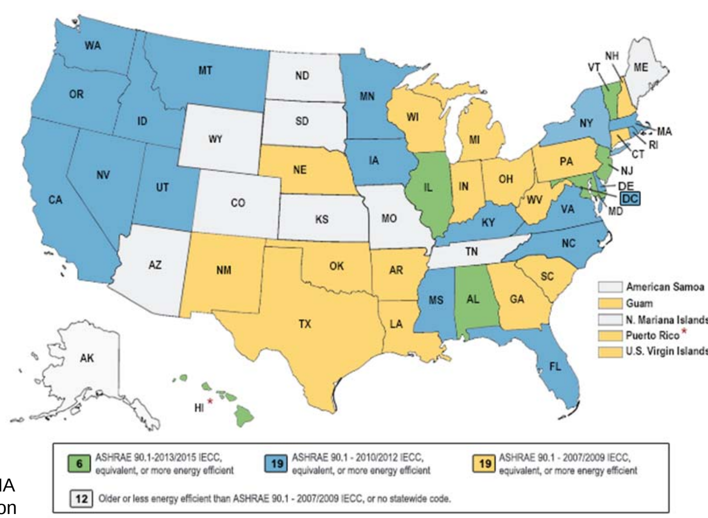
- 2012 is about 15% more efficient than 2009
- 2015 is about 11% more efficient
- References ASHREA 90.1 as an alternative – similar provisions




From NCMA Presentation

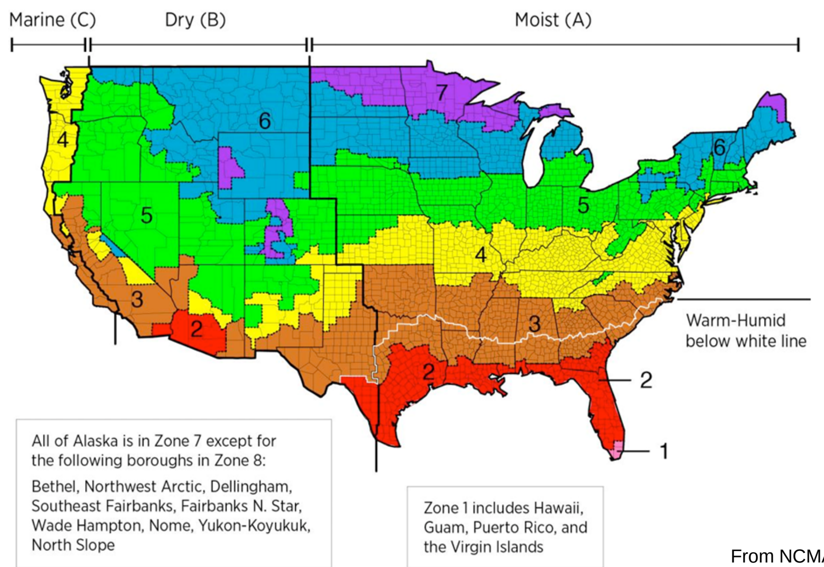


# International Energy Conservation Code (IECC)




From NCMA Presentation

# Climate Zones




From NCMA Presentation

7

# Compliance Options - IECC

Prescriptive → R-value table
Prescriptive → U-factor table

Trade-off Envelope → COMcheck

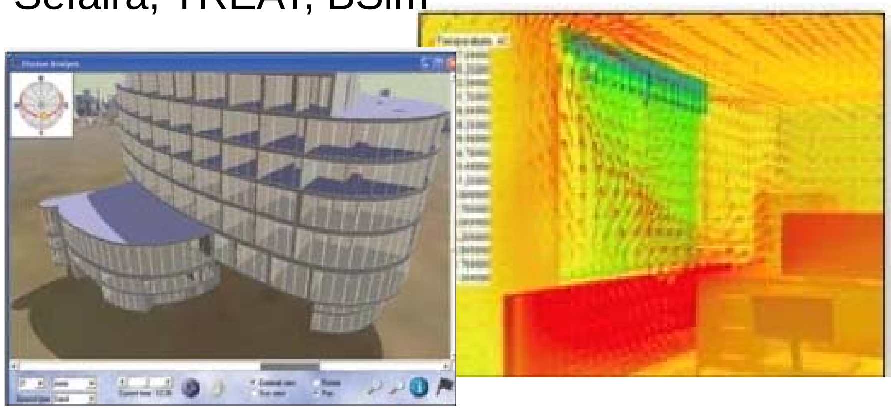
Total building performance → EnergyPlus/Design Builder, Sefaira, TREAT, BSim, etc.

From NCMA Presentation

8

# Total Building Performance

Tools include: EnergyPlus/DesignBuilder, Sefaira, TREAT, BSim



www.buildingenergysoftwaretools.com

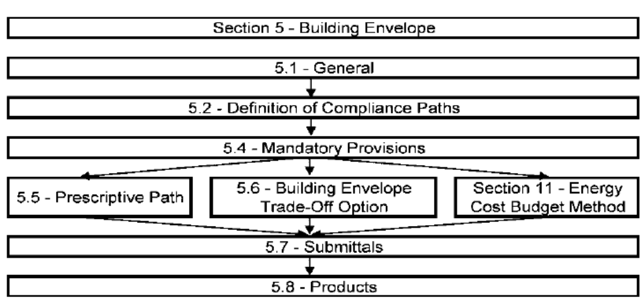
From NCMA Presentation



# Energy  Code Design ASHREA 90.1

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

**5. BUILDING ENVELOPE**



## Energy Code Design

**Prescriptive requirements – Envelope – Varies with Climate Zone**

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** | **Assembly Max. U** | **Assembly Max. SHGC** | **Assembly Max. U** | **Assembly Max. SHGC** | **Assembly Max. U** | **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 | |

**Climate Zone 4 B**

*Walls, Above-Grade*

| | | |
|---|---|---|
| Mass | U-0.104 | R-9.5 c.i. |



# Terminology

**R-value**: describes how well a material insulates under steady state temperature conditions; R = 1/U

**U-factor**: describes how well a material conducts heat under steady state temperature conditions; U = 1/R

**Heat capacity** (HC): describes how well a material stores and releases heat under transient temperature conditions (thermal mass)

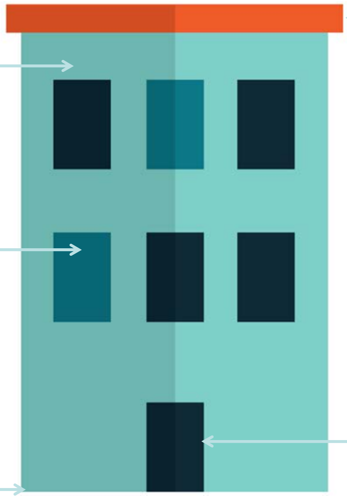
From NCMA Presentation

## Prescriptive Compliance
## Example Zone 4 – Envelope – R values

Above-grade walls, R9.5 continuous insulation

Fenestration, U0.38 max, 0.40 SHGC

Slab on grade, R10 for 24 in. below



Roof, R30 continuous insulation

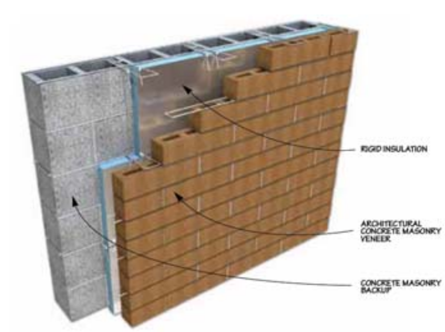
Opaque doors, R4.75

From NCMA Presentation

13

# Prescriptive R-Value Compliance

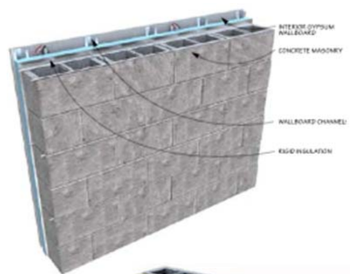
Masonry cavity wall:
• cavity width can be varied to accommodate insulation
• R-values largely independent of grout schedule
• exposed masonry provides maximum durability

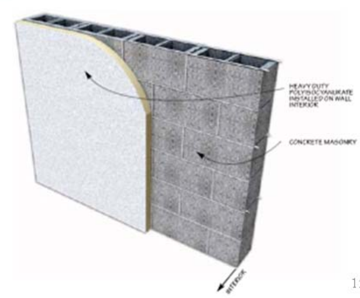



From NCMA Presentation

14

# Prescriptive R-Value Compliance




Continuous interior insulation:

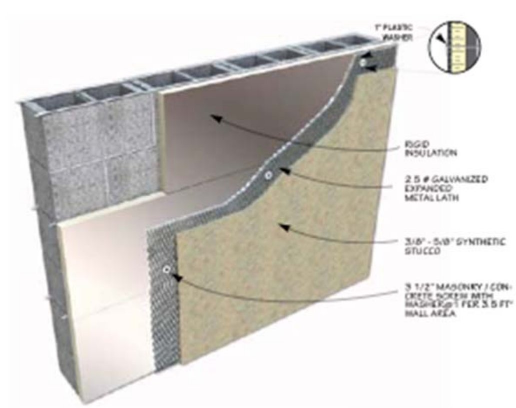
- R-values independent of grout schedule
- allows exterior exposed masonry
- furring space can be used for wiring and utilities



# Prescriptive R-Value Compliance

Continuous exterior insulation:

- R-values independent of grout schedule
- allows interior exposed masonry, maximizing thermal mass benefits



# Prescriptive R-Value Compliance
# Internal insulation

| CLIMATE ZONE | 1 | | 2 | | 3 | |
|---|---|---|---|---|---|---|
| | All other | Group R | All other | Group R | All other | Group R |
| Insulation entirely above roof deck | R-20ci | R-25ci | R-25ci | R-25ci | R-25ci | R-25ci |
| Metal buildings[b] | R-19 + R-11 LS | R-19 + R-11 LS | R-19 + R-11 LS | R-19 + R-11 LS | R-19 + R-11 LS | R-19 + R-11 LS |
| Attic and other | R-38 | R-38 | R-38 | R-38 | R-38 | R-38 |
| Mass | R-5.7ci[c] | R-5.7ci[c] | R-5.7ci[c] | R-7.6ci | R-7.6ci | R-9.5ci |
| Metal building | R-13 + R-6.5ci | R-13 + R-6.5ci | R-13 + R-6.5ci | R-13 + R-13ci | R-13 + R-6.5ci | R-13 + R-13ci |
| Metal framed | R-13 + R-5ci | R-13 + R-5ci | R-13 + R-5ci | R-13 + R-7.5ci | R-13 + R-7.5ci | R-13 + R-7.5ci |

From NCMA Presentation

[c] R-5.7ci is allowed to be substituted with concrete block walls complying with ASTM C90, ungrouted or partially grouted at 32 inches or less on center vertically and 48 inches or less on center horizontally, with ungrouted cores filled with materials having a maximum thermal conductivity of 0.44 Btu-in/h-f² °F.

17

# WHAT IF MY BUILDING DOESN'T MEET PRESCRIPTIVE INSULATION R-VALUES?

## Prescriptive U-Factor Compliance

***Note this is assembly U***

| *Walls, Above-Grade* | | |
|---|---|---|
| Mass | U-0.104 | R-9.5 c.i. |

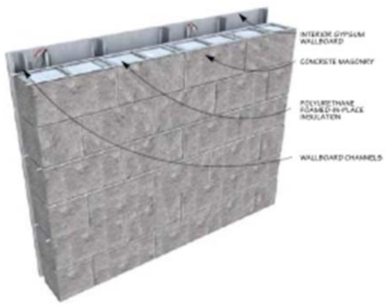
ASHRAE Provisions

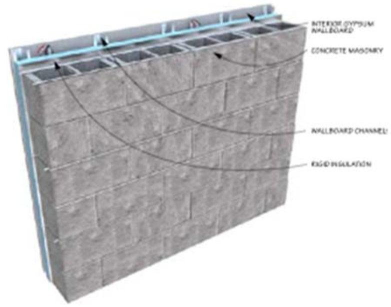
IECC – Has a Separate U value table – Assembly U

18

# Prescriptive U-Factor Compliance

Makes sense any time the preferred wall meets the prescriptive U-factor requirement.

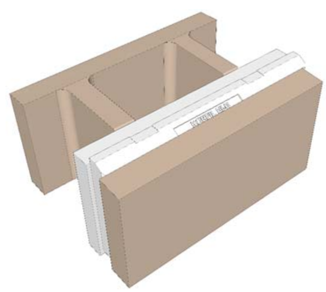



From NCMA Presentation



# CMU Products for Energy Efficiency



From NCMA Presentation

**Where Do I Find Masonry U-Factors?**
**NCMA WEB SITE CHANGING – No Spread sheet**


21

# Where Do I Find Masonry U-Factors?

**SECTION TWO**
**2-WEB CMU ASSEMBLIES**

**Assembly 2-1: Polyurethane foamed-in-place insulation in ungrouted cells, exposed masonry (interior and exterior)**

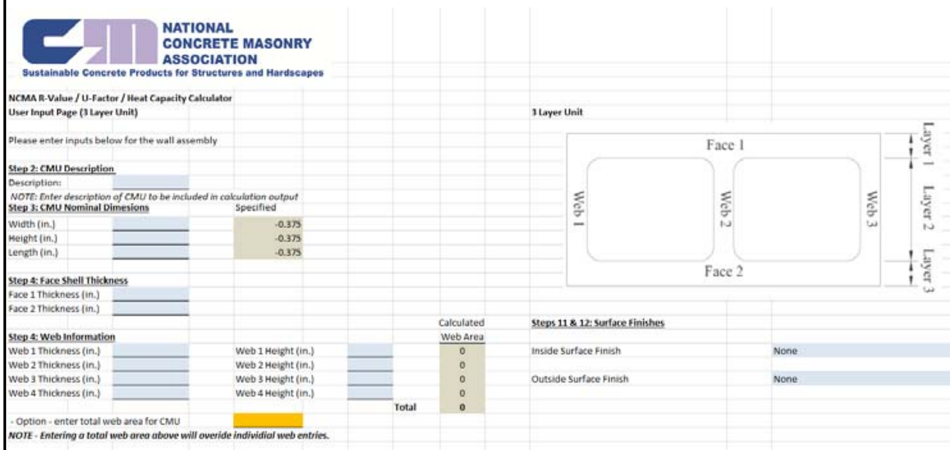

- Masonry exposed on both the interior and exterior provides maximum durability.
- Values in table assume no insulation in grouted cells. Note that some rigid inserts are configured to accommodate insulation, reinforcing steel and grout in the same cell, which can improve R-values.
- Other masonry cell insulations include molded polystyrene inserts, other types of foamed-in-place insulations and expanded perlite or vermiculite granular fills. These insulations will have different thermal properties than polyurethane which will affect the resulting R-value.
- Cell insulation, in contrast to additional insulation on either side of the wall, allows some of the thermal mass (masonry) to be in direct contact with the indoor air, providing excellent thermal mass benefits.
- Insulation should occupy all ungrouted cells.
- "Lightly reinforced" = grout 8 ft o.c. both vertically and horizontally (or vertical reinforcement only at 48 in. o.c.). "Heavily reinforced" = grout 32 in o.c. vertically and 48 in. o.c. horizontally (or vertical reinforcement only at 24 in. o.c.).

From NCMA Presentation

22

# Where Do I Find Masonry U-Factors?

**Use to have a Spread sheet that allowed Parallel and series analysis**



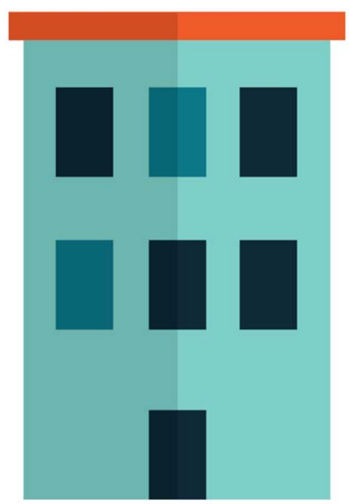

New – Changes to ASTM C 90 allow 2 web
Blocks – will reduce block U

From NCMA
Presentation

23

## Second Compliance Method

## Trade-Off Compliance/COMcheck



Three overall budgets:

Envelope

Mechanical

Lighting

From NCMA
Presentation

24

# COMcheck

www.energycodes.gov/comcheck

**COM*check*™ Software**

Windows | Mac | COM*check-Web* | Technical Support

**COM*check*™ for Windows®**
**Version 4.0.2 (Build Version: 4.0.2.8)**
Runs on Vista or Windows 7 in either single, multi-user, or network environments

**Supported Codes:**
2009, 2012 and 2015 IECC.
*ASHRAE Standard 90.1:*2007, 2010, and 2013
Various state-developed energy codes.

Version 4.0.2 includes support for the 2015 IECC energy code. This release also includes support for '2014 Florida Building Code, Energy Conservation'. 2006 IECC and 2011 Vermont Commercial Building Energy Standard are no longer supported by COMcheck.

Download COMcheck for Windows

*Download COMcheck Now!*

From NCMA Presentation

25

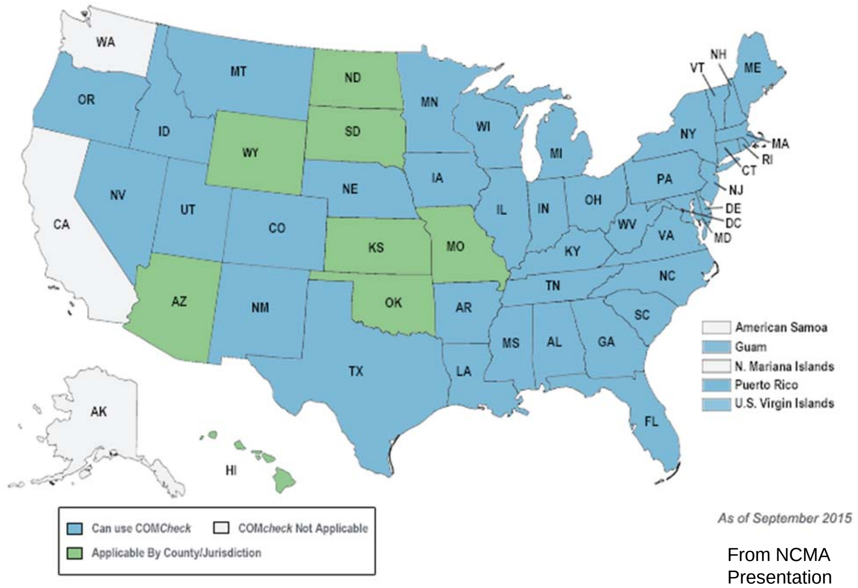
# COMcheck

- easy way to take advantage of trade-offs, ie, increase roof insulation to reduce wall or window requirements.
- program shows if the envelope complies, and how close it is to compliance
- allows individual elements to be tweaked for compliance, revisions are quick and easy.
- **<u>Trade offs are for envelope only</u>**

From NCMA Presentation

26

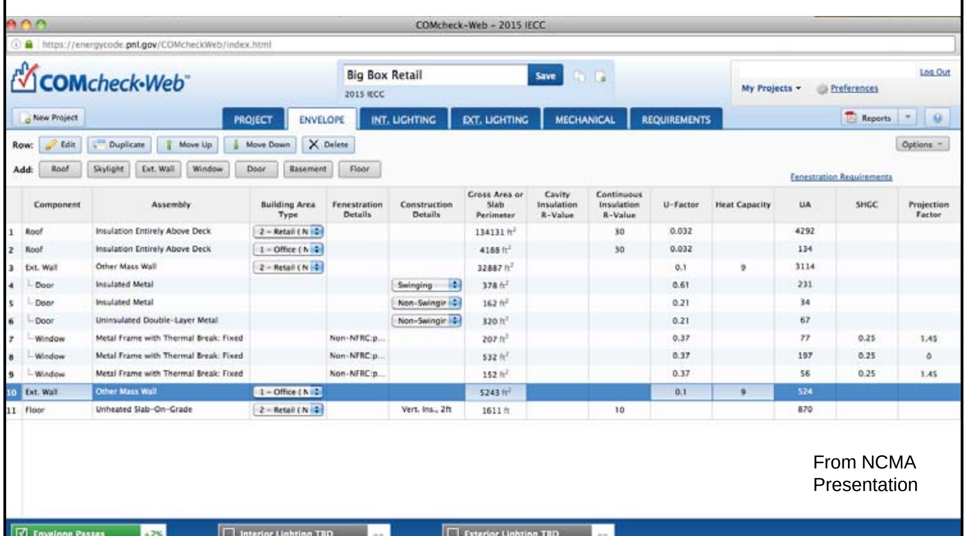
# Where Can I Use




From NCMA Presentation



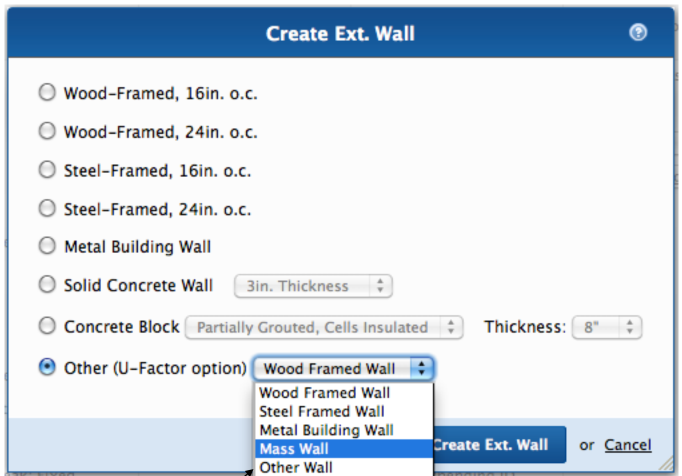
# COMcheck Input




| | Component | Assembly | Building Area Type | Fenestration Details | Construction Details | Gross Area or Slab Perimeter | Cavity Insulation R-Value | Continuous Insulation R-Value | U-Factor | Heat Capacity | UA | SHGC | Projection Factor |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Roof | Insulation Entirely Above Deck | 2 – Retail ( N | | | 134131 ft² | | 30 | 0.032 | | 4292 | | |
| 2 | Roof | Insulation Entirely Above Deck | 1 – Office ( N | | | 4188 ft² | | 30 | 0.032 | | 134 | | |
| 3 | Ext. Wall | Other Mass Wall | 2 – Retail ( N | | | 32887 ft² | | | 0.1 | 9 | 3114 | | |
| 4 | └ Door | Insulated Metal | | | Swinging | 378 ft² | | | 0.61 | | 231 | | |
| 5 | └ Door | Insulated Metal | | | Non-Swingir | 162 ft² | | | 0.21 | | 34 | | |
| 6 | └ Door | Uninsulated Double-Layer Metal | | | Non-Swingir | 320 ft² | | | 0.21 | | 67 | | |
| 7 | └ Window | Metal Frame with Thermal Break: Fixed | | Non-NFRC:p... | | 207 ft² | | | 0.37 | | 77 | 0.25 | 1.45 |
| 8 | └ Window | Metal Frame with Thermal Break: Fixed | | Non-NFRC:p... | | 532 ft² | | | 0.37 | | 197 | 0.25 | 0 |
| 9 | └ Window | Metal Frame with Thermal Break: Fixed | | Non-NFRC:p... | | 152 ft² | | | 0.37 | | 56 | 0.25 | 1.45 |
| 10 | Ext. Wall | Other Mass Wall | 1 – Office ( N | | | 5243 ft² | | | 0.1 | 9 | 524 | | |
| 11 | Floor | Unheated Slab-On-Grade | 2 – Retail ( N | | Vert. Ins., 2ft | 1611 ft | | 10 | | | 870 | | |

From NCMA Presentation

# COMcheck Input

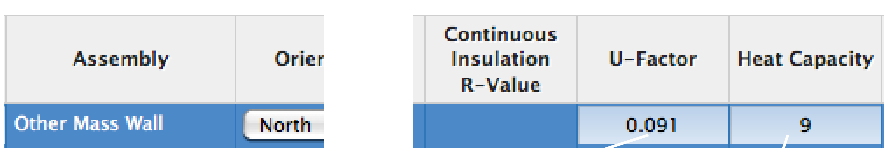



**Always use Other (mass) exterior wall input**
**Default value for CMU very conservative.**

From NCMA Presentation



# COMcheck Input – Other Mass Wall




Thermal Catalog
NCMA TEKs 6-1C & 6-2C
R-Value/U-Factor Calculator

NCMA TEK 6-16A

Also ACI 122R Guide to Thermal Properties of Concrete and Masonry Systems

From NCMA Presentation

## 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

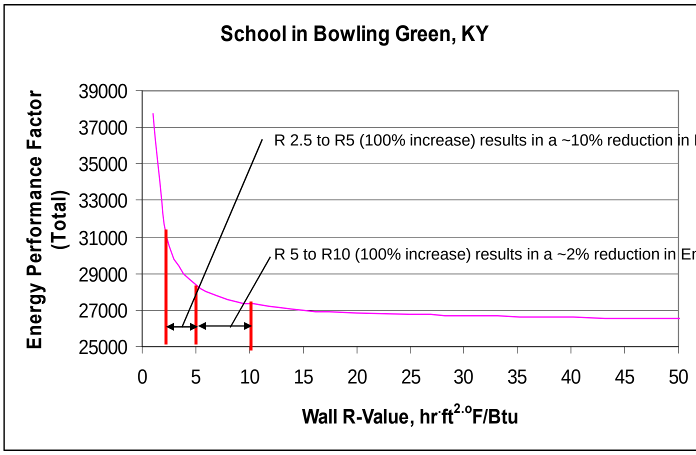
31

## COMcheck

- 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

32

Envelope Performance Factor (EPF) is a relative term that approximates the total heating and cooling energy flow 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

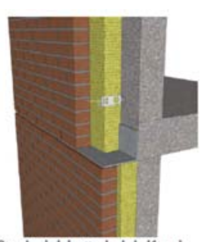
33

# Thermal Bridging

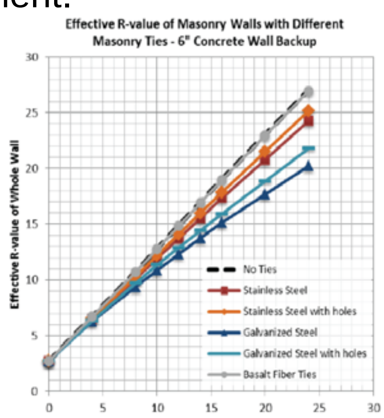
Thermal bridging can have a significant effect on Thermal resistance of the envelope – Thus the $C_i$ or U requirement.

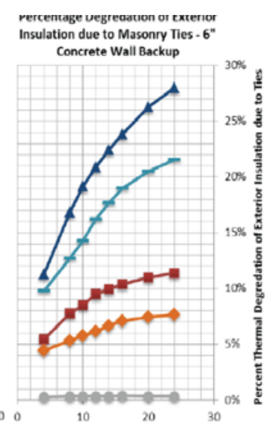
***Ties(anchors) angles can reduce steady state thermal resistance significantly***

***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**

34

## Thermal Bridging

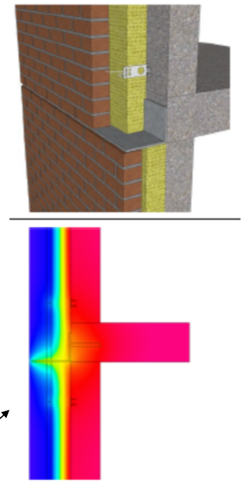
Thermal bridging can have a significant effect on Thermal resistance of the envelope – Thus the Ci requirement.

***Shelf angles can reduce steady state thermal resistance significantly***

***~40% reduction - SS but may not be this high dynamically***

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

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)

35

## BEST WAY TO EVALUATE THESE EFFECTS IS TO USE HOLISTIC ENERGY ANALYSIS – ENERGYPLUS, DOE 2.

- Basis of 3rd compliance method, Energy Budget method – Proposed building must have ≤ Energy cost to prescriptive methods – Also new Appendix G method index.
- Better accounts of thermal mass effects – dynamic weather and internal loads, etc.

36

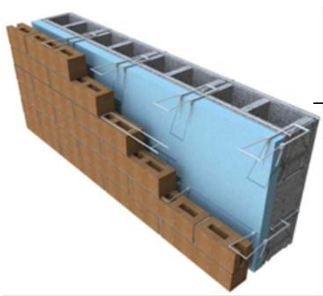
## Designed a Base Prototype Middle School to Meet prescriptive provisions -4B

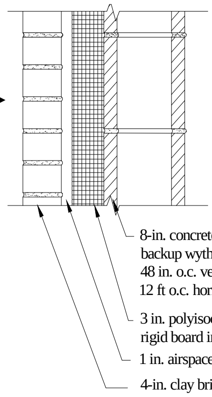
- Most Lights T 12- 2 and 4 lamp systems
- High bay halides
- HVAC VAV - Gas boilers and Chillers
- Typical school use schedules.
- Minimum Envelope U and R values ~ R 26 Roof, ~R 9.8 Walls
- Base EUI - ~132

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

37

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

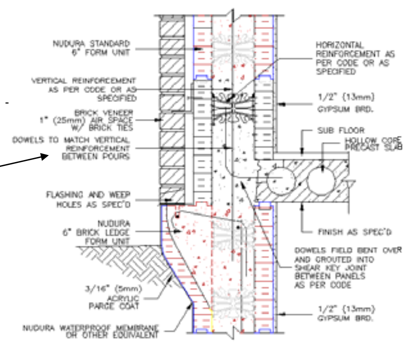


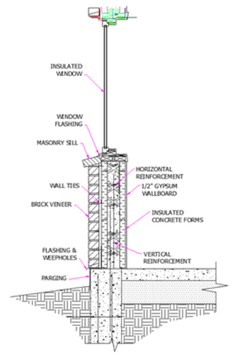



Vary the exterior masonry cavity wall insulation: 1 ¼" thick polystyrene, 1 ½" thick polystyrene, 2" thick polyisocyanurate foam board, 3" polyisocyanurate foam board. **Over 100% swing in insulation values.**

38

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




Exterior CMU wall structure to an insulated concrete form (ICF) wall system; 4" face brick, air space, 1 ½" polyurethane, 6" 140lb concrete, 1 ½" polyurethane, and ½" gypsum board.

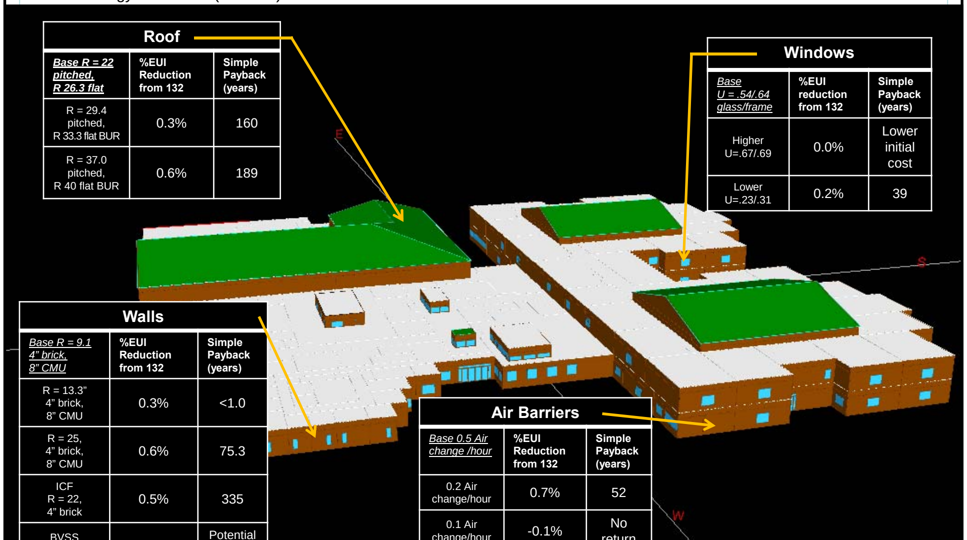
39

## 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
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

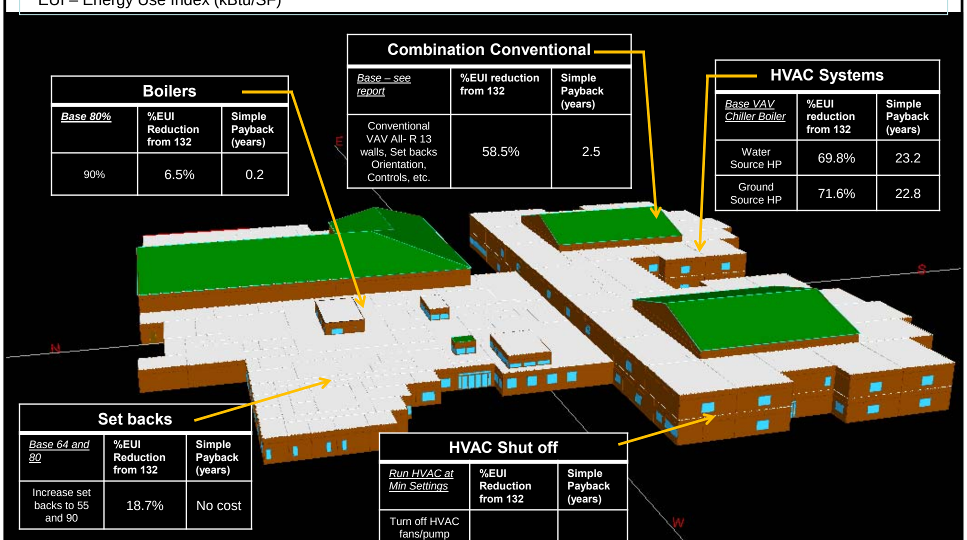
For more details See: *"Cost Effective Energy Efficient School Design" Report* (McGinley 2011)

Courtesy of the Indiana-Kentucky Structural Masonry Coalition

1

# Energy Savings and Payback in Typical Middle School*

*Louisville, KY – other climates similar
EUI – Energy Use Index (kBtu/SF)



**Boilers**

| Base 80% | %EUI Reduction from 132 | Simple Payback (years) |
|---|---|---|
| 90% | 6.5% | 0.2 |

**Combination Conventional**

| Base – see report | %EUI reduction from 132 | Simple Payback (years) |
|---|---|---|
| Conventional VAV All- R 13 walls, Set backs Orientation, Controls, etc. | 58.5% | 2.5 |

**HVAC Systems**

| Base VAV Chiller Boiler | %EUI reduction from 132 | Simple Payback (years) |
|---|---|---|
| Water Source HP | 69.8% | 23.2 |
| Ground Source HP | 71.6% | 22.8 |

**Set backs**

| Base 64 and 80 | %EUI Reduction from 132 | Simple Payback (years) |
|---|---|---|
| Increase set backs to 55 and 90 | 18.7% | No cost |

**HVAC Shut off**

| Run HVAC at Min Settings | %EUI Reduction from 132 | Simple Payback (years) |
|---|---|---|
| Turn off HVAC fans/pump 7pm -6am except as needed for set back temp | 21.1% | 2.8 |

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

Courtesy of the Indiana-Kentucky Structural Masonry Coalition

42

## ALTERNATIVE ENERGY DESIGNS IN SINGLE WYTHE MASONRY BUILDINGS

- U of L 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
- Also looked at Canadian Code

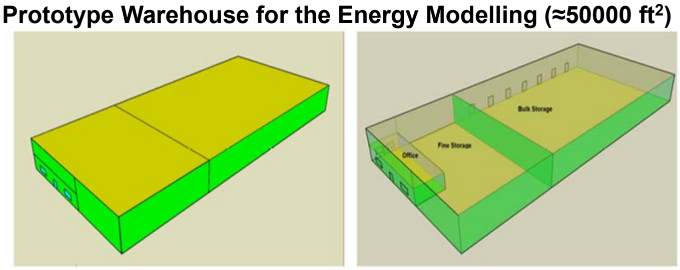
43

# 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].

.

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

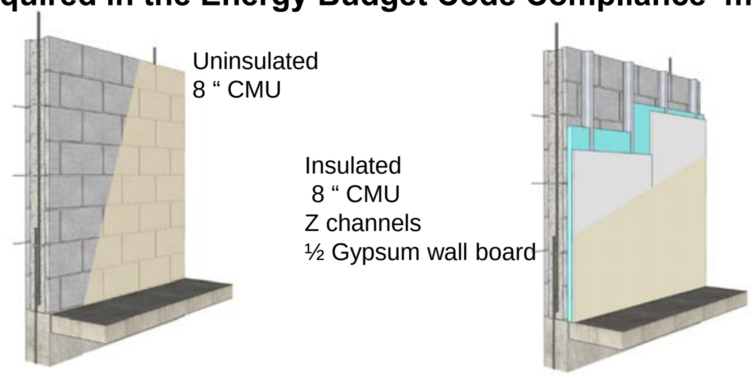



**Evaluated Climate Zones and cities.**

| 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 | | | |

44

**Prototype Warehouse <u>BASELINE DESIGNS - US</u> 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**




(Infiltration rate of 0.038 cfm/ft$^2$)

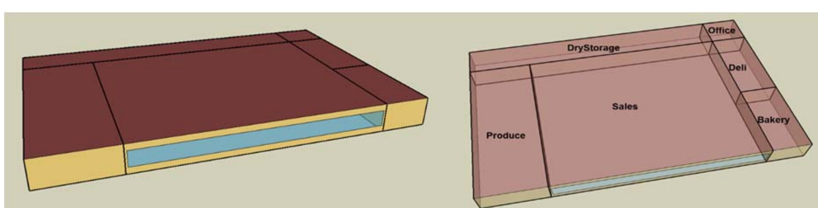
**Some climate zones required the exterior walls of the bulk storage to be insulated, some did not. The office and fine storage areas were insulated with varying R values**

45

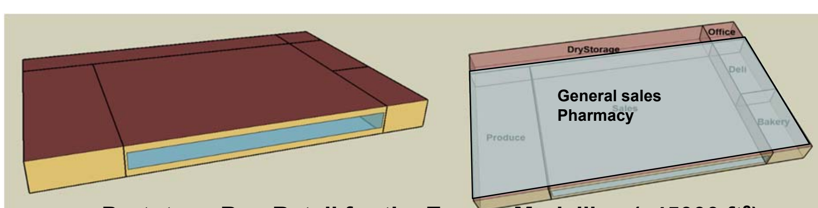
# Archetype 2 &3 Supermarket & Box Retail-US

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

.



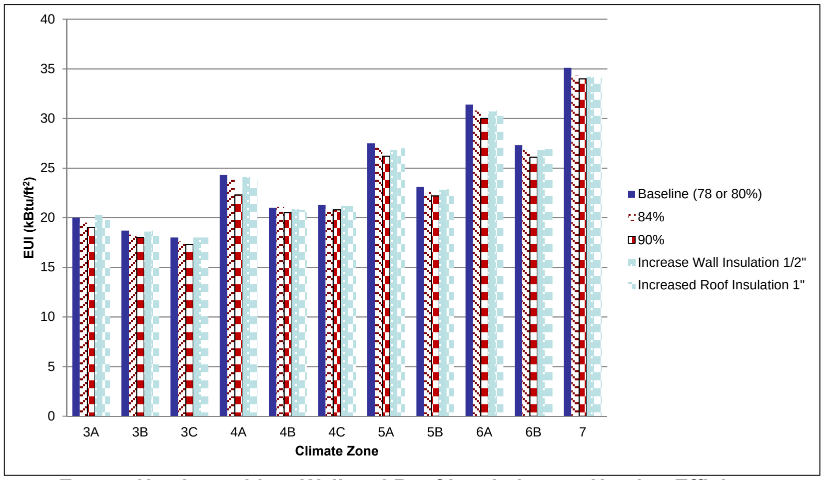

**Prototype Supermarket for the Energy Modelling (≈45000 ft$^2$)**




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

46

## Warehouse Sensitivity Analysis- US




**Energy Use Intensities: Wall and Roof Insulation vs. Heating Efficiency**
**Less effect of insulation more effect of HVAC effciency**

47

## Warehouse Sensitivity Analysis- US


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

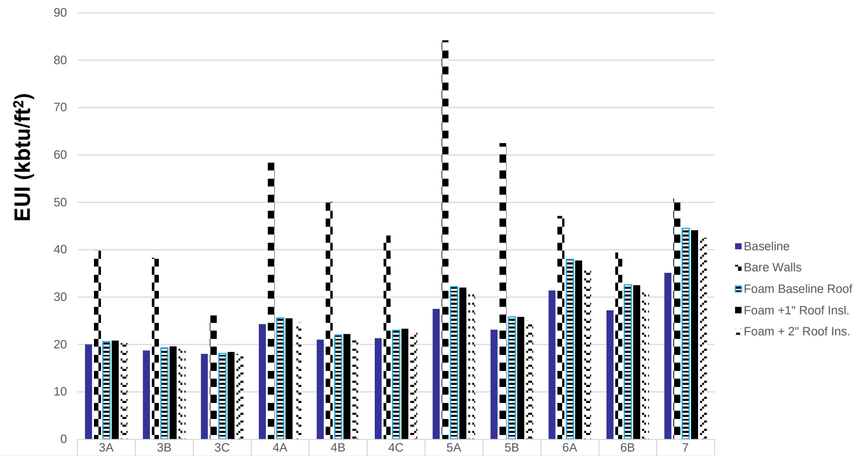
By NCMA TEK Note 6B [14] U- and R-values = 0.287 Btu/ft$^2$-h-°F and 3.48 ft$^2$-h-°F/Btu

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)).

48

# Warehouse Sensitivity Analysis- US

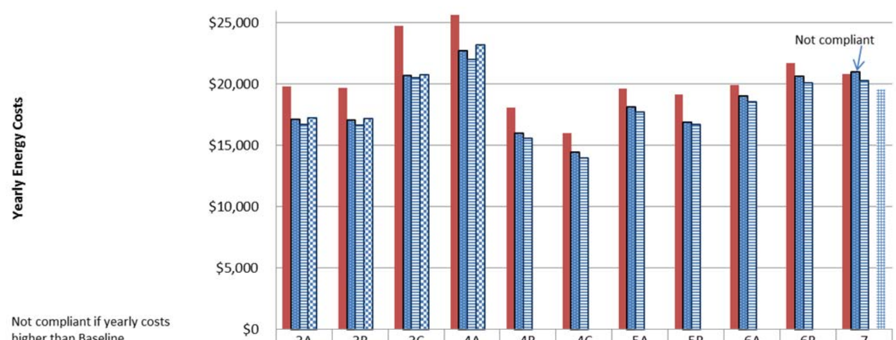



| | 3A | 3B | 3C | 4A | 4B | 4C | 5A | 5B | 6A | 6B | 7 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Baseline | 20 | 18.7 | 18 | 24.3 | 21 | 21.3 | 27.5 | 23.1 | 31.4 | 27.2 | 35.1 |
| Bare Walls | 39.8 | 38.3 | 26.1 | 58.4 | 50.1 | 43 | 84.2 | 62.5 | 47.1 | 39.4 | 50.8 |
| Foam Baseline Roof | 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

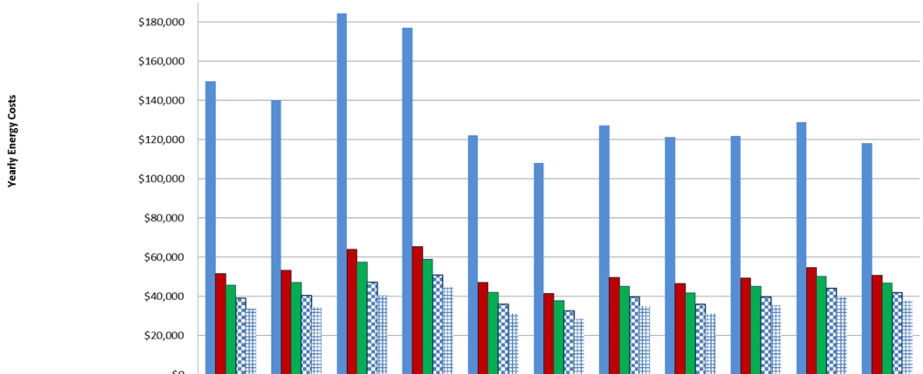



Not compliant if yearly costs higher than Baseline

| | 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)**

## 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. (see next slide)**

51

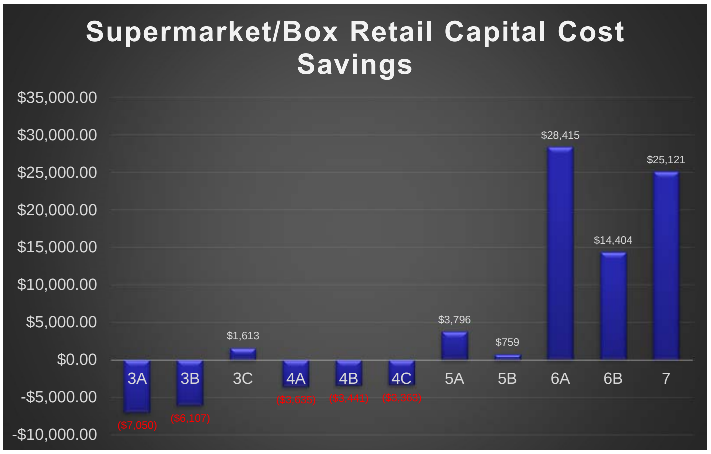
## Alternative Designs US Differential Construction Cost


**8"CMU Foam core Walls, Lower Ballast Factors**
**For 4B and above - +2" Roof insulation**
**For 7 - Occupancy Sensors**

52

# Alternative Designs US Differential Construction Cost

**Construction Cost Savings of Alternative Designs <u>Box Retail and Supermarkets – 8" CMU Foamed wall and LED Lights</u>**




53

# Conclusions

- Prescriptive Methods can be used but assembly U values may be the best way to achieve this especially with 8" or 12" CMU and foamed cores, or two web blocks.
- COM check – Envelope trade offs can work where your designs are close to prescriptive code configurations. Use OTHER Walls.
- Energy Budget method showed significant potential energy savings of over 50% for typical prescriptive configurations. Better lighting, HVAC systems and aggressive control strategies -paybacks < 3 years.

54

## Conclusions

- Envelope improvements beyond code minimums have little effect on yearly energy consumption.
- Thermal Bridging may have minimal effect on energy consumption and may be compensated with a little additional insulation.



## Masonry Walls and Energy Codes – Alternative Energy Code Compliant Designs for Single Wythe Masonry Structures in Hawaii

## Introduction

- The recent Hawaiian adoption of IECC 2015 complicated cost effective energy efficient design in this state by now prescriptively requiring continuous insulation for exterior masonry walls. – Residential & Non. (solid grouting)

57

## Introduction

- Discuss two phase investigation of energy efficient design of typical structures that use exterior masonry and concrete walls.
- Phase 1 – Looked at prescriptive approach, R , U and Com Check Trade off approaches
- Phase 2 - looked at whole building energy analysis and alternative approaches.

58

## IECC Prescriptive R table

**TABLE C402.1.4**
**OPAQUE THERMAL ENVELOPE ASSEMBLY MAXIMUM REQUIREMENTS, *U*-FACTOR METHOD[a, b]**

| CLIMATE ZONE | 1 | | 2 | | 3 | | 4 EXCEPT MARINE | | 5 AND MARINE 4 | | 6 | | 7 | | 8 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | All other | Group R | All other | Group R | All other | Group R | All other | Group R | All other | Group R | All other | Group R | All other | Group R | All other | Group R |
| **Roofs** | | | | | | | | | | | | | | | | |
| Insulation entirely above roof deck | U-0.048 | U-0.039 | U-0.039 | U-0.039 | U-0.039 | U-0.039 | U-0.032 | U-0.032 | U-0.032 | U-0.032 | U-0.032 | U-0.032 | U-0.028 | U-0.028 | U-0.028 | U-0.028 |
| Metal buildings | U-0.044 | U-0.035 | U-0.035 | U-0.035 | U-0.035 | U-0.035 | U-0.035 | U-0.035 | U-0.035 | U-0.035 | U-0.031 | U-0.031 | U-0.029 | U-0.029 | U-0.029 | U-0.029 |
| Attic and other | U-0.027 | U-0.027 | U-0.027 | U-0.027 | U-0.027 | U-0.027 | U-0.027 | U-0.027 | U-0.027 | U-0.021 | U-0.021 | U-0.021 | U-0.021 | U-0.021 | U-0.021 | U-0.021 |
| **Walls, above grade** | | | | | | | | | | | | | | | | |
| Mass | U-0.151 | U-0.151 | U-0.151 | U-0.123 | U-0.123 | U-0.104 | U-0.104 | U-0.090 | U-0.090 | U-0.080 | U-0.080 | U-0.071 | U-0.071 | U-0.061 | U-0.061 | U-0.061 |
| Metal building | U-0.079 | U-0.079 | U-0.079 | U-0.079 | U-0.079 | U-0.052 | U-0.052 | U-0.052 | U-0.052 | U-0.052 | U-0.052 | U-0.052 | U-0.052 | U-0.039 | U-0.052 | U-0.039 |
| Metal framed | U-0.077 | U-0.077 | U-0.077 | U-0.064 | U-0.064 | U-0.064 | U-0.064 | U-0.064 | U-0.064 | U-0.064 | U-0.064 | U-0.057 | U-0.064 | U-0.052 | U-0.045 | U-0.045 |
| Wood framed and other[c] | U-0.064 | U-0.064 | U-0.064 | U-0.064 | U-0.064 | U-0.064 | U-0.064 | U-0.064 | U-0.064 | U-0.064 | U-0.051 | U-0.051 | U-0.051 | U-0.051 | U-0.036 | U-0.036 |
| **Walls, below grade** | | | | | | | | | | | | | | | | |
| Below-grade wall[c] | C-1.140[e] | C-1.140[e] | C-1.140[e] | C-1.140[e] | C-1.140[e] | C-1.140[e] | C-0.119 | C-0.119 | C-0.119 | C-0.119 | C-0.119 | C-0.119 | C-0.092 | C-0.092 | C-0.092 | C-0.092 |
| **Floors** | | | | | | | | | | | | | | | | |
| Mass[d] | U-0.322[e] | U-0.322[e] | U-0.107 | U-0.087 | U-0.076 | U-0.076 | U-0.076 | U-0.074 | U-0.074 | U-0.064 | U-0.064 | U-0.057 | U-0.055 | U-0.051 | U-0.055 | U-0.051 |
| Joist/framing | U-0.066[e] | U-0.066[e] | U-0.033 | U-0.033 | U-0.033 | U-0.033 | U-0.033 | U-0.033 | U-0.033 | U-0.033 | U-0.033 | U-0.033 | U-0.033 | U-0.033 | U-0.033 | U-0.033 |
| **Slab-on-grade floors** | | | | | | | | | | | | | | | | |
| Unheated slabs | F-0.73[e] | F-0.73[e] | F-0.73[e] | F-0.73[e] | F-0.73[e] | F-0.73[e] | F-0.54 | F-0.54 | F-0.54 | F-0.54 | F-0.54 | F-0.52 | F-0.40 | F-0.40 | F-0.40 | F-0.40 |
| Heated slabs[f] | F-0.70 | F-0.70 | F-0.70 | F-0.70 | F-0.70 | F-0.70 | F-0.65 | F-0.65 | F-0.65 | F-0.65 | F-0.58 | F-0.58 | F-0.55 | F-0.55 | F-0.55 | F-0.55 |
| **Opaque doors** | | | | | | | | | | | | | | | | |
| Swinging | U-0.61 | U-0.61 | U-0.61 | U-0.61 | U-0.61 | U-0.61 | U-0.61 | U-0.61 | U-0.37 | U-0.37 | U-0.37 | U-0.37 | U-0.37 | U-0.37 | U-0.37 | U-0.37 |

59

# International Energy Conservation Code

IECC Section C 402 - prescriptive R requirements for building envelopes.

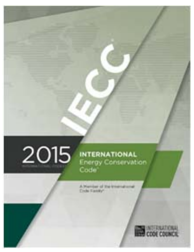
Zone 1 minimum thermal resistance (R) values - mass walls above grade (typical masonry walls) - minimum continuous insulation R= 5.7 °F. ft$^2$.hr/BTU. IECC Section C402.2.3 indicates that any integral insulation of CMU block cannot be used to meet this continuous R requirement.

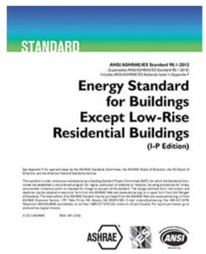
Footnote c in this table indicates that partially grouted (32” O.C.) ASTM C 90 block walls do not need continuous insulation if the ungrouted cells of the block are filled with materials having a maximum thermal conductivity of 0.44 Btu-in/h-f$^2$ °F.

60

# International Energy Conservation Code

IECC Allows use of ASHREA 90.1 Instead of IECC




"C401.2 Application. Commercial buildings shall comply with one of the following:
1. The requirements of ANSI/ASHRAE/IESNA 90.1.
2. The requirements of Sections C402 through C405. In addition, commercial buildings shall comply with SectionC406 and tenant spaces shall comply with Section C406.1.1.
3. The requirements of Sections C402.5, C403.2, C404, C405.2, C405.3, C405.4, C405.6 and C407. The building energy cost shall be equal to or less than 85 percent of the standard reference design building."

61

ASHREA 90.1 Prescriptive R table

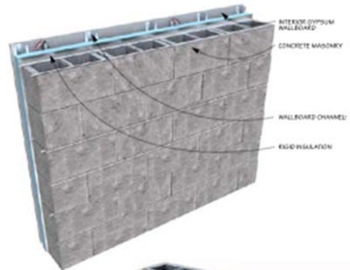
**Table 5.5-1 Building Envelope Requirements for Climate Zone 1 (A,B,C)[a]**

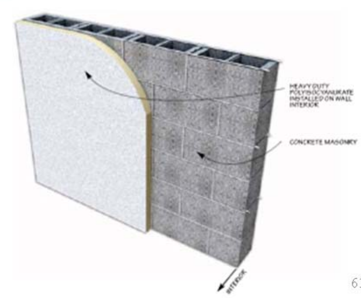
| Opaque Elements | Nonresidential | | Residential | | Semiheated | |
|---|---|---|---|---|---|---|
| | Assembly Maximum | Insulation Min. R-Value | Assembly Maximum | Insulation Min. R-Value | Assembly Maximum | Insulation Min. R-Value |
| *Roofs* | | | | | | |
| Insulation Entirely above Deck | U-0.048 | R-20 c.i. | U-0.039 | R-25 c.i. | U-0.218 | R-3.8 c.i. |
| Metal Building[a] | U-0.041 | R-10 + R-19 FC | U-0.041 | R-10 + R-19 FC | U-0.115 | R-10 |
| Attic and Other | U-0.027 | R-38 | U-0.027 | R-38 | U-0.081 | R-13 |
| *Walls, above Grade* | | | | | | |
| Mass | U-0.580 | NR | U-0.151[b] | R-5.7 c.i.[b] | U-0.580 | NR |
| Metal Building | U-0.094 | R-0 + R-9.8 c.i. | U-0.094 | R-0 + R-9.8 c.i. | U-0.352 | NR |
| Steel Framed | U-0.124 | R-13 | U-0.124 | R-13 | U-0.352 | NR |
| Wood Framed and Other | U-0.089 | R-13 | U-0.089 | R-13 | U-0.292 | NR |
| *Wall, below Grade* | | | | | | |
| Below Grade Wall | C-1.140 | NR | C-1.140 | NR | C-1.140 | NR |
| *Floors* | | | | | | |
| Mass | U-0.322 | NR | U-0.322 | NR | U-0.322 | NR |
| Steel Joist | U-0.350 | NR | U-0.350 | NR | U-0.350 | NR |
| Wood Framed and Other | U-0.282 | NR | U-0.282 | NR | U-0.282 | NR |

For Climate Zone 1 shows that mass walls above grade (CMU walls) do not require insulation when used in nonresidential construction.

62

# Prescriptive R-Value Compliance



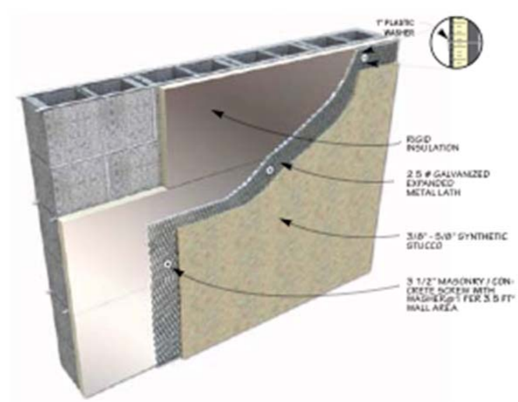

<u>Continuous interior insulation</u>:

• R 5.7 – Use 1.5 inches of Expanded Polystyrene - stucco ext. With finishes as shown - Solid grouting

•Using U–factor – 0.151 Can reduce ¾"of insulation.

63

# Prescriptive R-Value Compliance - Hawaii




<u>Continuous exterior insulation</u>:

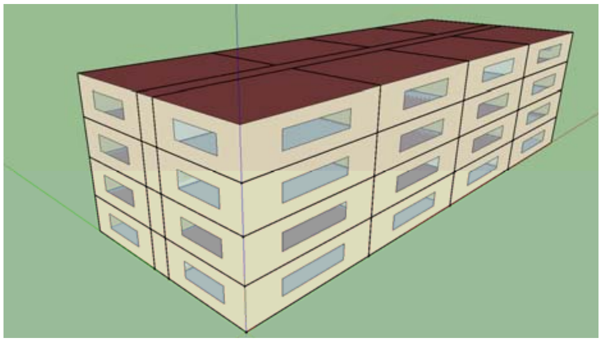
•R 5.7 – Use 1.5 inches of Expanded Polystyrene - stucco ext. – Solid grouting

•Using U–factor – 0.151 Can reduce ¾"of insulation.

•

64

# Phase 1 - Evaluated 4 Prototype buildings typically using Masonry exterior Walls using COMCheck

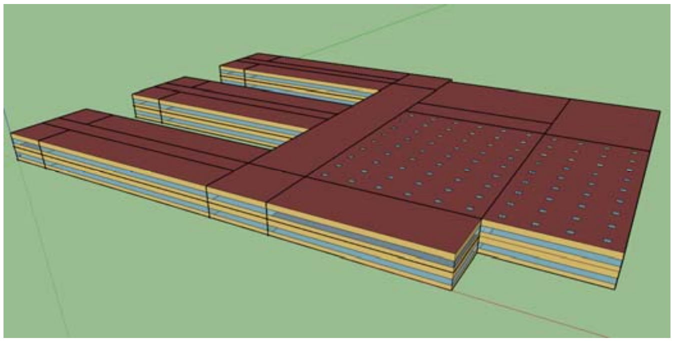


**A. Midrise Apartment**

The total floor area of the four story, DOE prototype midrise apartment building shown in Figure 1 is 33,741 $ft^2$ and it has an aspect ratio of 2.74. The window fraction for each orientation (north, south, east and west) is a constant 20%.



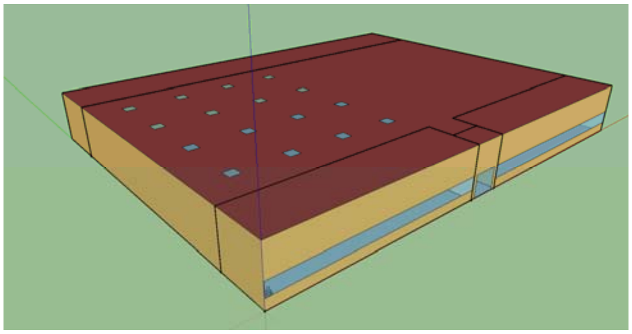
# Phase 1 - Evaluated 4 Prototype buildings typically using Masonry exterior Walls using COMCheck



B. Secondary School

The total floor area of the two story, DOE defined secondary school building is 210,886 $ft^2$, with an aspect ratio of 1.4. The window fraction for each orientation (north, south, east and west) was a constant 33%, with ribbon windows across all facades, on both floors. Floor to floor height is 13 ft.

## Phase 1 - Evaluated 4 Prototype buildings typically using Masonry exterior Walls using COMCheck

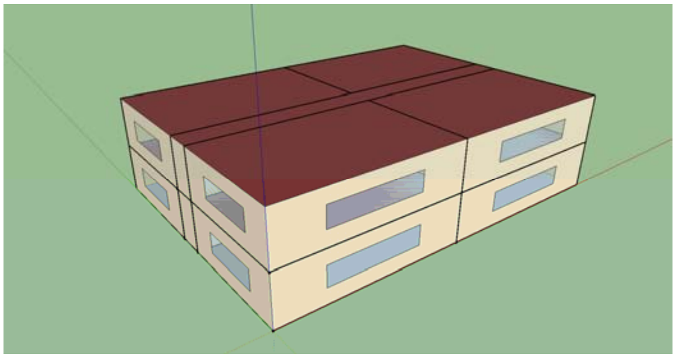


C. Stand-alone Retail

The total floor area of the one story, DOE prototype retail building is 24,692 $ft^2$, with an aspect ratio of 1.28 .The floor to ceiling height is 20 ft. The window fraction is 7.1% in total, with windows located on the street facing façade only.



## Phase 1 - Evaluated 4 Prototype buildings typically using Masonry exterior Walls using COMCheck



D . Low-rise Apartment - The total floor area of the two story, low-rise apartment building is 8,435 $ft^2$, with an aspect ratio of 1.37. This structure was based on the midrise apartment, but modified to represent a low-rise construction configuration common in Hawaii. The window fraction for each orientation (north, south, east and west) was a constant 20%.

# COMcheck

- easy way to take advantage of trade-offs, ie, increase roof insulation to reduce wall or window requirements.
- program shows if the envelope complies, and how close it is to compliance
- allows individual elements to be tweaked for compliance, revisions are quick and easy.
- **Trade offs are for envelope only**

From NCMA Presentation

69

# COMcheck

- The trade-off analysis clearly shows that, for the four prototype buildings investigated, no reasonable amount of roof insulation, or more thermally resistant windows could be used to make uninsulated fully grouted exterior concrete masonry or bare concrete walls code compliant through a trade-off analysis alone.

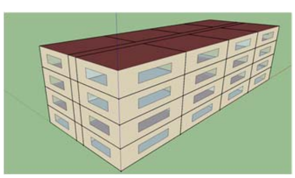
70

# Phase 2 Whole Building Analysis - Using 4 Prototypes

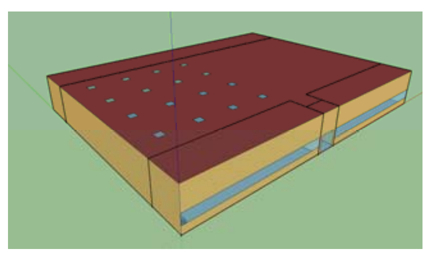
- Energy Budget method requires same yearly energy cost of prototype configured to prescriptive requirements.
- Used Openstudio and Energy plus Programs – Looked at changes in envelopes and building systems that were expected to be minimum costs.
- Also conducted a economic analysis

71

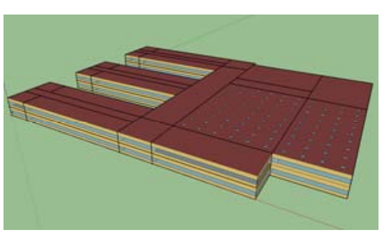
# Phase 2 Whole Building Analysis



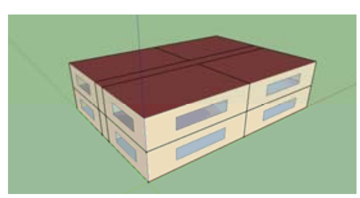
A . Mid-rise Apartment



C. Stand-alone Retail



B. Secondary School



D . Low-rise Apartment

72

# Baseline Configuration

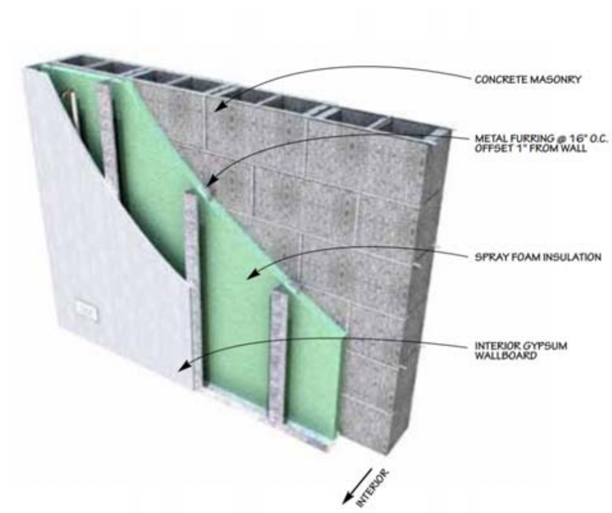



*Figure 5 CMU Walls (8 in.) with Wall Insulation + 0.5 in. Gypsum Board*

73

# Baseline Exterior Wall

*Table 1 Critical Exterior Wall Assembly Configuration Properties*

| Type of Wall | Wall Configurations | Conductivity (Btu·in/hr·ft$^2$·R) | Specific Heat (Btu/lb·R) | U factor (Btu/ft$^2$hR) |
|---|---|---|---|---|
| **Fully Grouted 105 pcf 8" CMU** | Solid Grouted | 8.400 | 0.209 | 0.528 |
| **Fully Grouted 120 pcf 8" CMU** | Solid Grouted | 9.600 | 0.211 | 0.566 |
| **Fully Grouted 130 pcf 8" CMU** | Solid Grouted | 10.7 | 0.220 | 0.591 |
| **Partially Grouted 8" CMU** | Cells Insulated | 3.248 | 0.162 | 0.294 |
| **Poured Concrete 120 pcf** | Limestone Concrete | 7.900 | 0.210 | 0.537 |
| **Poured Concrete 130 pcf** | Sand and Gravel or Stone Aggregate Concrete | 9.400 | 0.210 | 0.588 |
| **Poured Concrete 150 pcf** | Sand and Gravel or Stone Aggregate Concrete | 14.900 | 0.210 | 0.721 |

74

# Baseline Exterior Wall

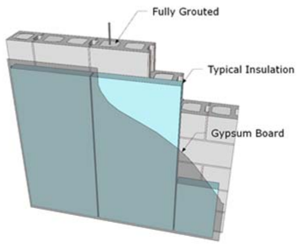



*Figure 10 Exterior CMU Wall Case A*

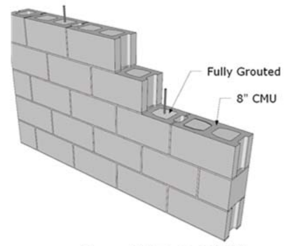



*Figure 11 Exterior Wall Cases 105/120/130FM_B&D&F&G&H*

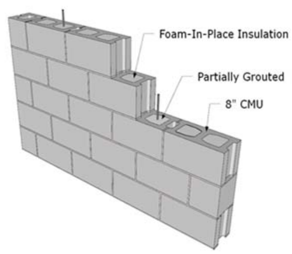



*Figure 12 Exterior Wall Cases 105PM_B&D&F&G&H*

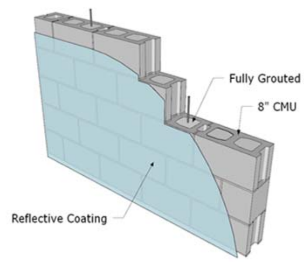



Figure 13 Exterior Wall Cases



# Baseline Exterior Wall

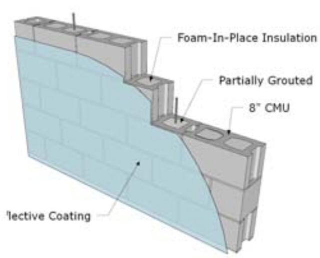



Figure 14 Exterior Wall Case 105PM_C&E


*Figure 15 Exterior Wall for Case 120/130/150PC_B&D&F&G&H*

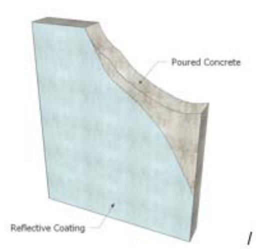



*Figure 16 Exterior Wall Case 120/130/150PC_C&E*

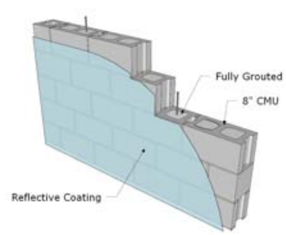



*Figure 17 Exterior Wall Assumed when Calculating Target U-factor,*

# Baseline Exterior Wall

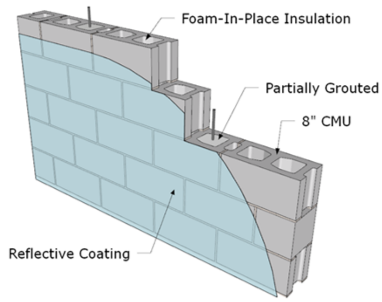



*Figure 18 Exterior Wall Assumed when Calculating* Target U-factor

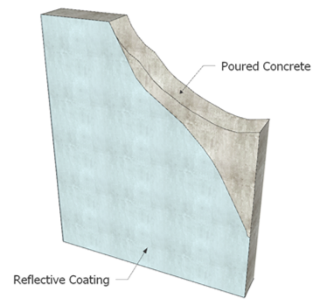



*Figure 19 Exterior Wall Assumed when Calculating Target U-factor (concrete)*



# Whole Building Analysis Configurations

ALL CASE A (Include 105/120/130 pcf Fully Grouted CMU (105/120/130FM), 105 pcf Partially Grouted CMU (105PM), 120/130/150 pcf Poured Concrete (120/130/150 PC)) - The U-factor - 0.151 Btu/ft$^2$hR). (Code minimum)

Case B
105 pcf Full Grouted CMU (105FM) CASE B -U-factor - 0.528 Btu/ft$^2$hR.
120 pcf Full Grouted CMU (120FM) U-factor -0.566 Btu/ft$^2$hR.
130 pcf Full Grouted CMU (130FM) - 0.591 Btu/ft$^2$hR.
105 pcf Partially Grouted CMU (105PM) -U-factor- 0.294 Btu/ft$^2$hR.
120 pcf Poured Concrete walls (120PC) -U-factor 0.537 Btu/ft$^2$hR.
130 pcf Poured Concrete walls (130PC) -U-factor 0.588 Btu/ft$^2$hR.
150 pcf Poured Concrete walls (150PC) -U-factor 0.721 Btu/ft$^2$hR.

# Whole Building Analysis Configurations

Case C – For all "C" cases, the exterior surface reflectance of the walls was increased to 0.64. (consistent with Hawaii Energy Code amendments for exceptions for lightweight walls).

Case D - Overhangs with a Projection Factor (PF) of 0.3 are added to all fenestrations in the basic (Case B) configurations.

Case E - Combined the Overhang of Case D and the increased wall reflectance of Case B.

Case F - Approximately twice the roof insulation was applied to the basic (CASE B) configurations (Roof U-factor decreased to 0.146 W/m2K (0.026 Btu/ft2hR).

79

# Whole Building Analysis Configurations

Case G - Lighting is a significant part of total energy use in most buildings, the impact of more efficient lighting was investigated. Although conventional wisdom suggests that LED lighting is much more efficient than conventional systems, a recent study by the DOE ("LED Replacements for Four-Foot Linear Fluorescent Lamps)[1], suggests that some fluorescent lamps can have similar luminaire efficacy (lumens/watt) as LEDs. Therefore, in this research, we assumed that there would only be a 10% reduction in lighting energy with LED lighting.

Case H – Higher efficiency HVAC systems were investigated. In this case, the HVAC system efficiency in the basic building configuration (case B) was increased. As per Trane product catalogs, models were listed that showed an increase from the Code minimum values of about 8% (based on EERE values). Thus, the HVAC coefficient of performance (COP) was increased by 8% in the EnergyPlus models.

80

# Phase 2 Whole Building Analysis

- Typical baseline energy use

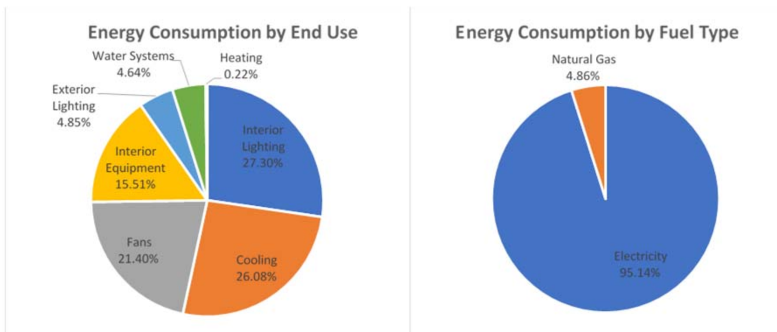



Figure 24 a) Stand-alone Retail Energy Use Break Down b) Stand-alone Retail Energy Use by Fuel

81

# Phase 2 Whole Building Analysis

- Typical baseline energy use

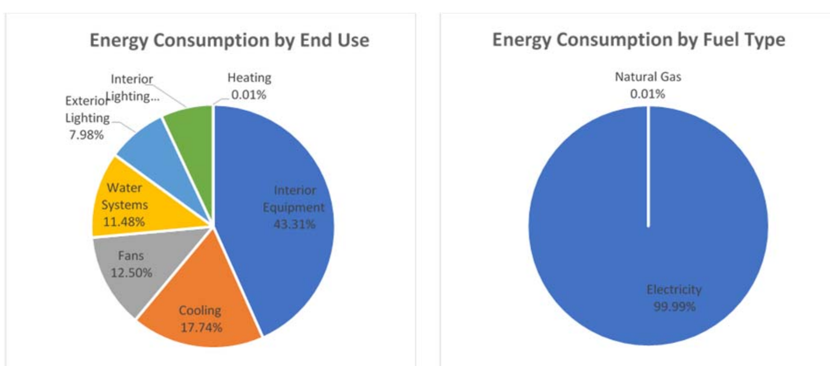



Figure 27 a) Low-rise Apartment Energy Use Break Down b) Low-rise Apartment Energy Use by Fuel

82

# Phase 2 Whole Building Analysis

*Table 3 Stand-alone Retail Energy Analyses - Partial*

| | U Factor (Btu/ft2hR ) | Case | Total Site Energy (GJ) | Electric Consumption (kWh) | Gas Consumption (MBtu) | Electric Peak Demand (kW) | Gas Peak Demand (kBtu/hr) | Change (%) | Net Cost ($) | Energy Saved ($/Year) | Payback Period (Year) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fully Grouted 8"CMU (105pcf) | 0.151 | 105FM_A | 1259.23 | 332747.26 | 58.14 | 84.51 | 100.23 | | | | |
| | 0.528 | 105FM_B | 1366.69 | 362581.23 | 58.19 | 92.71 | 105.17 | 8.5% | -234383 | -7460 | 31.4 |
| | | 105FM_C | 1261.89 | 333554.37 | 57.9 | 86.78 | 111.27 | 0.2% | -183705 | -195 | 944.1 |
| | | 105FM_D | 1360.36 | 360828.51 | 58.18 | 93.16 | 105.15 | 8.0% | -232003 | -7022 | 33.0 |
| | | 105FM_E | 1255.9 | 331889.7 | 57.97 | 87.26 | 103.75 | -0.3% | -181325 | 219 | - |
| | | 105FM_F | 1341.91 | 355700.73 | 58.18 | 90.3 | 107.19 | 6.6% | -169523 | -5740 | Ø |
| | | 105FM_G | 1316.84 | 348747.42 | 58.15 | 89.15 | 104.67 | 4.6% | * | * | * |
| | | 105FM_H | 1337.91 | 354587.06 | 58.19 | 89.68 | 105.17 | 6.2% | * | * | * |
| Fully Grouted 8"CMU (120pcf) | 0.151 | 120FM_A | 1260.17 | 333008.73 | 58.13 | 84.49 | 100.38 | | | | |
| | 0.566 | 120FM_B | 1373.34 | 364430.67 | 58.19 | 92.98 | 106.08 | 9.0% | -234383 | -7857 | 29.8 |
| | | 120FM_C | 1262.87 | 333813.64 | 57.95 | 86.81 | 100.54 | 0.2% | -183705 | -196 | 938.1 |
| | | 120FM_E | 1257.26 | 332258.95 | 57.94 | 87.3 | 100.53 | -0.2% | -181325 | 193 | - |
| Partially Grouted 8" CMU (Cells Insulated) | 0.151 | 120PM_A | 1261.75 | 333421.53 | 58.22 | 84.24 | 101.32 | | | | |
| | 0.294 | 120PM_B | 1294.54 | 342517.31 | 58.27 | 87.23 | 104.07 | 2.6% | -230576 | -2275 | 101.3 |
| | | 120PM_C | 1246.22 | 329184.87 | 57.96 | 84.44 | 100.1 | -1.2% | -179898 | 1067 | - |
| | | 120PM_D | 1288.99 | 340972.56 | 58.28 | 87.75 | 103.85 | 2.2% | -228196 | -1890 | 120.8 |
| | | 120PM_E | 1243.52 | 328433.51 | 57.97 | 85.04 | 100.09 | -1.4% | -177518 | 1255 | - |
| | | 120PM_F | 1288.7 | 340852.76 | 58.41 | 85.43 | 104.3 | 2.1% | -165716 | -1864 | Ø |
| | | 120PM_G | 1242.29 | 328010.81 | 58.25 | 83.59 | 103.51 | -1.5% | * | * | * |
| | | 120PM_H | 1268.62 | 335318.59 | 58.27 | 84.5 | 104.07 | 0.5% | * | * | * |

83

# Phase 2 Whole Building Analysis

*Table 4 Secondary School Energy Analyses- Partial*

| | U Factor (Btu/ft2hR) | Case | Total Site Energy (GJ) | Electric Consumption (kWh) | Gas Consumption (MBtu) | Electric Peak Demand (kW) | Gas Peak Demand (kBtu/hr) | Difference (%) | Net Cost ($) | Energy Saved ($/Year) | Payback Period (Year) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fully Grouted 8"CMU (105pcf) | 0.151 | 105FM_A | 12594.8 | 3178901.22 | 1090.71 | 778.63 | 869.78 | | | | |
| | 0.528 | 105FM_B | 13287.92 | 3364014.31 | 1116.02 | 811.49 | 1038.88 | 5.5% | -1188422 | -47038 | 25.3 |
| | | 105FM_C | 12714.9 | 3212337.67 | 1090.45 | 786.74 | 970.02 | 1.0% | -931466 | -8351 | 111.5 |
| | | 105FM_D | 13078.43 | 3316795.19 | 1078.58 | 792.79 | 1004.07 | 3.8% | -1129166 | -34110 | 33.1 |
| | | 105FM_E | 12524.39 | 3168140.03 | 1060.69 | 768.11 | 945.38 | -0.6% | -872210 | 3591 | - |
| | | 105FM_F | 13166.46 | 3334857.83 | 1100.39 | 800.4 | 985.35 | 4.5% | -851906 | -39280 | Ø |
| | | 105FM_G | 12976.34 | 3278013.43 | 1114.16 | 791.29 | 1028.84 | 3.0% | * | * | * |
| | | 105FM_H | 13200.52 | 3339736.81 | 1116.02 | 803.65 | 1038.88 | 4.8% | * | * | * |
| Fully Grouted 8"CMU (120pcf) | 0.151 | 120FM_A | 12593.65 | 3178322.45 | 1091.59 | 779.42 | 867.28 | | | | |
| | 0.566 | 120FM_B | 13324.74 | 3371894.93 | 1124.04 | 816.54 | 1060.24 | 5.8% | -1188422 | -49367 | 24.1 |
| | | 120FM_C | 12730.72 | 3215417.35 | 1094.94 | 789.43 | 984.7 | 1.1% | -931466 | -9374 | 99.4 |
| | | 120FM_E | 12556.28 | 3176329.66 | 1062.97 | 767.21 | 939.53 | -0.3% | -872210 | 1357 | - |
| Fully Grouted 8"CMU (130pcf) | 0.152 | 130FM_A | 12598.15 | 3178932 | 1093.77 | 777.77 | 863.32 | | | | |
| | 0.591 | 130FM_B | 13418.9 | 3398715.21 | 1121.77 | 809.11 | 1053.88 | 6.5% | -1188422 | -56004 | 21.2 |
| | | 130FM_C | 12769.86 | 3226513.65 | 1094.17 | 784.71 | 974.42 | 1.4% | -931466 | -12125 | 76.8 |
| | | 130FM_E | 12586.59 | 3184245.28 | 1064.69 | 765.87 | 940.87 | -0.1% | -872210 | -674 | - |
| Partially Grouted 8"CMU (Cells Insulated) | 0.151 | 120PM_A | 12602.25 | 3182026.68 | 1087.1 | 775.74 | 854.84 | | | | |
| | 0.294 | 120PM_B | 12874.97 | 3259852.18 | 1080.04 | 786.53 | 923.16 | 2.2% | -1169150 | -19245 | 60.8 |
| | | 120PM_C | 12521.71 | 3164384.37 | 1070.96 | 774.42 | 890.13 | -0.6% | -912194 | 4895 | - |
| | | 120PM_D | 12680.99 | 3214442.71 | 1051.13 | 767.54 | 890.46 | 0.6% | -1109894 | -7025 | 158.0 |

84

# Phase 2 Whole Building Analysis

*Table 5 Mid-rise Apartment Energy Analysis - Partial*

| | U Factor (Btu/ft2hR) | Case | Total Site Energy (GJ) | Electric Consumption (kWh) | Gas Consumption (MBtu) | Electric Peak Demand (kW) | Gas Peak Demand (kBtu/hr) | Difference (%) | Net Cost ($) | Energy Saved ($/Year) | Payback Period (Year) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fully Grouted 8"CMU (105pcf) | 0.151 | 105FM_A | 1441.47 | 400398.66 | 0.03 | 99.21 | 0.71 | | | | |
| | 0.528 | 105FM_B | 1603.11 | 445292.91 | 0.06 | 109.14 | 1.62 | 11.2% | -307070 | -11224 | 27.4 |
| | | 105FM_C | 1485.1 | 412515.1 | 0.04 | 103.67 | 2.26 | 3.0% | -240677 | -3029 | 79.4 |
| | | 105FM_D | 1580.89 | 439119.52 | 0.05 | 109.64 | 1.59 | 9.7% | -298363 | -9681 | 30.8 |
| | | 105FM_E | 1465.54 | 407083.41 | 0.04 | 103.5 | 2.2 | 1.7% | -231970 | -1671 | 138.8 |
| | | 105FM_F | 1595.51 | 443181.99 | 0.06 | 108.86 | 1.44 | 10.7% | -284913 | -10697 | 26.6 |
| | | 105FM_G | 1588.09 | 441119.29 | 0.05 | 108.4 | 1.65 | 10.2% | * | * | * |
| | | 105FM_H | 1571.61 | 436542.46 | 0.06 | 107.32 | 1.62 | 9.0% | * | * | * |
| Fully Grouted 8"CMU (120pcf) | 0.151 | 120FM_A | 1440.5 | 400129.41 | 0.03 | 99.1 | 0.63 | | | | |
| | 0.566 | 120FM_B | 1601.4 | 444817.21 | 0.05 | 109.15 | 1.64 | 11.2% | -307070 | -11173 | 27.5 |
| | | 120FM_C | 1491.04 | 414165.85 | 0.04 | 104.17 | 2.4 | 3.5% | -240677 | -3509 | 68.6 |
| | | 120FM_E | 1459.56 | 405421.52 | 0.04 | 103.07 | 2.18 | 1.3% | -231970 | -1323 | 175.3 |
| Fully Grouted 8"CMU (130pcf) | 0.151 | 130FM_A | 1439.83 | 399942.99 | 0.03 | 99.02 | 0.63 | | | | |
| | 0.591 | 130FM_B | 1603.45 | 445386.63 | 0.06 | 110.18 | 1.63 | 11.4% | -307070 | -11315 | 27.1 |
| | | 130FM_C | 1478.82 | 410771.94 | 0.04 | 103.79 | 1.94 | 2.7% | -240677 | -2661 | 90.4 |
| | | 130FM_E | 1459.76 | 405478.24 | 0.04 | 103.36 | 2.11 | 1.4% | -231970 | -1338 | 173.4 |
| Partially Grouted 8"CMU (Cells Insulated) | 0.151 | 120PM_A | 1438.64 | 399611.13 | 0.04 | 98.86 | 0.58 | | | | |
| | 0.294 | 120PM_B | 1505.56 | 418198.21 | 0.04 | 103.28 | 0.81 | 4.7% | -302091 | -4647 | 65.0 |
| | | 120PM_C | 1440.81 | 400215.41 | 0.04 | 100.37 | 1.23 | 0.2% | -235697 | -151 | 1560.2 |
| | | 120PM_D | 1485.51 | 412629.77 | 0.04 | 102.58 | 0.76 | 3.3% | -293384 | -3255 | 90.1 |
| | | 120PM_E | 1420.76 | 394645.21 | 0.03 | 99.9 | 1.18 | -1.2% | -226990 | 1242 | - |
| | | 120PM_F | 1496.94 | 415804.91 | 0.04 | 102.94 | 0.62 | 4.1% | -279934 | -4048 | 69.1 |
| | | 120PM_G | 1490.54 | 414028.24 | 0.04 | 102.49 | 0.8 | 3.6% | * | * | * |
| | | 120PM_H | 1477.24 | 410331.08 | 0.04 | 101.76 | 0.81 | 2.7% | * | * | * |



# Phase 2 Whole Building Analysis

*Table 6 Low-rise Apartment Energy Analysis - Partial*

| | U Factor (Btu/ft2hR) | Case | Total Site Energy (GJ) | Electric Consumption (kWh) | Gas Consumption (MBtu) | Electric Peak Demand (kW) | Gas Peak Demand (kBtu/hr) | Percentage Difference (%) | Extra Cost ($) | Energy Saved ($/Year) | Payback Period (Year) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fully Grouted 8"CMU (105pcf) | 0.197 | 105FM_A | 523.48 | 145394.46 | 0.06 | 36.13 | 0.66 | | | | |
| | 0.528 | 105FM_B | 568.1 | 157785.72 | 0.07 | 38.96 | 0.73 | 8.5% | -97300 | -3098 | 31.4 |
| | | 105FM_C | 529.54 | 147077.23 | 0.06 | 37.15 | 0.87 | 1.2% | -76262 | -421 | 181.3 |
| | | 105FM_D | 561.33 | 155905.65 | 0.07 | 38.77 | 0.71 | 7.2% | -94518 | -2628 | 36.0 |
| | | 105FM_E | 523.55 | 145414.62 | 0.06 | 37 | 0.84 | 0.0% | -73480 | -5 | 14579.3 |
| | | 105FM_F | 565.41 | 157037.47 | 0.07 | 38.86 | 0.73 | 8.0% | -75143 | -2911 | 25.8 |
| | | 105FM_G | 563.04 | 156379.36 | 0.07 | 38.74 | 0.71 | 7.6% | * | * | * |
| | | 105FM_H | 558.77 | 155192.17 | 0.07 | 38.43 | 0.73 | 6.7% | * | * | * |
| Fully Grouted 8"CMU (120pcf) | 0.197 | 120FM_A | 523.09 | 145285.01 | 0.06 | 36.08 | 0.66 | | | | |
| | 0.566 | 120FM_B | 568 | 157757.29 | 0.07 | 38.97 | 0.73 | 8.6% | -97300 | -3118 | 31.2 |
| | | 120FM_C | 527.6 | 146539.2 | 0.06 | 37.01 | 0.86 | 0.9% | -76262 | -314 | 243.2 |
| | | 120FM_E | 525.34 | 145912.71 | 0.06 | 37.15 | 0.85 | 0.4% | -73480 | -157 | 468.2 |
| Fully Grouted 8"CMU (130pcf) | 0.197 | 130FM_A | 522.77 | 145197.58 | 0.06 | 36.04 | 0.66 | | | | |
| | 0.591 | 130FM_B | 568.8 | 157977.96 | 0.07 | 39 | 0.74 | 8.8% | -97300 | -3174 | 30.7 |
| | | 130FM_C | 527.52 | 146516.64 | 0.06 | 37.08 | 0.87 | 0.9% | -76262 | -308 | 247.7 |
| | | 130FM_E | 521.62 | 144879.37 | 0.06 | 36.93 | 0.84 | -0.2% | -73480 | 101 | - |
| Partially Grouted 8"CMU (Cells Insulated) | 0.197 | 120PM_A | 522.08 | 145005.39 | 0.06 | 36.02 | 0.66 | | | | |
| | 0.294 | 120PM_B | 538.02 | 149432.32 | 0.06 | 37.06 | 0.7 | 3.1% | -95722 | -1107 | 86.5 |
| | | 120PM_C | 516.3 | 143400.91 | 0.06 | 36.06 | 0.64 | -1.1% | -74684 | 401 | - |
| | | 120PM_D | 531.22 | 147544.03 | 0.06 | 36.81 | 0.69 | 1.8% | -92940 | -635 | 146.4 |
| | | 120PM_E | 509.91 | 141624.77 | 0.06 | 35.88 | 0.64 | -2.3% | -71902 | 845 | - |
| | | 120PM_F | 535.09 | 148617.15 | 0.06 | 36.95 | 0.7 | 2.5% | -73565 | -903 | 81.5 |
| | | 120PM_G | 532.93 | 148018.62 | 0.06 | 36.84 | 0.69 | 2.1% | * | * | * |
| | | 120PM_H | 529.68 | 147116.04 | 0.06 | 36.63 | 0.7 | 1.5% | * | * | * |

# Phase 2 Whole Building Analysis

Investigated coating alone

Table 7 Target Exterior Wall U-factors for Code Compliance with Reflective Coatings

| Prototype | Wall Type | Target U factor (Btu/ft$^2$hrF) |
|---|---|---|
| Stand-alone Retail | Solid Grouted | 0.534 |
| | Partially Grouted | 0.474 |
| | Poured Concrete | 0.568 |
| Secondary School | Solid Grouted | 0.402 |
| | Partially Grouted | 0.418 |
| | Poured Concrete | 0.397 |
| Mid-rise Apartment | Solid Grouted | 0.369 |
| | Partially Grouted | 0.338 |
| | Poured Concrete | 0.391 |
| Low-rise Apartment | Solid Grouted | 0.380 |
| | Partially Grouted | 0.344 |
| | Poured Concrete | 0.397 |

87

# Phase 2 Whole Building Analysis

For partially grouted, foamed and coated masonry walls

| Prototype | 3 Web CMU | 2 Web CMU | 1 Web CMU |
|---|---|---|---|
| Stand-alone Retail | 85.7% | 86.0% | 86.4% |
| Secondary School | 70.5% | 73.1% | 74.5% |
| Mid-rise Apartment | 48.9% | 54.7% | 57.4% |
| Low-rise Apartment | 50.5% | 56.1% | 58.7% |

88

## Conclusions

- For all four prototypes (Stand-alone retail, secondary schools, mid-rise apartments and low-rise apartments), adding reflective coating is an efficient method for reducing the energy use in Hawaii's climate. In a number of exterior wall configurations, this reflective coating alone is sufficient to produce equivalent energy performance.

89

## Conclusions

- Combining reflective coatings with overhangs produce code compliant configurations for the Stand-alone retail, and secondary school prototype buildings. For solidly grouted CMU walls, overhangs and coatings produce yearly energy use values within 1% of the baseline values in all cases and prototypes. They are thus very close to being code compliant.

90

## Conclusions

- Reflective coatings and window shades (overhangs) have the greatest impact on energy use in the range of building types investigated. In every case addressed, the coatings and overhangs were able to reduce the yearly energy consumption values either below the baseline configuration (and code compliant), or to low enough levels of energy consumption that the difference between the baseline energy yearly costs would take well beyond the typical building design life to payback

91

J.B. SPEED SCHOOL OF ENGINEERING

# THANK YOU !

# QUESTIONS?

m.mcginley@louisville.edu

Masonry Institute of Hawaii

Masonry Institute of Hawaii

92