CAE 463/524
Building Enclosure Design
Spring 2016

Week 15: April 19, 2016
Codes and standards in building enclosure design

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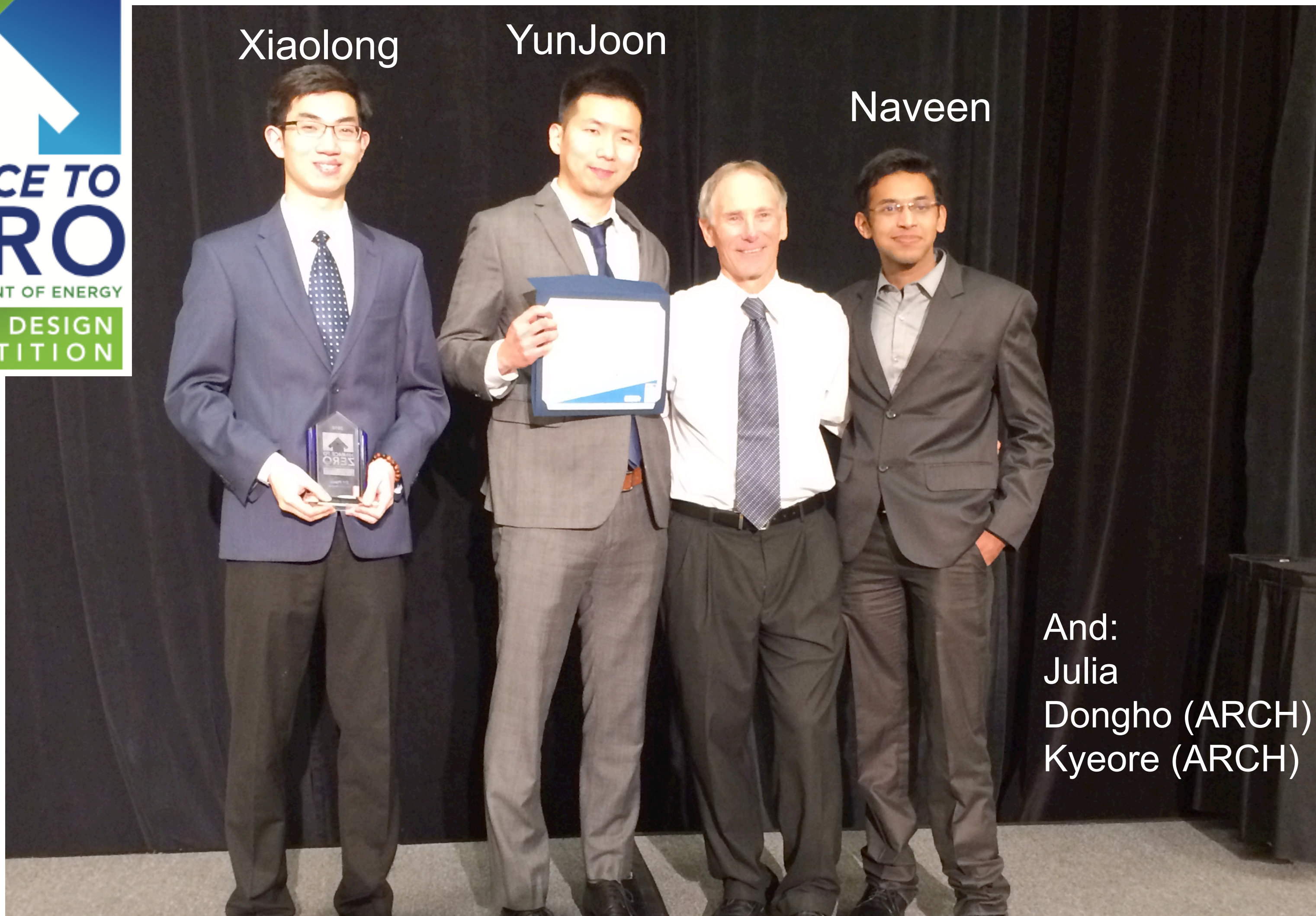
Congratulations!



2nd place Attached Housing category

Another job announcement

Environmental Systems Design, Inc.
Improving Society Through the Built Environment

Looking for junior/senior/master's degree level students for intern positions in the fall

Email me your resume if interested

Final project topic selection

Name	Final project topic
Blat Tatay, Andrea	Double skin facades
Curioni, Dina P.	Green roofs
Jarma, David A.	Double skin façade
Jordan, Taylor L.	BIPV
Kane, Benjamin M.	Double skin impact on energy
Lim, Keonho	Passive solar design
Mitchell, Alexander R.	Natural building materials
Panczak, Bianca J.	Smart glass
Rice, Lindsey E.	Water penetration limitation strategies
Townley, Nina V.	BIPV
Ashayeri Jahan Khanemloo, Mehdi	PCM
Babaei Sonbolabadi, Kamal	VIP
Cueto, Patrick Kevin M.	Green walls
Del Pino Torres, Julia Del Rosario	Green roofs
Faramarzi, Afshin	Aerogels
Foss, Stephen M.	Smart glazing
Qiu, Luanzhizi	Green roofs
Sharghi, Ali	Open joint ventilated facade
Sudhakaran, Naveen	VIP
Zhang, Xu	Green walls or cool roofs?
Castro, Jose L.	Cool roofs
Dipietro, Salvatore D.	ETFE or historic masonry
Lee, JiWan	EIFS

Course evaluations

- Available online now in MyIIT
- Very important that you complete the evaluation!
  - It’s the only way I get graded
  - It’s the only way our courses get graded
  - It’s one of the best ways for us to improve courses/ teaching
  - It’s anonymous

- We usually only get about 50% response rate
  - Let’s try to do better than this
  - If you have an internet connection you can do it right now

This time

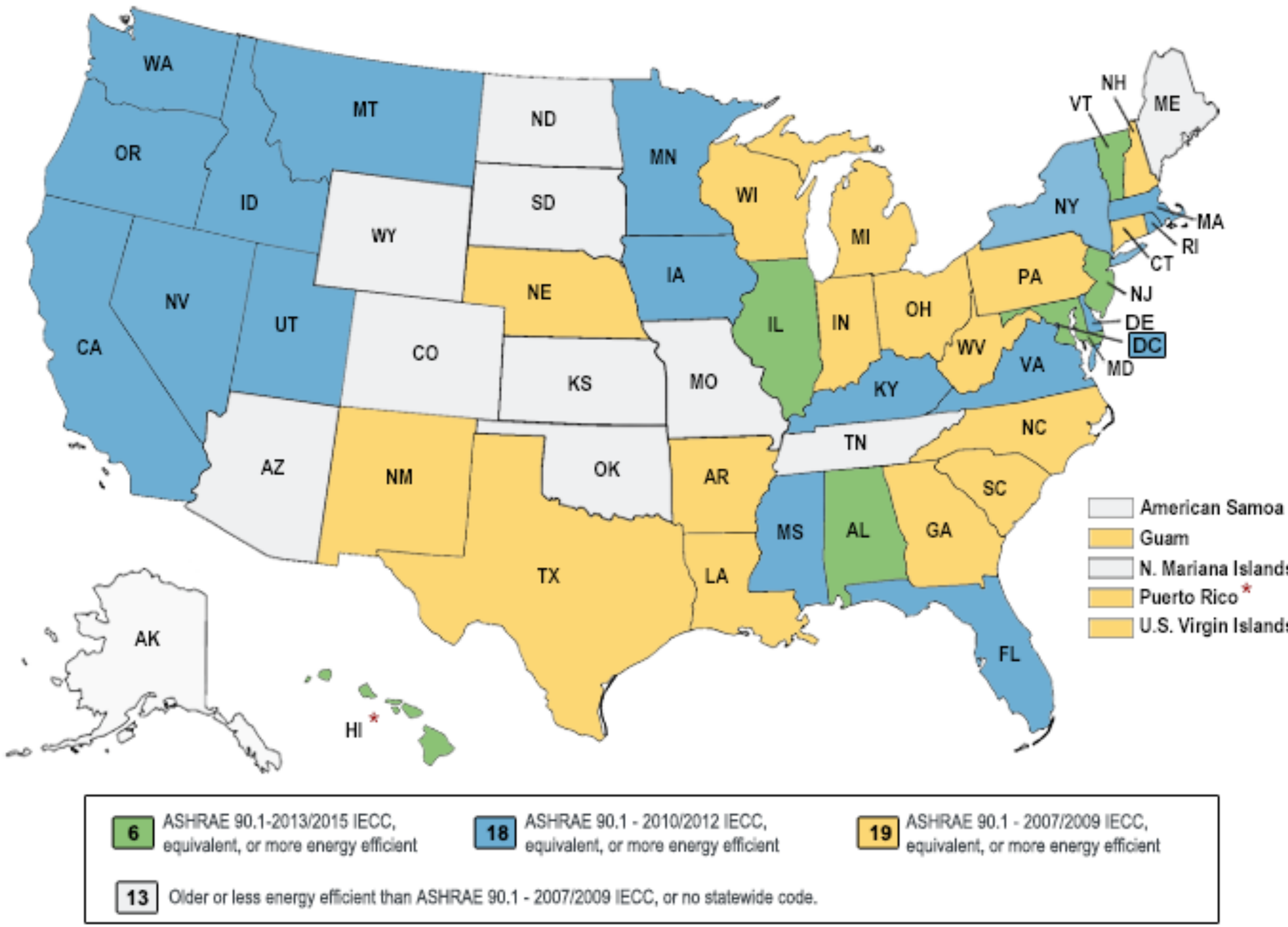
- Codes and standards in building enclosure design

- A few last application notes

Codes and standards

- There are a number of building codes and standards that relate to building enclosure design
- **Codes** generally provide ***minimum*** criteria
  - Your building can’t be worse than this
  - City codes, state codes, national codes, etc.
- **Standards** often go above and beyond code
  - Or can become cited in code
- Green building standards and rating systems
  - Several green building standards exist with varying levels of building enclosure criteria

State energy codes: Commercial buildings

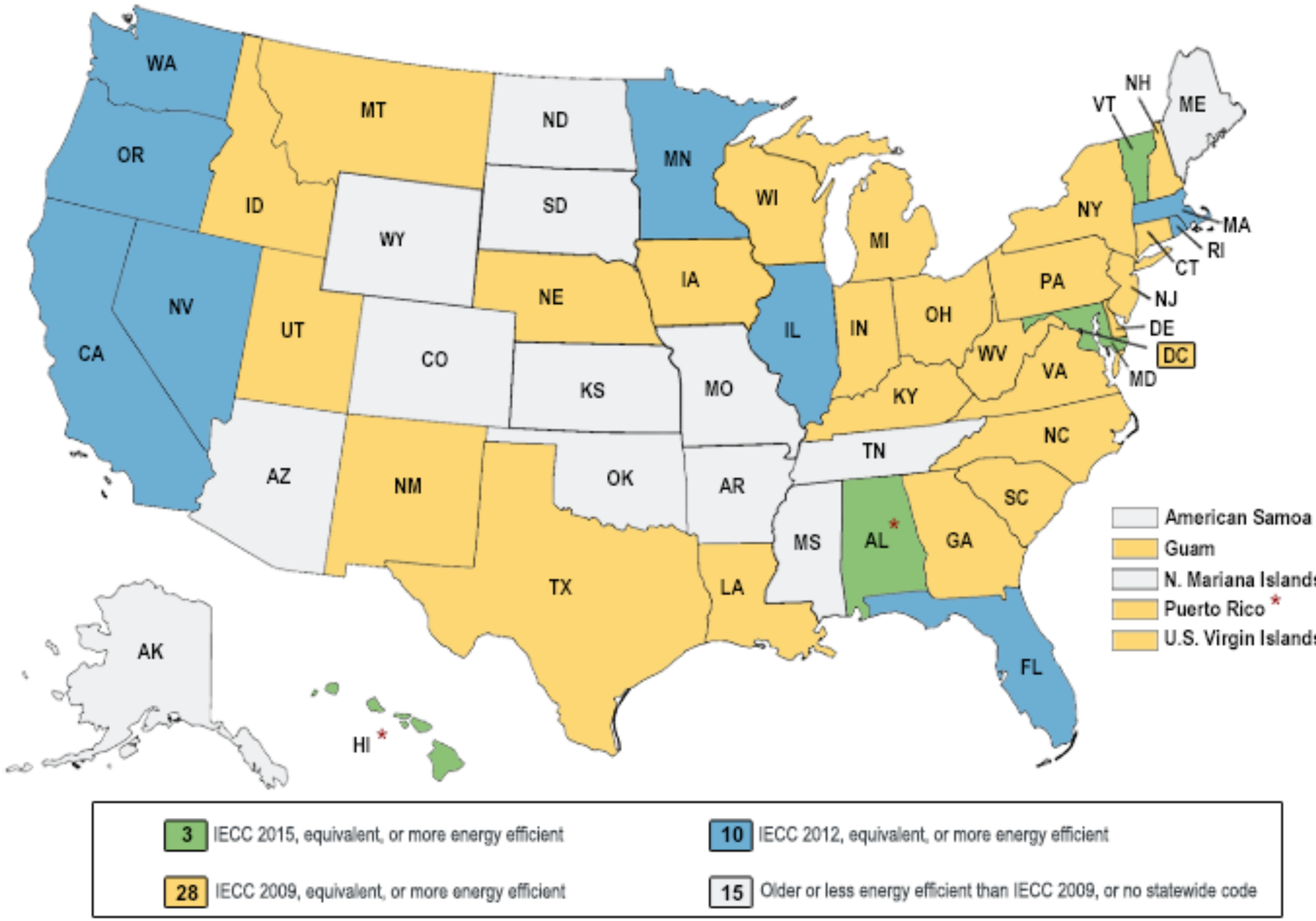


* Adopted new Code to be effective at a later date

As of April 2016

http://www.energycodes.gov/status-state-energy-code-adoption

State energy codes: Residential buildings



* Adopted new Code to be effective at a later date

As of April 2016

http://www.energycodes.gov/status-state-energy-code-adoption

Energy code-publishing organizations

- ASHRAE
  - Standard 90.1: Energy standard for buildings except low-rise residential buildings
  - Standard 90.2: Energy Efficient Design of Low-Rise Residential Buildings
  - Standard 189.1: Standard for the design of high-performance, green buildings

- IECC: International Energy Conservation Code
  - From the International Code Council (ICC)
  - 2012 version most recent

- IRC: International Residential Code
  - Addresses energy as well as structure, plumbing, etc.
  - IRC references IECC

Chicago Energy Efficiency Code (CEEC)

- The City of Chicago has its own energy efficiency code (IECC of Chicago)
  - Section 18-13 of the City of Chicago Municipal Code
  - You can download the full text of the energy efficiency code:
    - http://www.cityofchicago.org/dam/city/depts/bldgs/general/Energycode/EnergyCodeChapter18_13.pdf
    - Section 18-13-501.1 states that commercial buildings must meet either ASHRAE 90.1-2004 for climate zone 6 or the "Chicago Prescriptive code"
- CEEC also has several other mandatory requirements in sections 18-13-101 to 18-13-302
  - 18-13-101.5.3 is a **cool roof** requirement to reduce heat island effects
    - Low slope roofs constructed before 2009 have a minimum solar reflectance of 0.25
    - After 2009, the minimum initial solar reflectance is 0.72 and it must be maintained above 0.5 for three years after installation
    - There are exceptions for green roofs or roofs with solar panels

Chicago Energy Efficiency Code (CEEC)

- Maximum U-values and minimum R-values for most enclosure elements

TABLE 18-13-502.3
BUILDING ENVELOPE REQUIREMENTS: FENESTRATION

Vertical Fenestration (40% maximum of above-grade wall)	
U-Factor	
Framing materials other than metal with or without metal reinforcement or cladding	
U-Factor	0.35
Metal framing with or without thermal break	
Curtain Wall/Storefront U-Factor	0.45
Entrance Door U-Factor	0.80
All Other U-Factor[a]	0.55
SHGC-All Frame Types	
SHGC: PF ≤0.25	0.4

TABLE 18-13-502.2(1)
BUILDING ENVELOPE REQUIREMENTS – OPAQUE ASSEMBLIES

Roofs	
Insulation entirely above deck	R-20 ci
Metal joists (with R-5 thermal blocks[a])[b]	R-19
Wood framed and other non-metal (between joists)	R-30
Walls, Above Grade	
Mass only	R-9.5 ci
Metal building[b]	R-13 + R-13
Metal framed (inside mass wall)	R-13 + R-3.8 ci
Wood framed and other	R-13

- Can also meet a total UA requirement
- Air sealing requirements
- Many references point back to to ASHRAE Standards and Handbooks

ENERGY USE, CODES, AND STANDARDS: ASHRAE STANDARD 90.1

"Energy standard for building except low-rise residential buildings"

Energy standards

- Building codes have had minimum energy standards for some time
  - Designed to reduce energy waste (increase energy efficiency)

- Allowed energy use is related to building use and size
  - A restaurant or shopping mall have different requirements than a warehouse or a home would

- Most codes defer to the ASHRAE 90.1 or 90.2 standards
  - Or are based on them

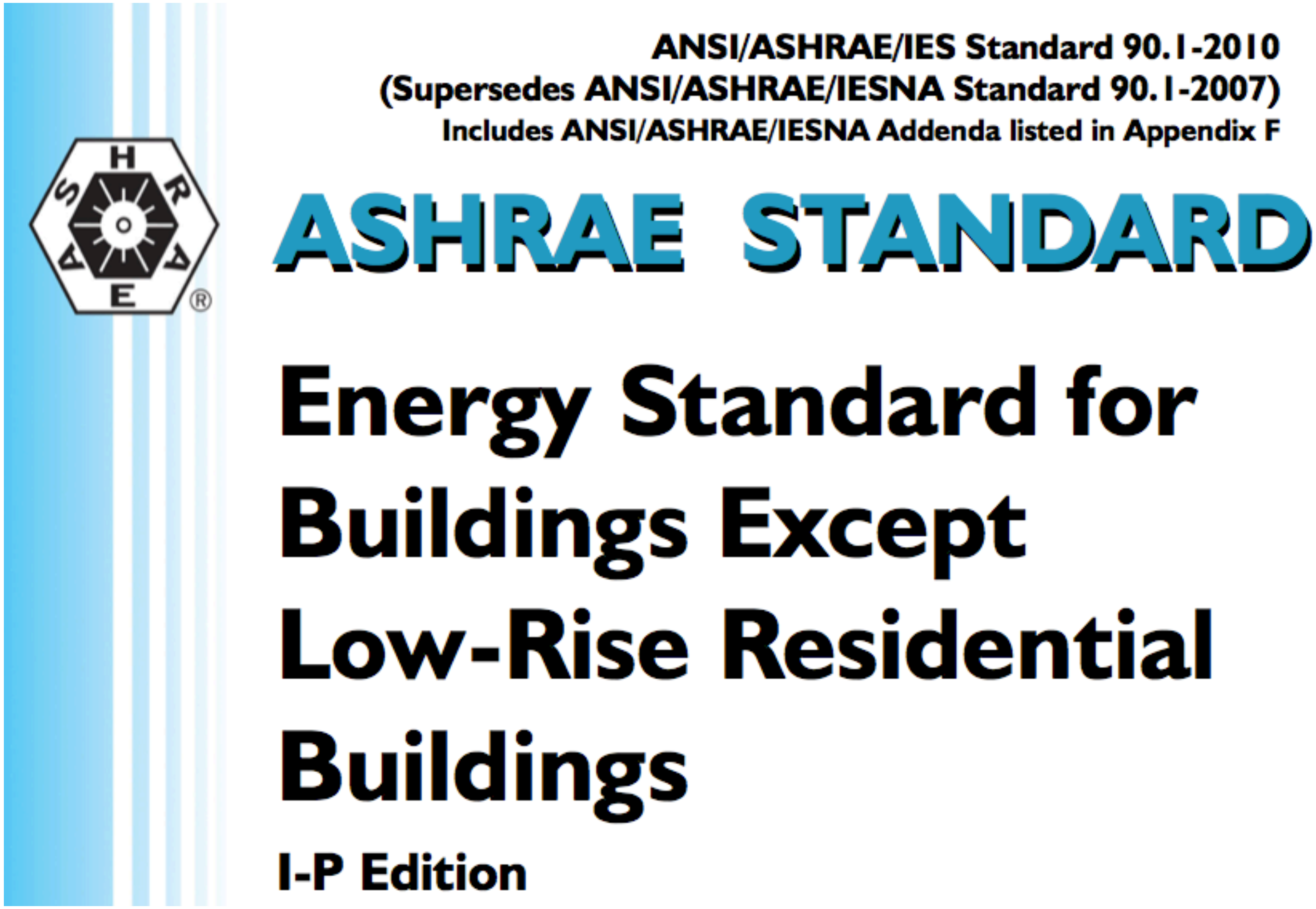
Objectives for exploring ASHRAE 90.1

- Understand the difference between prescriptive requirements and performance requirements of ASHRAE 90.1

- Understand how to find the prescriptive requirements of 90.1 for your building

- Understand what the building enclosure tradeoff option lets you “trade off”

- Understand what software is available to help you with the required calculations



- ASHRAE 90.1-2007, 2010, & now 2013, *Energy Standard for Buildings Except Low-Rise Residential Buildings*
- Look for Addenda to the standard
  - Corrections and changes
  - http://www.ashrae.org/standards-research--technology/standards-addenda

ASHRAE Standards 90.1 and 90.2

- ASHRAE/ANSI/IESNA 90.1
  - Energy Standard for Buildings Except Low-Rise Residential Buildings
  - Will continue to be reference for commercial buildings
  - First appeared in 1975 with major updates in 80,89,99,04,07,10,13
    - Major changes include a change in climatic categories and lighting power density

- ASHRAE 90.2
  - Energy Efficient Design of Low-Rise Residential Buildings
  - May be superseded by IECC International Energy Conservation Code

- ASHRAE Standard 90.1 is the basis of energy efficiency for nearly all Building Codes and Green Building Ratings
  - ICC codes, DOE/Federal Government Codes, State and City Codes, LEED, Green Globes

ASHRAE user manuals

- ASHRAE sells “user manuals” to aid the designer in interpreting and understanding several of their standards including 90.1 and 62.1 (IAQ standard)

- Enclosure and HVAC design engineers should get a copy of the 90.1 user manual and keep up to date with the revisions in order to better understand the changing requirements

IECC

- International Energy Conservation Code
  - Latest edition is 2012

- IECC has a commercial and residential version just as ASHRAE 90.1/90.2
  - Different sections of one document
  - Residential section is similar to 90.2
    - But not identical
  - Commercial section actually allows you to simply comply with ASHRAE 90.1 and the modifications from 90.1 are really quite minimal

IECC 2012

CHAPTER 4: Commercial Energy Efficiency

Section C401: General

COMMERCIAL ENERGY EFFICIENCY

SECTION C401
GENERAL

C401.1 Scope. The requirements contained in this chapter are applicable to commercial buildings, or portions of commercial buildings.

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, C403, C404 and C405.

Accessing 90.1 and IECC

- ASHRAE 90.1-2010 has been uploaded to Blackboard
  – Both SI and IP unit versions

- Also an ASHRAE 90.1-2004 User's Manual

- IECC 2009 and 2012 are available for you to access through the IIT libraries MADCAD system
  – The URLs below work when on campus
  – http://www.madcad.com/library/IECC-12/
  – http://www.madcad.com/library/IECC-09/

What is in ASHRAE Standard 90.1?

- 90.1 has energy performance requirements for:
  - The building enclosure
  - Lighting
  - HVAC equipment
  - Water heating
  - Power delivery systems, and more

- We will only discuss the building enclosure requirements

- **Purpose and scope**

1. PURPOSE

To establish the minimum *energy efficiency* requirements of buildings, other than low rise *residential* buildings, for:

1. design, *construction*, and a plan for operation and maintenance, and
2. utilization of on-site, renewable *energy* resources.

2. SCOPE

2.1 This standard provides:

a. minimum *energy*-efficient requirements for the design, *construction*, and a plan for operation and maintenance of:
   1. new buildings and their *systems*
   2. new portions of buildings and their *systems*
   3. new *systems* and *equipment* in existing buildings
   4. new *equipment* or building *systems* specifically identified in the standard that are part of industrial or manufacturing processes

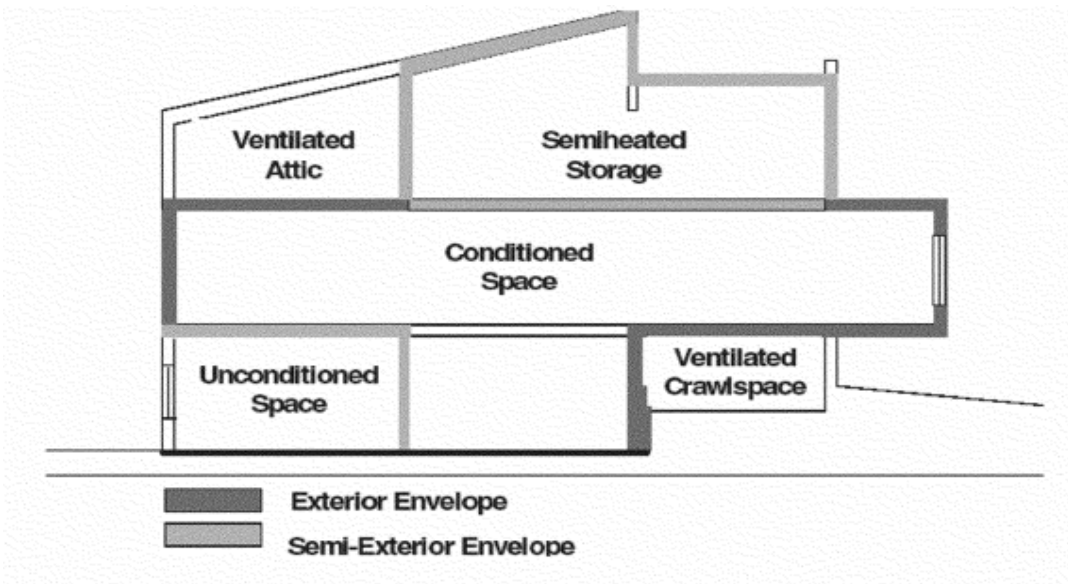
90.1 table of contents

CONTENTS

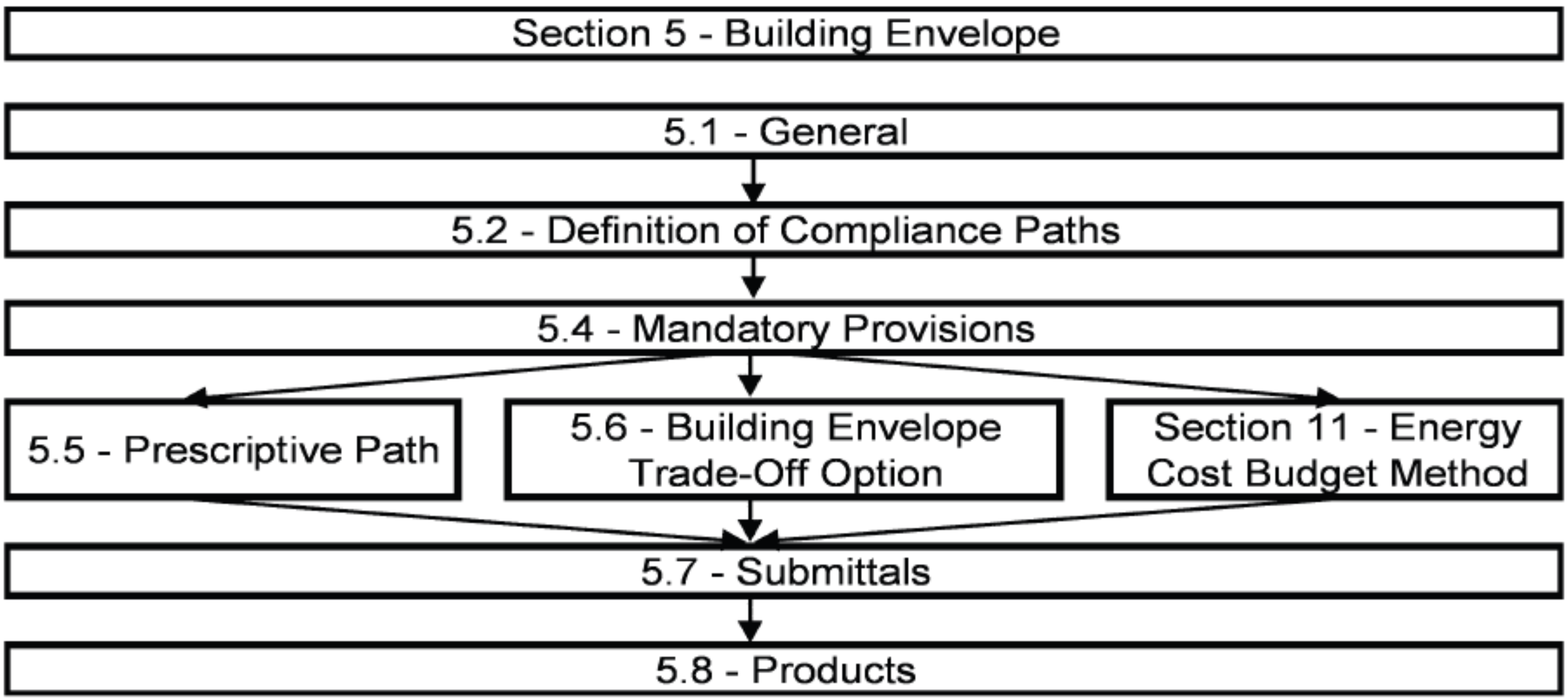
ANSI/ASHRAE/IESNA Standard 90.1-2007
Energy Standard for Buildings Except Low-Rise Residential Buildings

Section 5: Building Envelopes

- Deals with the exterior and semi-exterior envelopes
  - Separation of conditioned and unconditioned space



Process of applying 90.1 to design



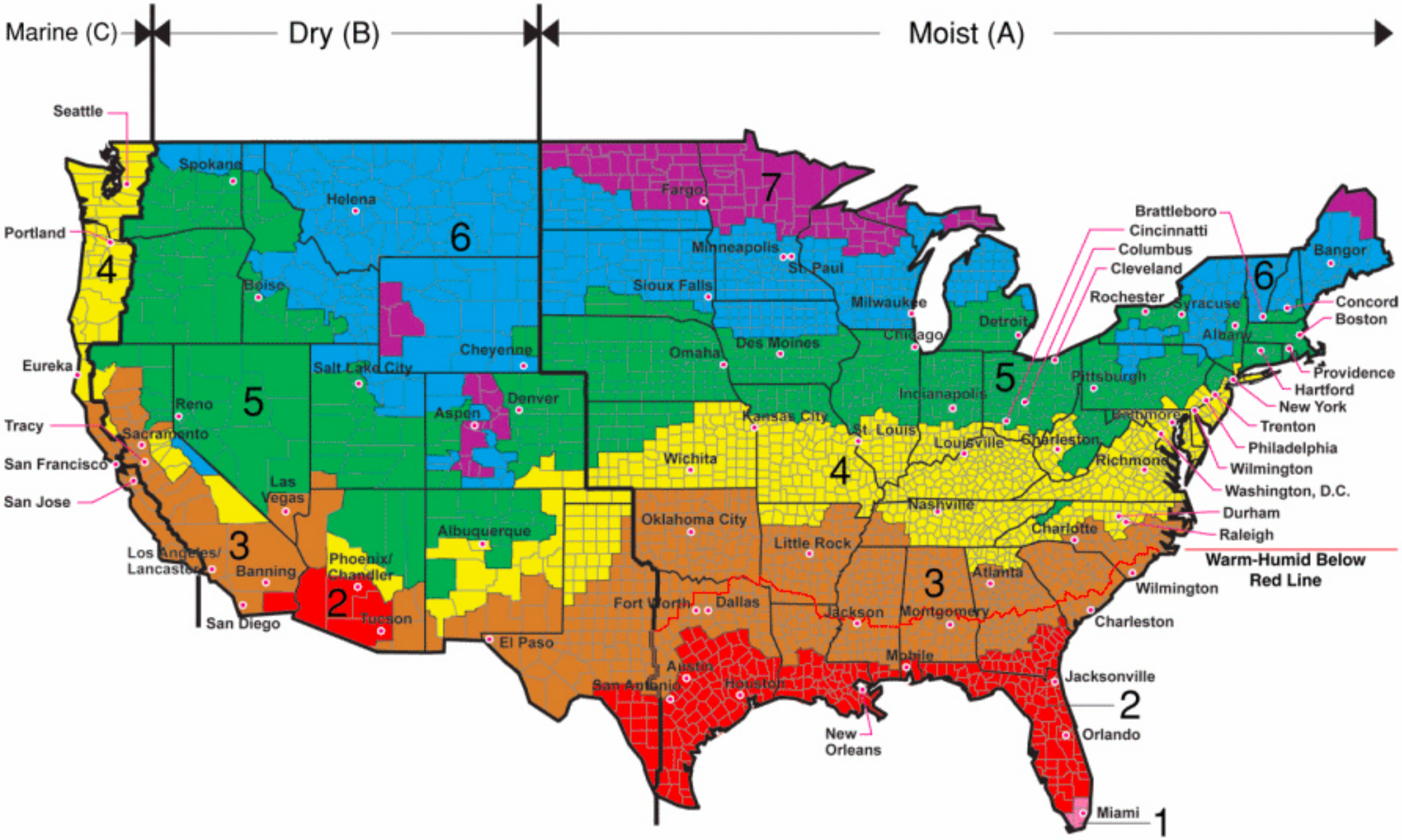
5.1 General

The general section requires us to:

- Break the building into spaces and categorize the conditioning as
  - Non-Residential Conditioned
  - Residential Conditioned, or
  - Semi-Heated

- Determine the Climate Zone using Figure B-1 or Table B-1
  - Note: IECC of Chicago says to use Climate Zone 6 for city compliance regardless of what the tables say

Climate zones



All of Alaska in Zone 7 except for the following Boroughs in Zone 8: Bethel, Dellingham, Fairbanks, N. Star, Nome North Slope, Northwest Arctic, Southeast Fairbanks, Wade Hampton, and Yukon-Koyukuk

Zone 1 includes: Hawaii, Guam, Puerto Rico, and the Virgin Islands

Shoshone	5B
Twin Falls	5B
Washington	5B
Illinois (IL)	
Zone 5A Except	
Alexander	4A
Bond	4A
Christian	4A
Clay	4A
Clinton	4A
Crawford	4A
Edwards	4A
Effingham	4A
Fayette	4A
Franklin	4A

Chicagoland is actually in Climate Zone 5A, but use 6

5.4 Mandatory Provisions

- Compliance with 90.1 carries several requirements that cannot be avoided regardless of the compliance path that is chosen

These include:

- Sealant requirements
  - Locations where joints must have sealants applied
- Air leakage
  - Maximum air leakage of doors and windows
- Vestibule entrances
  - Requirements for the use of vestibules or revolving-doors at an entrance

Assemblies of materials and components (sealants, tapes, etc.) that have an average air leakage not to exceed 0.04 cfm/ft^2 under a pressure differential of 0.3 in. w.g. (1.57psf) when tested in accordance with ASTM E 2357 ASTM E 1677, ASTM E 1680 or ASTM E283; The following assemblies meet the requirements of 5.4.3.1.3 b.

5.4.3.4 Vestibules

- All entrances to conditioned spaces must have vestibules with doors into/out of the vestibules equipped with *self-closing* doors

- Exceptions:
  - Building Entrances with Revolving Doors
  - Doors direct to/from a dwelling unit
  - Any Entrances in Zones 1 or 2
  - Entrances in Zones 3 or 4 to spaces < 10000 ft^2 in area
  - Entrances in Zones 5-8 to spaces < 1000 ft^2
  - Doors direct to a space < 3000 ft^2 and is separate from the main building entrance

5.2.1 Compliance Path Options

There are three **compliance options** for 90.1, whereby the building envelope must meet one of the following:

1. Prescriptive requirements of Section 5.5

   or

2. Envelope tradeoff option of Section 5.6
   – Envelope performance factor (EPF) must be less than that of a base design calculated using the methods of Appendix C
   – Allows you to trade efficiency between enclosure elements

   or

3. Energy Cost Budget maximums
   – This is a total building energy performance criterion where you show that the building meets a certain maximum energy usage
   – This involves modeling of the enclosure, full HVAC, and complete lighting systems for the building

5.5.1 The Prescriptive Method

- This is the most popular way of designing to 90.1
  - But the method limits innovation in design
- Building Envelope elements must have a performance that meets or exceeds the values in Tables 5.5-1 through 5.5-8
  - These values vary by climate zone
  - Tables include required R, U and/or SHGC values for various components
    - Tables A1-A26 have a great deal of data for various standard enclosure components constructions so you do not always have to calculate them from scratch

5.5.3 Opaque Areas

All opaque areas (except doors) must have either:

- A minimum R value of the entire assembly

or

- A maximum U-Factor, C-Factor, or F-Factor for the entire assembly
  - C and F factors describe below-grade and on-grade heat transfer

Requirements for roofs, walls, and floors

TABLE 5.5-6 Building Envelope Requirements for Climate Zone 6 (A, B)*

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-0.093	R-10.0 c.i.
Metal Building[a]	U-0.049	R-13.0 + R-19.0	U-0.049	R-13.0 + R-19.0	U-0.072	R-16.0
Attic and Other	U-0.027	R-38.0	U-0.027	R-38.0	U-0.034	R-30.0
Walls, Above-Grade						
Mass	U-0.080	R-13.3 c.i.	U-0.071	R-15.2 c.i.	U-0.151[b]	R-5.7 c.i.[b]
Metal Building	U-0.069	R-13.0 + R-5.6 c.i.	U-0.069	R-13.0 + R-5.6 c.i.	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-0.051	R-13.0 + R-7.5 c.i.	U-0.051	R-13.0 + R-7.5 c.i.	U-0.089	R-13.0
Walls, Below-Grade						
Below-Grade Wall	C-0.119	R-7.5 c.i.	C-0.119	R-7.5 c.i.	C-1.140	NR
Floors						
Mass	U-0.064	R-12.5 c.i.	U-0.057	R-14.6 c.i.	U-0.137	R-4.2 c.i.
Steel-Joist	U-0.038	R-30.0	U-0.032	R-38.0	U-0.052	R-19.0
Wood-Framed and Other	U-0.033	R-30.0	U-0.033	R-30.0	U-0.051	R-19.0
Slab-On-Grade Floors						
Unheated	F-0.540	R-10 for 24 in.	F-0.520	R-15 for 24 in.	F-0.730	NR
Heated	F-0.860	R-15 for 24 in.	F-0.688	R-20 for 48 in.	F-1.020	R-7.5 for 12 in.

Note that frame walls MUST have both in frame and external continuous insulation and mass walls have reduced insulation requirements

5.4.4 Fenestration

- The area weighted average U and SHGC of windows for each space conditioning area must meet the requirements of Tables 5.5-1 through 5.5-8
  - So, there is the ability to have some glazing with higher U and/or SHGC values
    - Only if you have enough low U and SHGC windows to offset the high ones and keep the overall average low enough

Fenestration U and SHGC

TABLE 5.5-6 Building Envelope Requirements For Climate Zone 6 (A, B)*

	Nonresidential		Residential		Semiheated	
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-0.35	SHGC-0.40 all	U-0.35	SHGC-0.40 all	U-0.65	SHGC-NR all
Metal framing (curtainwall/storefront)[d]	U-0.45		U-0.45		U-0.60	
Metal framing (entrance door)[d]	U-0.80		U-0.80		U-0.90	
Metal framing (all other)[d]	U-0.55		U-0.55		U-0.65	
Skylight with Curb, Glass, % of Roof						
0%–2.0%	U_{all}–1.17	$SHGC_{all}$–0.49	U_{all}–0.98	$SHGC_{all}$–0.46	U_{all}–1.98	$SHGC_{all}$–NR
2.1%–5.0%	U_{all}–1.17	$SHGC_{all}$–0.49	U_{all}–0.98	$SHGC_{all}$–0.36	U_{all}–1.98	$SHGC_{all}$–NR
Skylight with Curb, Plastic, % of Roof						
0%–2.0%	U_{all}–0.87	$SHGC_{all}$–0.71	U_{all}–0.74	$SHGC_{all}$–0.65	U_{all}–1.90	$SHGC_{all}$–NR
2.1%–5.0%	U_{all}–0.87	$SHGC_{all}$–0.58	U_{all}–0.74	$SHGC_{all}$–0.55	U_{all}–1.90	$SHGC_{all}$–NR
Skylight without Curb, All, % of Roof						
0%–2.0%	U_{all}–0.69	$SHGC_{all}$–0.49	U_{all}–0.58	$SHGC_{all}$–0.49	U_{all}–1.36	$SHGC_{all}$–NR
2.1%–5.0%	U_{all}–0.69	$SHGC_{all}$–0.49	U_{all}–0.58	$SHGC_{all}$–0.39	U_{all}–1.36	$SHGC_{all}$–NR

*The following definitions apply: c.i. = *continuous insulation* (see Section 3.2), NR = no (insulation) requirement.
[a]When using R-value compliance method, a thermal spacer block is required; otherwise use the *U-factor* compliance method. See Table A2.3.
[b]Exception to Section A3.1.3.1 applies.
[c]Nonmetal framing includes framing materials other than metal with or without metal reinforcing or cladding.
[d]Metal framing includes metal framing with or without thermal break. The "all other" subcategory includes operable windows, fixed windows, and non-entrance *doors*.

5.5.4.2 Fenestration restriction

The prescriptive method limits the amount of glass that can be installed for most uses

- Vertical glass < 40% of wall area

5.5.4.2 Fenestration Area

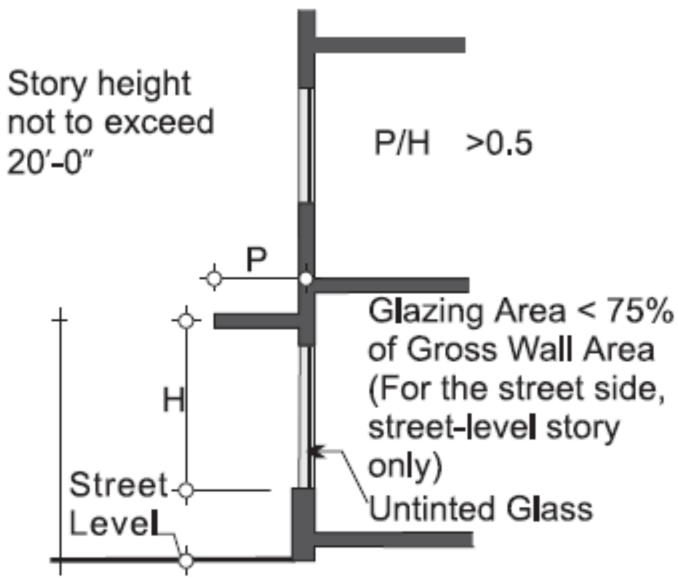
5.5.4.2.1 Vertical Fenestration Area. The total *vertical fenestration area* shall be less than 40% of the *gross wall area.*

- Skylight area < 5% of roof

5.5.4.2.2 Maximum Skylight Fenestration Area. The total *skylight area* shall not exceed 5% of the *gross roof area*.

Storefront exemption for fenestration

- There is an exemption to the 40% rule designed for storefronts



PF = P/H

c. *Vertical fenestration* that is located on the street side of the street-level story only, provided that

1. the street side of the street-level story does not exceed 20 ft in height,
2. the *fenestration* has a continuous overhang with a weighted average *PF* greater than 0.5, and
3. the *fenestration area* for the street side of the street-level story is less than 75% of the *gross wall area* for the street side of the street-level story.

5.5.4.4.1 SHGC multipliers

- With the use of overhangs, SHGC values can be relaxed
  - Scale the proposed window SHGC by the given multiplier

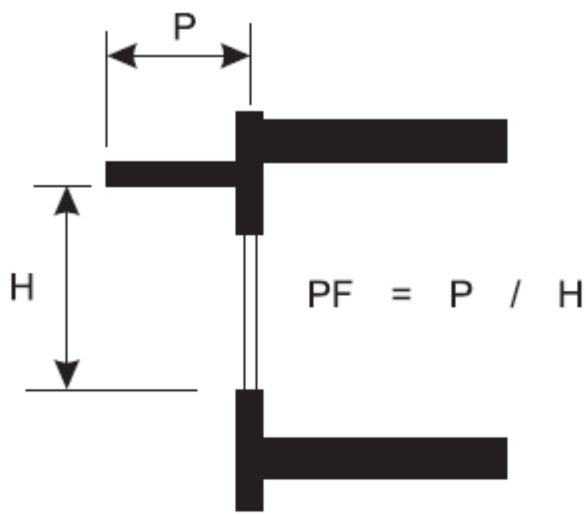


TABLE 5.5.4.4.1 SHGC Multipliers for Permanent Projections

Projection Factor	SHGC Multiplier (All Other Orientations)	SHGC Multiplier (North-Oriented)
0–0.10	1.00	1.00
>0.10–0.20	0.91	0.95
>0.20–0.30	0.82	0.91
>0.30–0.40	0.74	0.87
>0.40–0.50	0.67	0.84
>0.50–0.60	0.61	0.81
>0.60–0.70	0.56	0.78
>0.70–0.80	0.51	0.76
>0.80–0.90	0.47	0.75
>0.90–1.00	0.44	0.73

Opacity correction, O_s

- If part of the shading is semi-transparent there is an additional correction factor O_s

$$O_s = (A_i \cdot O_i) + (A_f \cdot O_f)$$

where

O_s = percent opacity of the shading device

A_i = percent of the area of the shading device that is a partially opaque infill

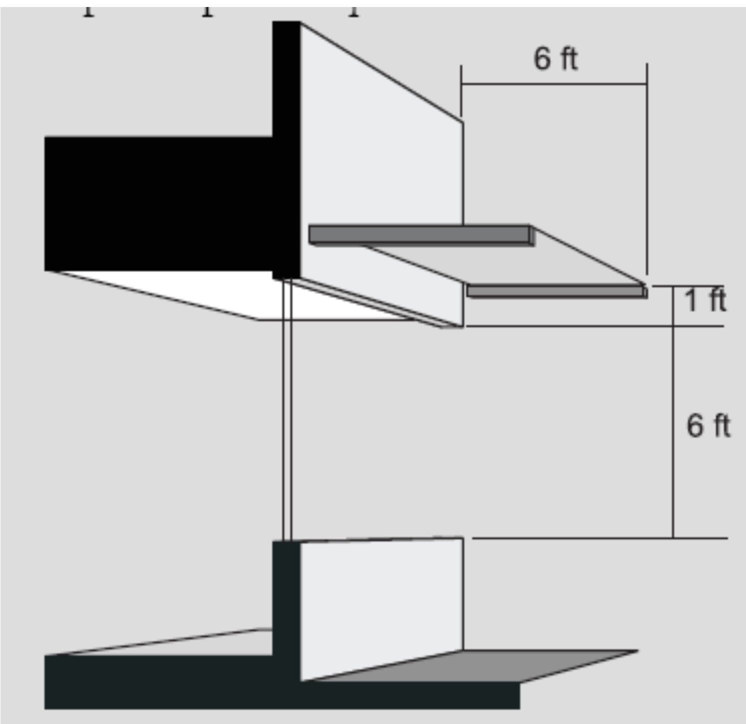
O_i = percent opacity of the infill—for glass O_i = (100% – T_s), where T_s is the solar transmittance as determined in accordance with NFRC 300; for perforated or decorative metal panels O_i = percentage of solid material

A_f = percent of the area of the shading device that represents the framing members

O_f = percent opacity of the framing members; if solid, then 100%

Window shading example

- A 6 ft window with SHGC=0.4 has a 6 ft wide 30% transparent projected shade. What is the adjusted SHGC?



$$PF = \frac{6}{1+6} = 0.857$$

$$O_s = (A_i \times O_i) + (A_f \times O_f)$$

$$= (0.917 \times (1 - 0.30)) + (0.083 \times 1.0) = 0.725$$

$$PF_{Adj} = PF \times O_s = 0.857 \times 0.725 = 0.621$$

$$M = 0.56 \left(\text{From Table 5.5.4.4.1}\right)$$

$$SHGC_{Adj} = SHGC \times M = 0.40 \times 0.56 = 0.22$$

TABLE 5.5.4.4.1 SHGC Multipliers for Permanent Projections

Projection Factor	SHGC Multiplier (All Other Orientations)	SHGC Multiplier (North-Oriented)
0–0.10	1.00	1.00
>0.10–0.20	0.91	0.95
>0.20–0.30	0.82	0.91
>0.30–0.40	0.74	0.87
>0.40–0.50	0.67	0.84
>0.50–0.60	0.61	0.81
>0.60–0.70	0.56	0.78
>0.70–0.80	0.51	0.76
>0.80–0.90	0.47	0.75
>0.90–1.00	0.44	0.73

Appendix A

- Appendix A of ASHRE 90.1 has pre-computed U values for a large number of assemblies
- If your assembly is like one of these, use the pre-computed number for comparison
- If your assembly is not here, you must compute the U value yourself using the prescribed methods
  - Use prescribed R values for steel and wood frame wall layers
  - Methods include:
    - Actual testing, parallel path, modified zone, THERM

5.6 Building Envelope Trade-Off Option (BETO)

- Instead of following *prescriptive* levels, we could instead show that our overall enclosure meets some <u>maximum energy use</u> requirements
  - Max. heat loss through walls, heat capacity, solar gain
- BTO allows us to trade off efficiencies between enclosure elements
  - More architectural and design freedom with the same (or better) overall energy performance
- If the Envelope Performance Factor (EPF) for our building is less than for the base (“budget”) building
  - Then it passes the standard
- EPF calculations outlined in Appendix C

5.6 BETO required building data

- At building level:
  - Floor area broken down by space-conditioning categories
- For exterior surfaces:
  - Gross area of exterior
  - U factor
  - For mass walls: heat capacity and insulation position
- For below grade walls:
  - Avg depth of bottom of wall
  - C factor (i.e., U value)
- For fenestration:
  - U factor
  - SHGC
  - VLT (Visible Transmission)
  - Overhang projection factors
  - Dimensions of skylight wells
- For opaque doors:
  - U factor
  - Heat capacity
  - Insulation position
- Slab-on-grade walls:
  - Perimeter length
  - F factor (i.e., U value)

5.6 BETO required outputs

1. Tables summarizing the required building data

2. Envelope performance factor (EPF) differential broken down by envelope component
   - The differential is the difference between the EPF of the proposed building and the EPF of the base envelope design
   - Envelope components include opaque roof, skylights, above grade walls, vertical fenestration, doors, below-grade walls and slab-on-grade floors

Calculating EPF

- To calculate the EPF you basically calculate the energy required for heating cooling and lighting and add it up
  - $EPF = E_{heat} + E_{cool} + E_{lighting}$
  - Heating and cooling energy based upon HDD and CDD

- The algorithms reduce lighting and heating and increase energy based upon the expected daylighting and passive solar contribution of your design

EPF algorithms

- Envelope Performance Factors are calculated using some pretty **ridiculous** equations in Appendix C of 90.1
  - Function of HVAC loads and lighting needs

$$EPF = FAF \times [\Sigma HVAC_{surface} + \Sigma Lighting_{zone}]$$

$$HVAC_{surface} = 0.0939 \times COOL + 1.22 \times HEAT$$

$$COOL = 1000/(1200 \times 12.24) \times [CLU + CLUO + CLXUO + CLM + CLG + CLS + CLC] \quad \text{(C-13)}$$

$$CLU = Area_{opaque} \times U_{ow} \times [CU1 \times CDH80 + CU2 \times CDH80^2 + CU3 \times (VS \times CDH80)^2 + CU4 \text{ x } DR]$$

Variable	Orientation of Surface			
	North	East	South	West
CU1	0.001539	0.003315	0.003153	0.00321
CU2	–3.0855E-08	–8.9662E-08	–7.1299E-08	–8.1053E-08

EPF calculations

$$CLG = Area_{grosswall} \times \{G \times [CG1 + CG2 \times CDD50 + CG3 \times EA_C \times (VS \times CDD50)^2 + CG4 \times EA_C{}^2 \times VS \times CDD50 + CG5 \times CDD65 + CG6 \times CDD50^3 + CG7 \times CDD65^3] + G^2 \times [CG8 \times EA_C \times VS \times CDD50 + CG9 \times EA_C{}^2 \times VS \times CDD50]\}$$

$$CLS = Area_{grosswall} \times \{EA_C \times [CS1 + CS2 \times VS \times CDD50 + CS3 \times (VS \times CDD50)^2 + CS4 \times VS \times CDD65 + CS5 \times (VS \times CDD65)^2] + EA_C{}^2 \times [CS6 + CS7 \times (VS \times CDD65)^2]\}$$

ed using some of 90.1

$+ CLXUO +$

$CLC = Area$

No one does this by hand! Just use software!

$$+ CC3 \times CDH80 + CC4 \times CDH80^2 + CC5 \times CDD65 + CC6 \times (VS \times CDD65)^2 + CC7 \times VS \times CDD50 + CC8 \times (VS \times CDD50)^2 + CC9 \times (VS \times CDH80)^2 + CC10 \times VS + CC11 \times DR + CC12 \times DR^2 + CC13]$$

$0 + CU2 \times CDH80^2$

J4 x DR]

				West
				0.00321
CU2	–3.0855E-08	–8.9662E-08	–7.1299E-08	–8.1053E-08

Software to help you out

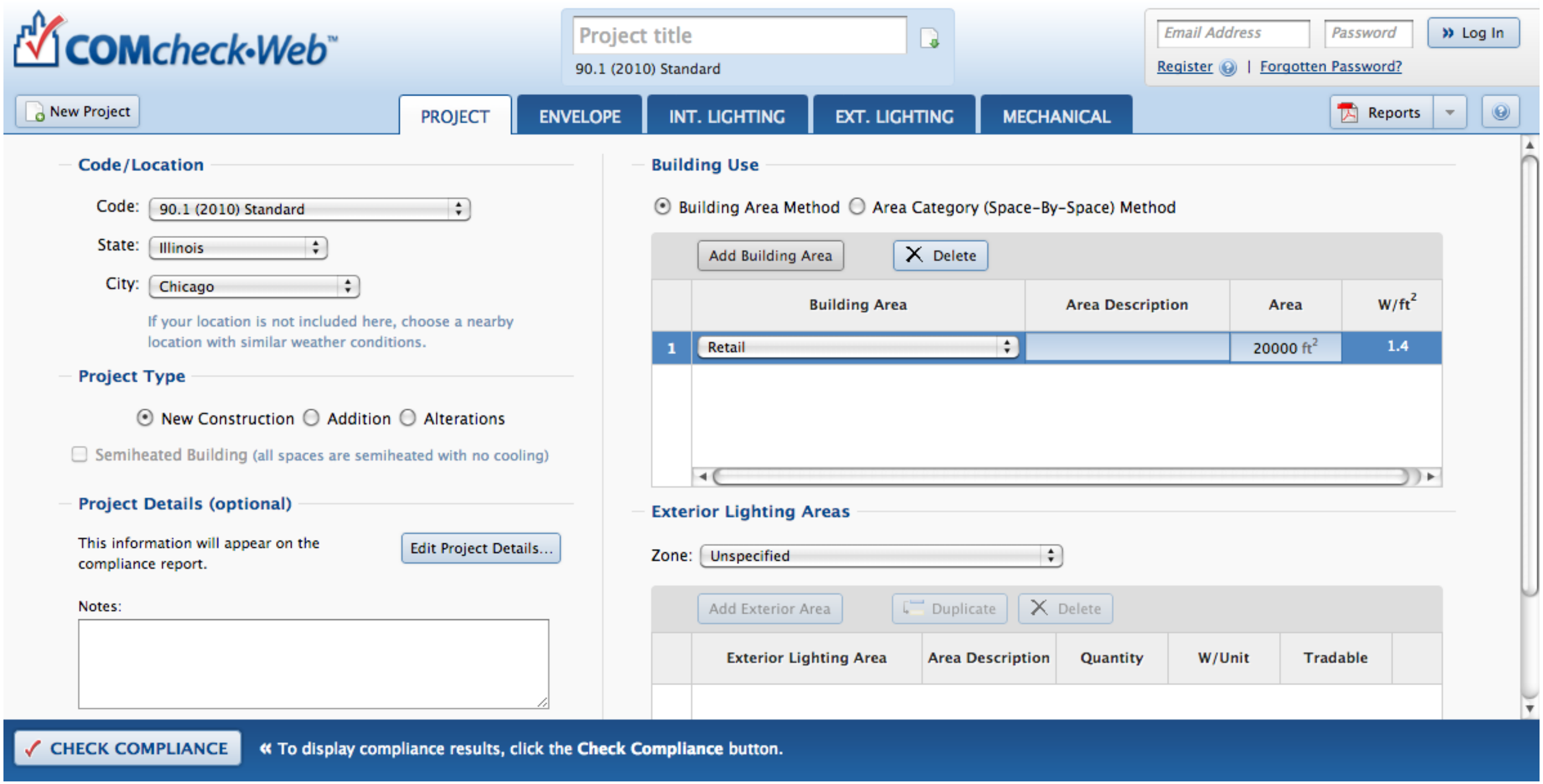
COM*check* and RES*check* from DOE

http://www.energycodes.gov/comcheck/

- COM*check* Prescriptive Package Generator
  - Web based app for generating a list of required values for building elements
- COM*check (Formerly COMcheck-ez)*
  - Windows/MAC/web program for using the tradeoff approach
- RES*check*
  - Same software but designed for checking residential building energy codes

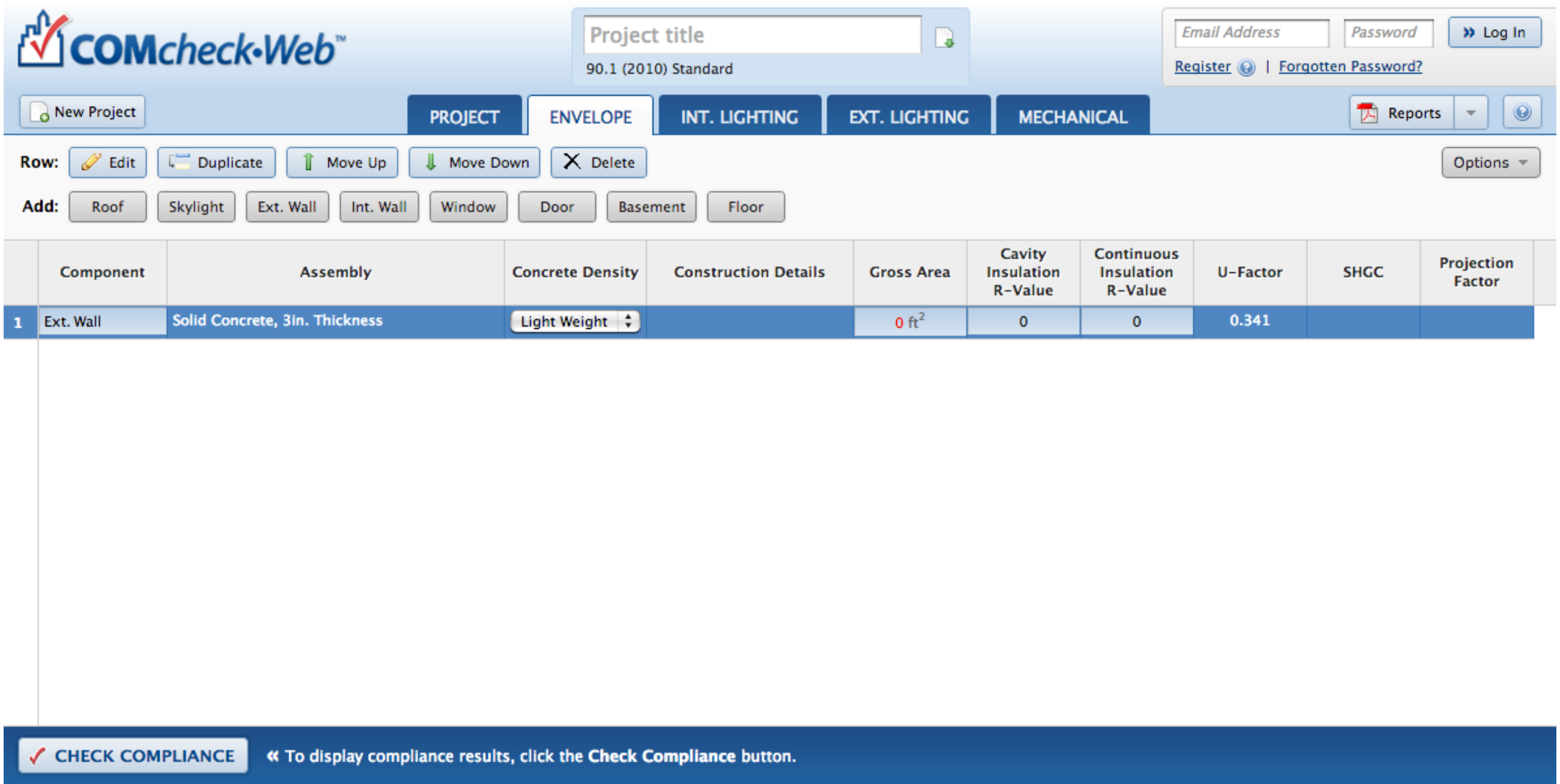
COM*check*

- Free web-based version



COM*check*

- Input building parameters just like you were going to perform building energy simulations
  - The program will check for compliance with ASHRAE 90.1 or IECC or anything else you choose



EPF: Calculating base design

- The EPF calculation is redone for your building assuming prescriptive U values for all components and a maximum of 40% glazing
  - Glazing is reduced proportionally in size on all walls until the max 40% is reached

- The EPF of your design must not exceed the EPF of the base design for you to meet ASHRAE 90.1

Last method for 90.1: Energy Cost Budget Modeling

- This is a <u>**performance**</u> requirement
  - Can be used in lieu of the prescriptive requirements
- Allows for far more <u>flexibility</u> in design
  - But requires ability to model full energy use of building
- Trade off efficiencies between systems as well as components within a system
    - e.g., use higher efficiency lighting to be able to use more windows
    - e.g., use a higher efficiency HVAC to be able to reduce insulation
  - Must use software like eQUEST, IES-VE, EnergyPlus, Carrier HAP, or Trane Trace 700 to model full building energy use
- You must use this method when doing energy calculations for any LEED rated building
  - BETO and prescriptive methods are not allowed

GREEN BUILDING STANDARDS AND RATING SYSTEMS

USGBC LEED and enclosures

LEED 2009 FOR NEW CONSTRUCTION AND MAJOR RENOVATIONS

System of 110 possible points;

- Site (26)
- Water (10)
- Energy and atmosphere (35)
- Materials and resources (14)
- Indoor environmental quality (15)
- Innovation in design (6)
- Regional priorities (4)

Newest version: LEED v4

LEED® for Homes Rating System

System of 136 possible points;

- Innovation and design (11)
- Location and linkages (10)
- Sustainable sites (22)
- Water efficiency (15)
- Energy and atmosphere (38)
- Materials and resources (16)
- Indoor environmental quality (21)
- Awareness and education (3)

U.S. GREEN BUILDING COUNCIL LEED USGBC™

GREEN BUILDING INITIATIVE™

GREEN GLOBES

LEED and energy use/enclosures

- USGBC LEED-NC 2009
  - "NC" = new construction

Energy and Atmosphere			35 Possible Points
☑	Prerequisite 1	Fundamental Commissioning of Building Energy Systems	Required
☑	Prerequisite 2	Minimum Energy Performance	Required
☑	Prerequisite 3	Fundamental Refrigerant Management	Required
☐	Credit 1	Optimize Energy Performance	1–19
☐	Credit 2	On-site Renewable Energy	1–7
☐	Credit 3	Enhanced Commissioning	2
☐	Credit 4	Enhanced Refrigerant Management	2
☐	Credit 5	Measurement and Verification	3
☐	Credit 6	Green Power	2

LEED and energy use/enclosures

EA Prerequisite 2: Minimum Energy Performance

Requirements

OPTION 1. Whole Building Energy Simulation

Demonstrate a 10% improvement in the proposed building performance rating for new buildings, or a 5% improvement in the proposed building performance rating for major renovations to existing buildings, compared with the baseline building performance rating.

Calculate the baseline building performance rating according to the building performance rating method in Appendix G of ANSI/ASHRAE/IESNA Standard 90.1-2007 (with errata but without addenda[1]) using a computer simulation model for the whole building project. Projects outside the U.S. may use a USGBC approved equivalent standard[2].

OPTION 2. Prescriptive Compliance Path: ASHRAE Advanced Energy Design Guide

Comply with the prescriptive measures of the ASHRAE Advanced Energy Design Guide appropriate to the project scope, outlined below. Project teams must comply with all applicable criteria as established in the Advanced Energy Design Guide for the climate zone in which the building is located. Projects outside the U.S. may use ASHRAE/ASHRAE/IESNA Standard 90.1-2007 Appendices B and D to determine the appropriate climate zone.

PATH 1. ASHRAE Advanced Energy Design Guide for Small Office Buildings 2004

The building must meet the following requirements:

- Less than 20,000 square feet (1,800 square meters).
- Office occupancy.

PATH 2. ASHRAE Advanced Energy Design Guide for Small Retail Buildings 2006

The building must meet the following requirements:

- Less than 20,000 square feet (1,800 square meters).
- Retail occupancy.

PATH 3. ASHRAE Advanced Energy Design Guide for Small Warehouses and Self Storage Buildings 2008

LEED and energy use/enclosures

EA Credit 1: Optimize Energy Performance

1–19 Points

OPTION 1. Whole Building Energy Simulation (1–19 points)

Demonstrate a percentage improvement in the proposed building performance rating compared with the baseline building performance rating. Calculate the baseline building performance according to Appendix G of ANSI/ASHRAE/IESNA Standard 90.1-2007 (with errata but without addenda[1]) using a computer simulation model for the whole building project. Projects outside the U.S. may use a USGBC approved equivalent standard[2]. The minimum energy cost savings percentage for each point threshold is as follows:

New Buildings	Existing Building Renovations	Points
12%	8%	1
14%	10%	2
16%	12%	3
18%	14%	4
20%	16%	5
22%	18%	6
24%	20%	7
26%	22%	8
28%	24%	9
30%	26%	10
32%	28%	11
34%	30%	12
36%	32%	13
38%	34%	14
40%	36%	15
42%	38%	16
44%	40%	17
46%	42%	18
48%	44%	19

ASHRAE Advanced Energy Design Guides

- Targets of 30% energy savings or 50% energy savings
  - Over ASHRAE 90.1-1999

- Guidelines for many types of buildings:
  - Medium to big box retail buildings
  - Small to medium office buildings
  - K-12 school buildings
  - Large hospitals
  - Small office buildings
  - Highway lodging
  - Small warehouses
  - etc.

- You can download most of these for free
  - http://aedg.ashrae.org/GetSubscription.aspx

ASHRAE AEDG: 30% savings in small offices

- Office buildings smaller than 20,000 ft^2
- Only a **recommendation** document
  - Not a code or standard (unless a standard implements this)
- Represents “a way” to build energy efficient small offices
- Recommendations for energy-efficiency in:
  - Building envelope
  - Lighting
  - HVAC equipment and systems
  - Service water heating
- Focus on integrated process

ASHRAE AEDG: 30% savings in small offices

Climate Zone 6 Recommendation Table

	Item	Component	Recommendation	How-To's in Chapter 4
Envelope	Roof	Insulation entirely above deck	R-20 c.i.	EN2, 17, 20-21
		Metal building	R-13 + R-19	EN3, 17, 20-21
		Attic and other	R-38	EN4, 17-18, 20-21
		Single rafter	R-38 + R-5 c.i.	EN5, 17, 20-21
		Surface reflectance/emittance	No recommendation	
	Walls	Mass (HC > 7 Btu/ft^2)	R-11.4 c.i.	EN6, 17, 20-21
		Metal building	R-13 + R-13	EN7, 17, 20-21
		Steel framed	R-13 + R-7.5 c.i.	EN8, 17, 20-21
		Wood framed and other	R-13 + R-3.8 c.i.	EN9, 17, 20-21
		Below grade walls	R-7.5 c.i.	EN10, 17, 20-21
	Floors	Mass	R-10.4 c.i.	EN11, 17, 20-21
		Steel framed	R-30	EN12, 17, 20-21
		Wood framed and other	R-30	EN12, 17, 20-21
	Slabs	Unheated	R-10 for 24 in	EN13, 17, 19-21
		Heated	R-10 for 36 in.	EN14, 17, 19-21
	Doors	Swinging	U-0.70	EN15, 20-21
		Non-swinging	U-0.50	EN16, 20-21
	Vertical Glazing	Window to wall ratio (WWR)	20% to 40% maximum	EN23, 36-37
		Thermal transmittance	U-0.42	EN25, 31
		Solar heat gain coefficient (SHGC)	N, S, E, W - 0.46 / N only - 0.46	EN27-28
		Window orientation	$(A_N * SHGC_N + A_S * SHGC_S) > (A_E * SHGC_E + A_W * SHGC_W)$	A_x–Window area for orientation x EN26-32
		Exterior sun control (S, E, W only)	No recommendation	EN24, 28, 30, 36, 40, 42 DL5-6
	Skylights	Maximum percent of roof area	3%	DL5-7, DL8, DL13
		Thermal transmittance	U-0.69	DL7, DL8, DL13
		Solar heat gain coefficient (SHGC)	0.49	DL8, DL13

ASHRAE AEDG: 30% savings in small offices

- "How to" guides in the AEDG

EN2 ***Roofs, Insulation Entirely above Deck* (Climate Zones: all)**

The insulation entirely above deck should be continuous insulation (c.i.) rigid boards because there are no framing members present that would introduce thermal bridges or short circuits to bypass the insulation.

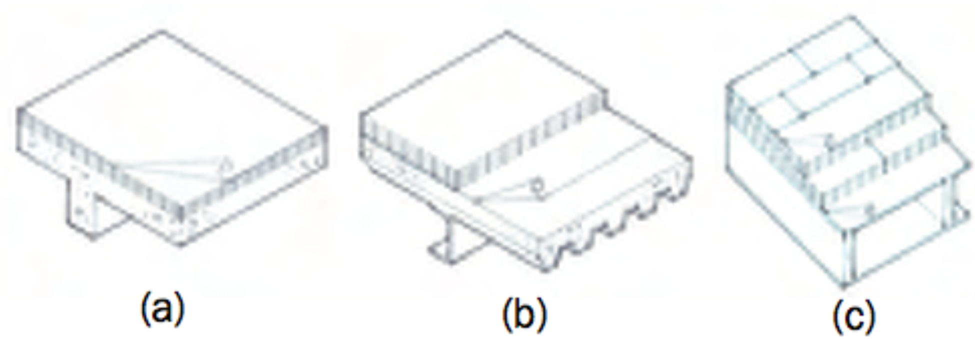


Figure 4-1. (EN2) Insulation entirely above deck. Insulation is installed above a (a) concrete, (b) metal, or (c) wood deck in a continuous manner.

When two layers of continuous insulation are used in this construction, the board edges should be staggered to reduce the potential for convection losses or thermal bridging. If an inverted or protected membrane roof system is used, at least one layer of insulation is placed above the membrane while a maximum of one layer is placed beneath the membrane.

ASHRAE AEDG: 30% savings in small offices

- “How to” guides in the AEDG

EN6 ***Walls, Mass* (Climate Zones: all)**

Mass walls are defined as those with a heat capacity exceeding 7 Btu/ft^2·°F. Insulation may be placed either on the inside or the outside of the masonry wall. When insulation is placed on the exterior of the wall, (a) rigid continuous insulation (c.i.) is recommended. When insulation is placed (b) on the interior of the wall, a furring or framing system should be used, provided the total wall assembly has a U-factor that is less than or equal to the appropriate climate zone construction listed in Appendix A.

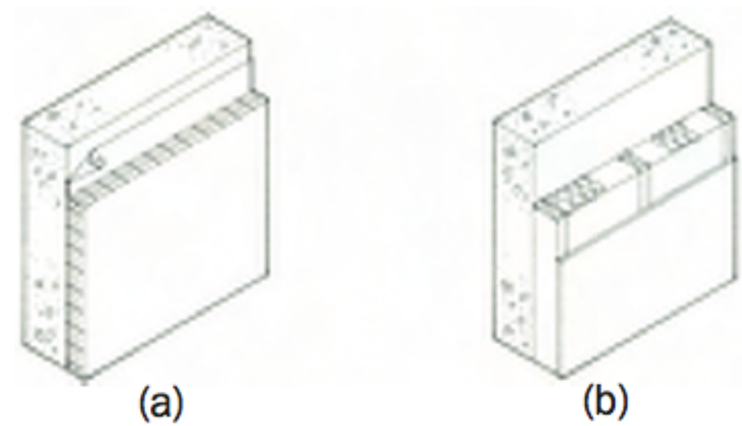


Figure 4-5. (EN6) Walls, mass. Any concrete or masonry wall with a heat capacity exceeding 7 Btu/ft^2·°F.

The greatest advantages of mass can be obtained when insulation is placed on the exterior of the mass. In this case, the mass absorbs internal heat gains that are later released in the evenings when the buildings are not occupied.

ASHRAE AEDG: 30% savings in small offices

- “How to” guides in the AEDG

EN8 ***Walls, Steel Framed* (Climate Zones: all)**

Cold-formed steel framing members are thermal bridges to the cavity insulation. Adding exterior foam sheathing as continuous insulation (c.i.) is the preferred method to upgrade the wall thermal performance because it will increase the overall wall thermal performance and tends to minimize the impact of the thermal bridging. Cavity insulation should be used within the steel-framed wall, while rigid continuous insulation should be placed on the exterior side of the steel framing. Alternative combinations of cavity insulation and sheathing in thicker steel-framed walls can be used provided that the proposed total wall assembly has a U-factor that is less than or equal to the U-factor for the appropriate climate zone construction listed in Appendix A.

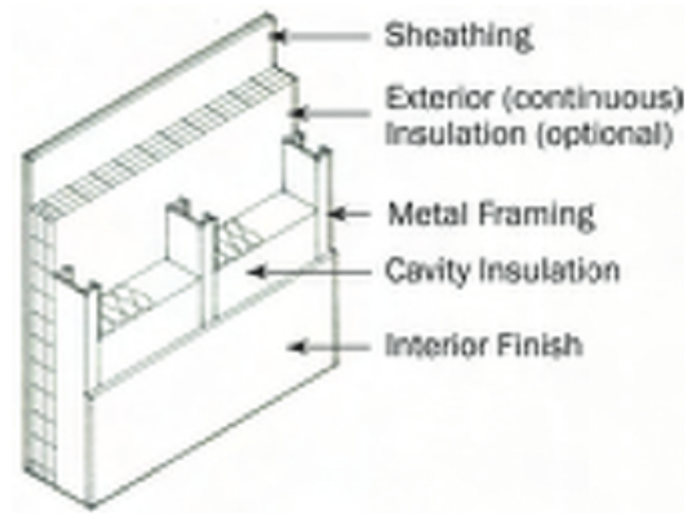
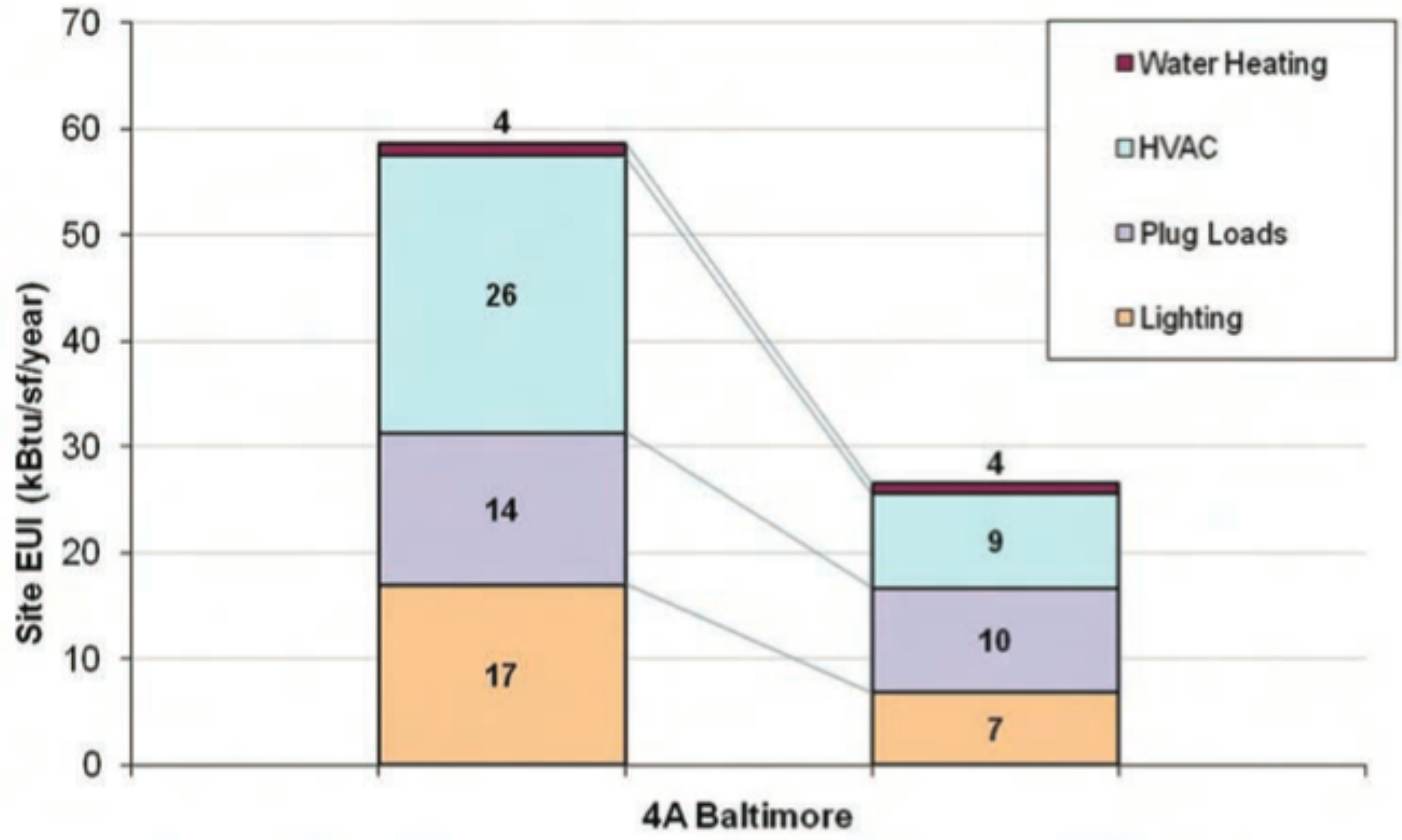


Figure 4-7. (EN8) Walls, steel framed. A common construction type in nonresidential buildings.

ASHRAE AEDG: 50% savings in small offices

- Similar to the 2004 30% guide but more stringent
  - Target: 50% lower energy than ASHRAE 90.1-2004



ASHRAE AEDG: 50% savings in small offices

Climate Zone 6 Recommendation Table for Small to Medium Office Buildings

	Item	Component	Recommendation	How-To Tips	✓
Envelope	Roofs	Insulation entirely above deck	R-30.0 c.i.	EN2, 17, 19, 21–22	
		Attic and other	R-49.0	EN3, 17, 19, 20–21	
		Metal building	R-25.0 + R-11.0 Ls	EN4, 17, 19, 21	
		SRI	No recommendation	None	
	Walls	Mass (HC > 7 Btu/ft^2)	R-19.0 c.i.	EN5, 17, 19, 21	
		Steel framed	R-13.0 + R-18.8 c.i.	EN6, 17, 19, 21	
		Wood framed and other	R-13.0 + R-12.5 c.i.	EN7, 17, 19, 21	
		Metal building	R-0.0 + R-19.0 c.i.	EN8, 17, 19, 21	
		Below-grade walls	R-10.0 c.i.	EN9, 17, 19, 21–22	
	Floors	Mass	R-16.7 c.i.	EN10, 17, 19, 21	
		Steel joint	R-38.0	EN11, 17, 19, 21	
		Wood framed and other	R-38.0	EN11, 17, 19, 21	
	Slabs	Unheated	R-20.0 for 24 in.	EN12, 14, 17, 19, 21–22	
		Heated	R-20.0 for 48 in.	EN13–14, 17, 19, 21–22	
	Doors	Swinging	U-0.50	EN15, 17–18	
		Nonswinging	U-0.50	EN16–17	
	Vestibules	At building entrance	Yes	EN18	
	Continuous Air Barriers	Continuous air barrier	Entire building envelope	EN17	
	Vertical Fenestration	WWR	20% to 40%	EN25; DL6	
		Window orientation	Area of W and E windows each less than area of S windows (N in southern hemisphere)	EN30–31	
		Exterior sun control (S, E, and W only)	No recommendation	None	
		Thermal transmittance	Nonmetal framing windows = U-0.35 Metal framing windows = U-0.39	EN23–24	
		SHGC	Nonmetal framing windows = 0.35 Metal framing windows = 0.38	EN24, 32–33; DL12	
	Daylighting	Light-to-solar-gain ratio	Minimum VT/SHGC = 1.10	EN34–40	
		Vertical fenestration EA	0.12	DL7–11	

ASHRAE AEDG: 30% savings in small offices

Climate Zone 6 Recommendation Table

	Item	Component	Recommendation	How-To's in Chapter 4
Envelope	Roof	Insulation entirely above deck	R-20 c.i.	EN2, 17, 20-21
		Metal building	R-13 + R-19	EN3, 17, 20-21
		Attic and other	R-38	EN4, 17-18, 20-21
		Single rafter	R-38 + R-5 c.i.	EN5, 17, 20-21
		Surface reflectance/emittance	No recommendation	
	Walls	Mass (HC > 7 Btu/ft^2)	R-11.4 c.i.	EN6, 17, 20-21
		Metal building	R-13 + R-13	EN7, 17, 20-21
		Steel framed	R-13 + R-7.5 c.i.	EN8, 17, 20-21
		Wood framed and other	R-13 + R-3.8 c.i.	EN9, 17, 20-21
		Below grade walls	R-7.5 c.i.	EN10, 17, 20-21
	Floors	Mass	R-10.4 c.i.	EN11, 17, 20-21
		Steel framed	R-30	EN12, 17, 20-21
		Wood framed and other	R-30	EN12, 17, 20-21
	Slabs	Unheated	R-10 for 24 in	EN13, 17, 19-21
		Heated	R-10 for 36 in.	EN14, 17, 19-21
	Doors	Swinging	U-0.70	EN15, 20-21
		Non-swinging	U-0.50	EN16, 20-21
	Vertical Glazing	Window to wall ratio (WWR)	20% to 40% maximum	EN23, 36-37
		Thermal transmittance	U-0.42	EN25, 31
		Solar heat gain coefficient (SHGC)	N, S, E, W - 0.46 / N only - 0.46	EN27-28
		Window orientation	$(A_N * SHGC_N + A_S * SHGC_S) > (A_E * SHGC_E + A_W * SHGC_W)$	A_x–Window area for orientation x EN26-32
		Exterior sun control (S, E, W only)	No recommendation	EN24, 28, 30, 36, 40, 42 DL5-6
	Skylights	Maximum percent of roof area	3%	DL5-7, DL8, DL13
		Thermal transmittance	U-0.69	DL7, DL8, DL13
		Solar heat gain coefficient (SHGC)	0.49	DL8, DL13

ASHRAE AEDG: 50% savings in small offices

- "How to" guides in the AEDG

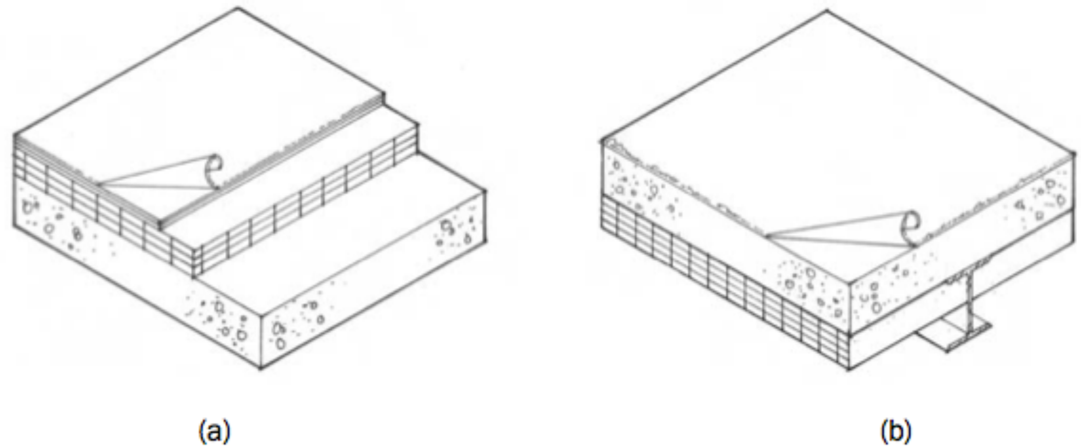


Figure 5-8 (EN10) Mass Floors—(a) Insulation Above Slab and (b) Insulation Below Slab
Any floor with a HC exceeding 7 Btu/ft^2·°F.

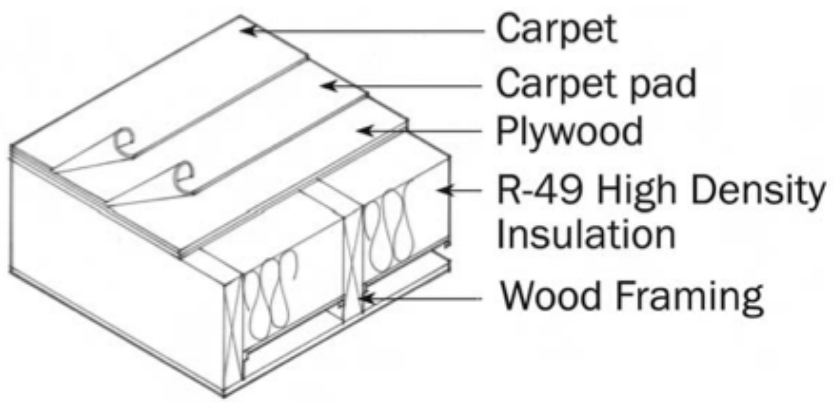


Figure 5-9 (EN11) Wood-Frame Floors

ASHRAE AEDG: 50% savings in small offices

EN17 ***Air Infiltration Control*** **(Climate Zones: all)**

The building envelope should be designed and constructed with a continuous air barrier system to control air leakage into or out of the conditioned space and should extend over all surfaces of the building envelope (at the lowest floor, exterior walls, and ceiling or roof). An air barrier system should also be provided for interior separations between conditioned space and space designed to maintain temperature or humidity levels that differ from those in the conditioned space by more than 50% of the difference between the conditioned space and design ambient conditions. If possible, a blower door should be used to depressurize the building to find leaks in the infiltration barrier. At a minimum, the air barrier system should have the following characteristics.

- It should be continuous, with all joints made airtight.
- Air barrier materials used in frame walls should have an air permeability not to exceed 0.004 cfm/ft^2 under a pressure differential of 0.3 in. w.c. (1.57 lb/ft^2) when tested in accordance with ASTM E 2178 (ASTM 2003).
- The system should be able to withstand positive and negative combined design wind, fan, and stack pressures on the envelope without damage or displacement and should transfer the load to the structure. It should not displace adjacent materials under full load.
- It should be durable or maintainable.
- The air barrier material of an envelope assembly should be joined in an airtight and flexible manner to the air barrier material of adjacent assemblies, allowing for the relative movement of these assemblies and components due to thermal and moisture variations, creep, and structural deflection.
- Connections should be made between the following:
  - Foundation and walls
  - Walls and windows or doors
  - Different wall systems
  - Wall and roof
  - Wall and roof over unconditioned space

ASHRAE AEDG: 50% savings in small offices

EN31 ***Window Orientation*** **(Climate Zones: 4 5 6 7 8)**

Only the south glass receives much sunlight during the cold winter months. If possible, maximize south-facing windows by elongating the floor plan in the east-west direction and relocate windows to the south face. Careful configuration of overhangs or other simple solar control devices will allow for passive heating when desired but prevent unwanted glare and solar overheating in the warmer months. To improve performance, operable shading systems should be employed that achieve superior daylight harvesting and passive solar gains and also operate more effectively when facing east and west directions. Unless such operable shading systems are used, glass facing east and west should be significantly limited. Areas of glazing facing north should be optimized for daylighting and view and focus on low U-factors to minimize heat loss and maintain thermal comfort by considering triple glazing to eliminate drafts and discomfort. During early building configuration studies and predesign, preference should be given to sites that permit elongating the building in the east-west direction and that permit orienting more windows to the south. See DL5 and DL6 for more information on building orientation and shape as they relate to daylighting strategies.

EN32 ***Passive Solar*** **(Climate Zones: 4 5 6 7 8)**

Passive solar energy-saving strategies should be limited to nonpermanently occupied spaces such as lobbies and circulation areas, unless those strategies are designed so that the occupants are not affected by direct beam radiation. Consider light-colored blinds, blinds within the fenestration, light shelves, or silk screen ceramic coating (frit) to control solar heat gain. In spaces where glare is not an issue, the usefulness of the solar heat gain collected by these windows can be increased by using hard massive and darker-colored floor surfaces such as tile or concrete in the locations where the transmitted sunlight will fall. These floor surfaces absorb the transmitted solar heat gain and release it slowly over time, providing a more gradual heating of the structure. Consider higher SHGC and low-e glazing with optimally designed exterior overhangs.

ASHRAE 189.1

1. PURPOSE

The purpose of this standard is to provide minimum requirements for the siting, design, construction, and plan for operation of high-performance green buildings to:

a. balance environmental responsibility, resource efficiency, occupant comfort and well being, and community sensitivity, and
b. support the goal of development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

ANSI/ASHRAE/USGBC/IES
Standard 189.1-2011

Standard for the Design of High-Performance Green Buildings

Except Low-Rise Residential Buildings

ASHRAE 189.1

- Mandatory provisions
- Prescriptive options
- Performance options

ANSI/ASHRAE/USGBC/IES Standard 189.1-2011
Standard for the Design of High-Performance Green Buildings
Except Low-Rise Residential Buildings

SECTION **PAGE**

ASHRAE 189.1: Energy efficiency provisions

Mandatory

- Must comply with ASHRAE 90.1
- Must have space for future on-site renewables
- Must collect energy use data

Prescriptive

- Requirements in 189.1 supersede 90.1
- Must have on-site renewables (20 kWh/m^2)

189.1 envelope requirements

TABLE A-6 (Supersedes Table 5.5-6 in ANSI/ASHRAE/IES Standard 90.1)
Building Envelope Requirements for Climate Zone 6 (A, B) (I-P)

	Nonresidential		Residential		Semiheated	
	Assembly	Insulation	Assembly	Insulation	Assembly	Insulation
Opaque Elements	Max.	Min. R-Value	Max.	Min. R-Value	Max.	Min.R-Value
Roofs						
Insulation Entirely above Deck	U-0.032	R-30.0 ci	U-0.032	R-30.0 ci	U-0.063	R-15.0 ci
Metal Building	U-0.031	R-25.0 + R-11.0 Ls	U-0.031	R-25.0 + R-11.0 Ls	U-0.068	R-13.0 +R- 19.0
Attic and Other	U-0.021	R-49.0	U-0.021	R-49.0	U-0.027	R-38.0
Walls, Above Grade						
Mass	U-0.071	R-15.2 ci	U-0.060	R-20.0 ci	U-0.104	R-9.5 ci
Metal Building	U-0.052	R-13.0 + R-13.0 ci	U-0.052	R-13.0 + R-13.0 ci	U-0.079	R-13.0 + R-6.5 ci
Steel Framed	U-0.055	R-13.0 + R-10.0 ci	U-0.055	R-13.0 + R-10.0 ci	U-0.084	R-13.0 + R-3.8 ci
Wood Framed and Other	U-0.045	R-13.0 + R-10.0 ci	U-0.045	R-13.0 + R-10.0 ci	U-0.064	R-13.0 + R-3.8 ci
Wall, Below Grade						
Below Grade Wall	C-0.092	R-10.0 ci	C-0.092	R-10.0 ci	C-0.119	R-7.5 ci
Floors						
Mass	U-0.057	R-14.6 ci	U-0.051	R-16.7 ci	U-0.107	R-6.3 ci
Steel Joist	U-0.032	R-38.0	U-0.023	R-38.0 + R-12.5 ci	U-0.038	R-30.0
Wood Framed and Other	U-0.026	R-30.0 + R-7.5 ci	U-0.026	R-30.0 + R-7.5 ci	U-0.033	R-30.0
Slab-On-Grade Floors						
Unheated	F-0.520	R-15 for 24 in.	F-0.510	R-20 for 24 in.	F-0.540	R-10 for 24 in.
Heated	F-0.440	R-15.0 for 36 in. + R-5 ci below	F-0.440	R-15.0 for 36 in. + R-5 ci below	F-0.900	R-10 for 24 in.

189.1 envelope requirements

Opaque Doors						
Swinging	U-0.400		U-0.400		U-0.600	
Non-Swinging	U-0.400		U-0.400		U-0.500	
	Assembly	**Assembly**	**Assembly**	**Assembly**	**Assembly**	**Assembly**
Fenestration	**Max. U**	**Max. SHGC**	**Max. U**	**Max. SHGC**	**Max. U**	**Max. SHGC**
Vertical Fenestration, 0%–40% of Wall						
Nonmetal framing: all[b]	U-0.25	SHGC-0.40 all	U-0.25	SHGC-0.40 all	U-0.45	SHGC-NR all
Metal fr: curtainwall/storefront[c]	U-0.35		U-0.35		U-0.50	
Metal framing: entrance door[c]	U-0.70		U-0.70		U-0.80	
Metal framing: all other[c]	U-0.45		U-0.45		U-0.55	
Skylight with Curb, Glass, % of Roof						
0%–2.0%	U_{all}-0.67	$SHGC_{all}$-0.46	U_{all}-0.67	$SHGC_{all}$-0.46	U_{all}-1.98	$SHGC_{all}$-NR
2.1%–5.0%	U_{all}-0.67	$SHGC_{all}$-0.46	U_{all}-0.67	$SHGC_{all}$-0.46	U_{all}-1.98	$SHGC_{all}$-NR
Skylight with Curb, Plastic, % of Roof						
0%–2.0%	U_{all}-0.69	$SHGC_{all}$-0.49	U_{all}-0.69	$SHGC_{all}$-0.49	U_{all}-1.90	$SHGC_{all}$-NR
2.1%–5.0%	U_{all}-0.69	$SHGC_{all}$-0.49	U_{all}-0.69	$SHGC_{all}$-0.49	U_{all}-1.90	$SHGC_{all}$-NR
Skylight without Curb, All, % of Roof						
0%–2.0%	U_{all}-0.45	$SHGC_{all}$-0.46	U_{all}-0.45	$SHGC_{all}$-0.39	U_{all}-1.36	$SHGC_{all}$-NR
2.1%–5.0%	U_{all}-0.45	$SHGC_{all}$-0.46	U_{all}-0.45	$SHGC_{all}$-0.39	U_{all}-1.36	$SHGC_{all}$-NR

The following definitions apply: ci = continuous insulation, Ls = *liner system*, NR = no (insulation) requirement.
[a] Mass *walls* with a heat capacity greater than 12 Btu/ft^2·°F which are unfinished or finished only on the interior do not need to be insulated.
[b] Nonmetal framing includes framing materials other than metal with or without metal reinforcing or cladding.
[c] Metal framing includes metal framing with or without thermal break. The all other subcategory includes operable windows, fixed windows, and non-entrance doors.

Passive House

- A Passive House is a very well-insulated, virtually air-tight building that is primarily heated by passive solar gain and by internal gains from people and equipment
- Performance characteristics:
  - Airtight shell: 0.6 ACH @ 50 Pa
  - Annual heating requirement less than 15 kWh/m^2 (4.75 kBTU/ft^2)
  - Primary energy less than 120 kWh/m^2 (38.1 kBTU/ft^2)
  - Window u-value less than 0.8 W/m^{2}K (0.15 Btu/hrft^{2}F)
  - Ventilation system with heat recovery greater than 75%
  - Thermal bridge free construction

PHIUS
Passive House Institute US

ENCLOSURE COMMISSIONING

Building enclosure commissioning

- An important component related to codes and standards is actual **commissioning** of the building envelope
  - Commissioning is the process of ensuring that systems are designed, installed, functionally tested, and capable of being operated and maintained to perform in conformity with the design intent

- The only way to prove that what is on paper exists in reality

Guidelines and standards:

- National Institute of Building Sciences NIBS Guideline 03
  - Building Enclosure Commissioning Process (BECx)
  - http://www.wbdg.org/ccb/browse_doc.php?d=7167
- ASTM E-2813-12 Standard for Enclosure Commissioning

Building enclosure commissioning

Keys to enclosure performance:

- Design – plans and specifications
- Review of the enclosure design
- Preconstruction qualification of contractors, materials, and subs
- Enclosure coordination programs – field testing of mockups
- Construction QA/QC
- Field inspection and testing

ASTM E2813-12

- Standard Practice for Building Enclosure Commissioning

Designation: E2813 – 12

Standard Practice for Building Enclosure Commissioning[1]

This standard is issued under the fixed designation E2813; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

Building Enclosure Commissioning (BECx) is a process that begins with the establishment of the Owner's Project Requirements (OPR) and endeavors to ensure that the exterior enclosure and those elements intended to provide environmental separation within a building or structure meet or exceed the expectations of the Owner as defined in the OPR. A fundamental understanding of the most current published edition of ASHRAE Guideline 0 and NIBS Guideline 3 is recommended for optimal use and application of this practice.

1. Scope

1.1 This practice is intended to serve as a concise, authoritative, and technically sound practice for Building Enclosure Commissioning (BECx) that establishes two levels of BECx: *Fundamental* and *Enhanced* (refer also to Section 4).

1.2 The BECx process as defined in this practice includes the following phases and sub-phases:

1.2.1 Pre-design,

1.2.2 Design,

1.2.2.1 Schematic Design,

1.2.2.2 Design Development,

1.5 This practice mandates independent, third-party design peer review during the Design Phase of both Fundamental and Enhanced BECx.

1.6 This practice recognizes that the OPR for exterior enclosure performance and environmental separation may exceed the baseline requirements of applicable building codes and standards and provides guidance for the development of an OPR based on the following attributes as defined in Annex A1 of this practice:

1.6.1 Energy,

1.6.2 Environment,

1.6.3 Safety,

ASTM E2813-12

1.1 This practice is intended to serve as a concise, authoritative, and technically sound practice for Building Enclosure Commissioning (BECx) that establishes two levels of BECx: *Fundamental and Enhanced (refer also to Section 4).*

1.2 The BECx process as defined in this practice includes the following phases and sub-phases:
1.2.1 Pre-design,
1.2.2 Design,
1.2.2.1 Schematic Design,
1.2.2.2 Design Development,
1.2.2.3 Construction Documentation,
1.2.3 Pre-Construction,
1.2.4 Construction, and
1.2.5 Occupancy and Operations

ASTM E2813-12

1.3 This practice includes a mandatory OPR Development Guideline (Annex A1) and requires the development of an OPR for both Fundamental and Enhanced BECx that addresses, at a minimum, the performance attributes and metrics included in Annex A1 of this practice.

1.4 This practice includes mandatory BECx Performance Testing Requirements (Annex A2) approved for use with this practice to evaluate the performance and durability of enclosure materials, components, systems, and assemblies.

A1. OPR DEVELOPMENT GUIDELINE

A1.1 The OPR is a written document that includes the programmatic, aesthetic, and functional performance requirements of a building or structure and the expectations of the Owner relative to its intended use, occupancy, operation, and service-life.

ASTM E2813-12

A1.1.1 - Development of the OPR must include, at a minimum, documented and verifiable consideration of the following attributes:

(1) Energy
(2) Environment
(3) Safety
(4) Security
(5) Durability
(6) Sustainability
(7) Operation

A2.1 - Table A2.1 includes an outline of the minimum required tests for *Fundamental and Enhanced BECx* as defined by this practice. The minimum number of tests required to achieve *Fundamental or Enhanced BECx* refers to the number of tests required per unique type of enclosure element as defined by the *AOR in consultation with the BECxA,*

A2.2 - Mandatory field tests are indicated in Table A2.1 with a check mark ("✓"), followed by the minimum number of tests required to achieve either *Fundamental or Enhanced BECx.*

ASTM E2813-12

Property	Standard Designation	Title	Lab System Testing	Enhanced: Field Mockup Testing[A]	Enhanced: In-Situ Field Testing	Fundamental: Field Mockup Testing	Fundamental: In-Situ Field Testing
		Water Penetration					
Water penetration	ASTM E331	Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference	L (M)	. . .	. . .	. . .	. . .
	ASTM E514	Test Method for Water Penetration and Leakage Through Masonry	OL	(OF)	(OF)	(OF)	(OF)
	ASTM C1601	Test Method for Field Determination of Water Penetration of Masonry Wall Surfaces	. . .	(OF)	(OF)	(OF)	(OF)
	ASTM D5957[F]	Guide for Flood Testing Horizontal Waterproofing Installations	. . .	(OF)	✓ (All horizontal surfaces)	(OF)	✓ (All horizontal surfaces)
Static water penetration	ASTM E1105	Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform or Cyclic Static Air Pressure Difference	. . .	✓ (1X)	✓ (2X)	✓ (1X)	✓ (1X)
Dynamic water penetration	AAMA 501.1	Standard Test Method for Water Penetration of Windows, Curtain Walls, and Doors Using Dynamic Pressure	OL (M)	(OF)	✓ (1X)	(OF)	(OF)
	ASTM E2268[G]	Standard Test Method for Water Penetration of Exterior Windows, Skylights, and Doors by Rapid Pulsed Air Pressure Difference	OL	(OF)	(OF)	(OF)	(OF)
	AAMA 501.2	Quality Assurance and Diagnostic Water Leakage Field Check of Installed Storefronts, Curtain Walls, and Sloped Glazing Systems	. . .	✓ (1X)	✓ (1X)	✓ (1X)	✓ (1X)

NIBS Building Enclosure Commissioning

- Mock-up testing
  - The contractor has to direct subs in constructing mock-up for review by the architect/engineer

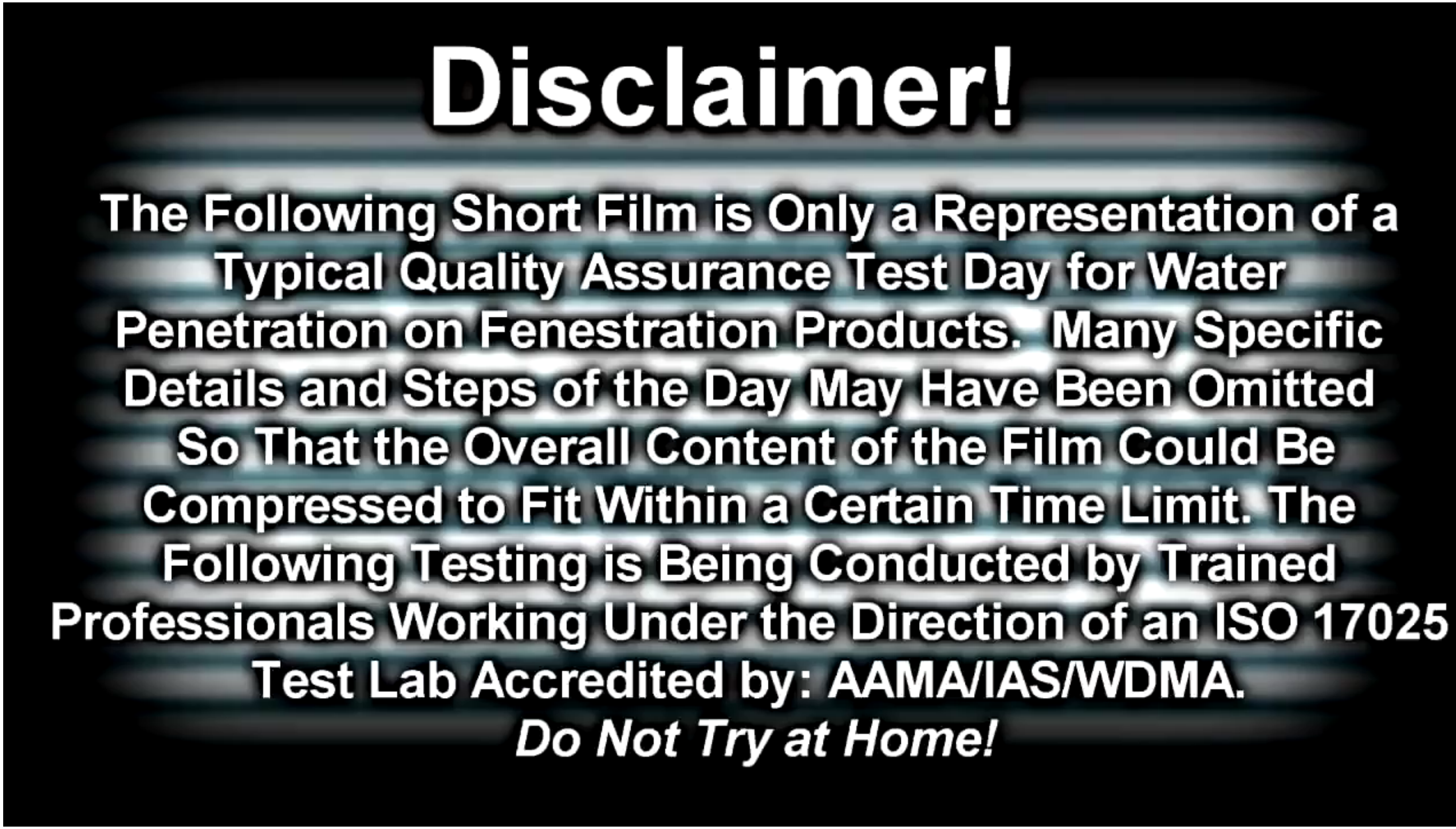


NIBS Building Enclosure Commissioning

NIBS Building Enclosure Commissioning

Typical E1105 Field Test Set-Up
Exterior Pressure Chamber

ASTM E1105 water penetration test demos



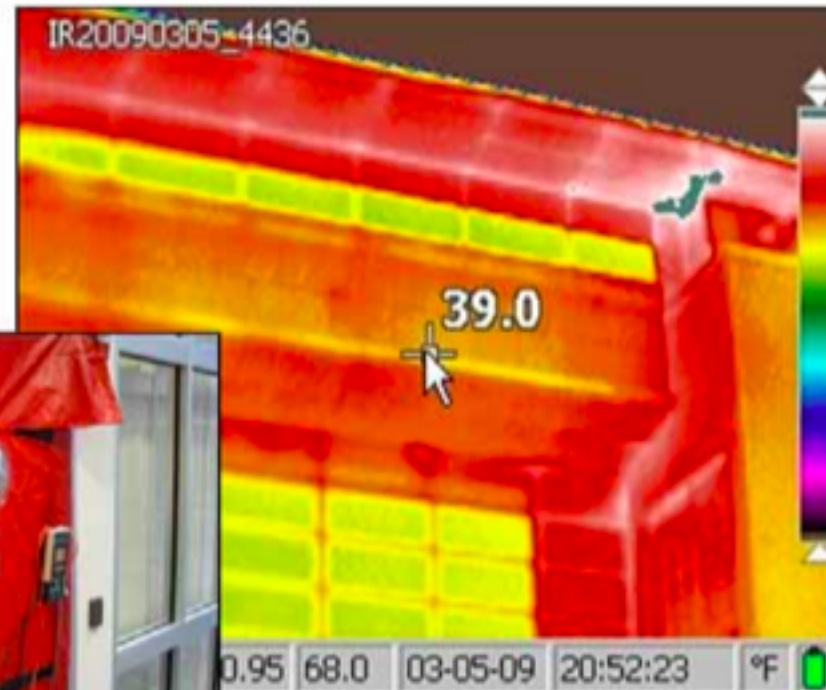
http://www.youtube.com/watch?v=MbRPoTK_BFo

ASTM E1105 water penetration test demos

http://www.youtube.com/watch?v=edvKJrytu5c

NIBS Building Enclosure Commissioning

- Testing for air leakage
  - ASTM E 779 Air leakage by fan pressurization
  - ASTM E 1827 Air tightness by blower door
- Defined performance: cfm/ft^2



NIBS Building Enclosure Commissioning

- ASTM C1601 Determination of water penetration of masonry wall surfaces

- Provides an estimate of the rate of water penetration through masonry
- Useful quality control test
- Provides quantitative method to evaluate installation methods
- A/E-Defined performance

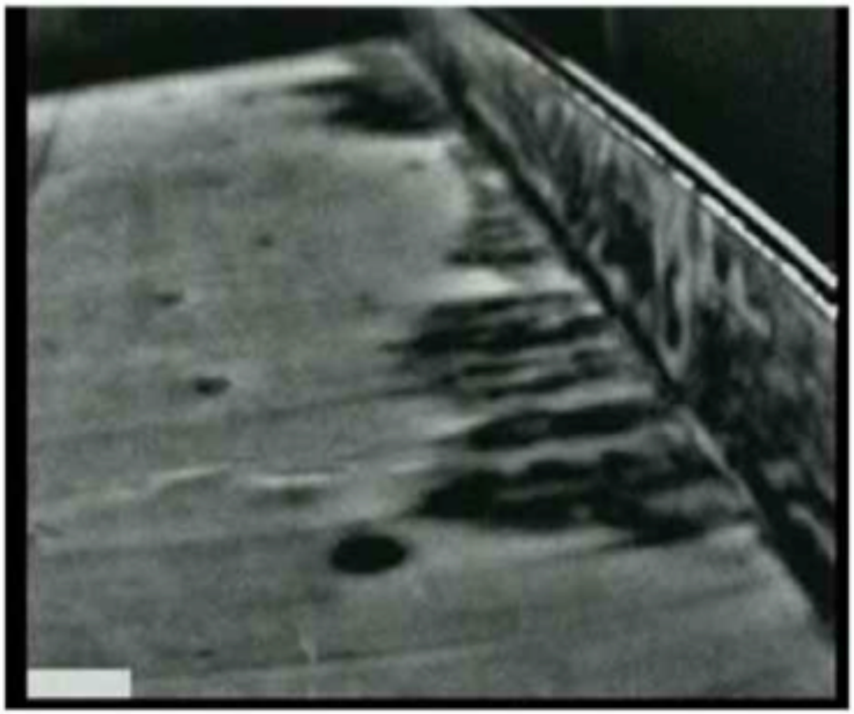
NIBS Building Enclosure Commissioning

ASTM C1715 -Standard Test Method for Evaluation of Water Leakage Performance of Masonry Wall Drainage Systems

- Water Volume Calculated From ASTM C1601 Test Results & Introduced Through Tubes
- Useful For Testing Flashing Lines to Assess Global Flashing Performance
- Removes Variables Other Than Flashing Performance
- Provides No Quantitative Data

NIBS Building Enclosure Commissioning

ASTM C1153 – Standard Practice for Location of Wet Insulation in Roofing Systems Using Infrared Imaging



- Surveyed Post Construction
- Locate Defective Installation
- Isolate Non-Functional Details
- Verify Extent of Construction Damage or Trapped Water
- Provide Baseline Survey for Future Data Collection

GLAZING AND WIND LOADS

Standards

Wind loads for exterior cladding

- In addition to the main building structure, the building enclosure (cladding) must also be able to handle the pressure variations and differentials that are created by the wind
  - Cladding elements include wall panels, fenestration, roof components and membranes

- We don't have time to discuss in detail, but will discuss the cladding wind load requirements in the Chicago Building Code (and the International Building Code)

Steps for wind load design

1. Determine the design wind pressures on the building enclosure elements
   – This will vary from code to code, but many refer back to ASCE 7 *Minimum Design Loads for Buildings and Other Structures*
2. Determine the allowable pressures of the cladding components
   – This can come from manufacturers data or using ASTM or other standards
3. Ensure that the allowable pressures exceed the design wind pressures

Chicago wind loads

- The City of Chicago has prescribed design wind loads in Table 13.52.310 of the Municipal Code:

Height (ft)	A: Main wind force resisting system (lb/ft^2)	B: Cladding Wind Pressure (other than corner) (lb/ft^2)	C: Cladding Wind Pressure (corner) (lb/ft^2)
200 or less	20	25	30
300	21	27	32
400	25	32	38
500	28	35	41
600	31	39	49
700	33	42	49
800	36	45	54
900	39	49	58
1000	42	53	63

- Column (A) applies to the main structure
- Column (B) applies to non-corner cladding (e.g., windows, curtain walls, exterior cavity walls, and wall panel units)
- The corner pressures in Column (C) apply at each corner of the building for a distance of 10% of building width or 50% of height above grade, whichever is smaller

Notes for Table 13.52.310

- Reductions in wind pressure due to neighboring structures and terrain are not to be considered
- The height is to be measured above the average level of the ground adjacent to the building or structure
- Wind pressures should be linearly interpolated between table values
- Example:
  - Q: What are the maximum cladding design wind loads for a 280 feet tall in Chicago?
  - A: We interpolate between the 200 feet and 300 feet and round up to be safe and find the design wind load is:
    - 32 lb/ft^2 (psf)

ASTM E 1300

- How do you tell if your cladding (e.g., glazing unit) can withstand that load?

INTERNATIONAL

Designation: E 1300 – 09a

Standard Practice for
Determining Load Resistance of Glass in Buildings[1]

This standard is issued under the fixed designation E 1300; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

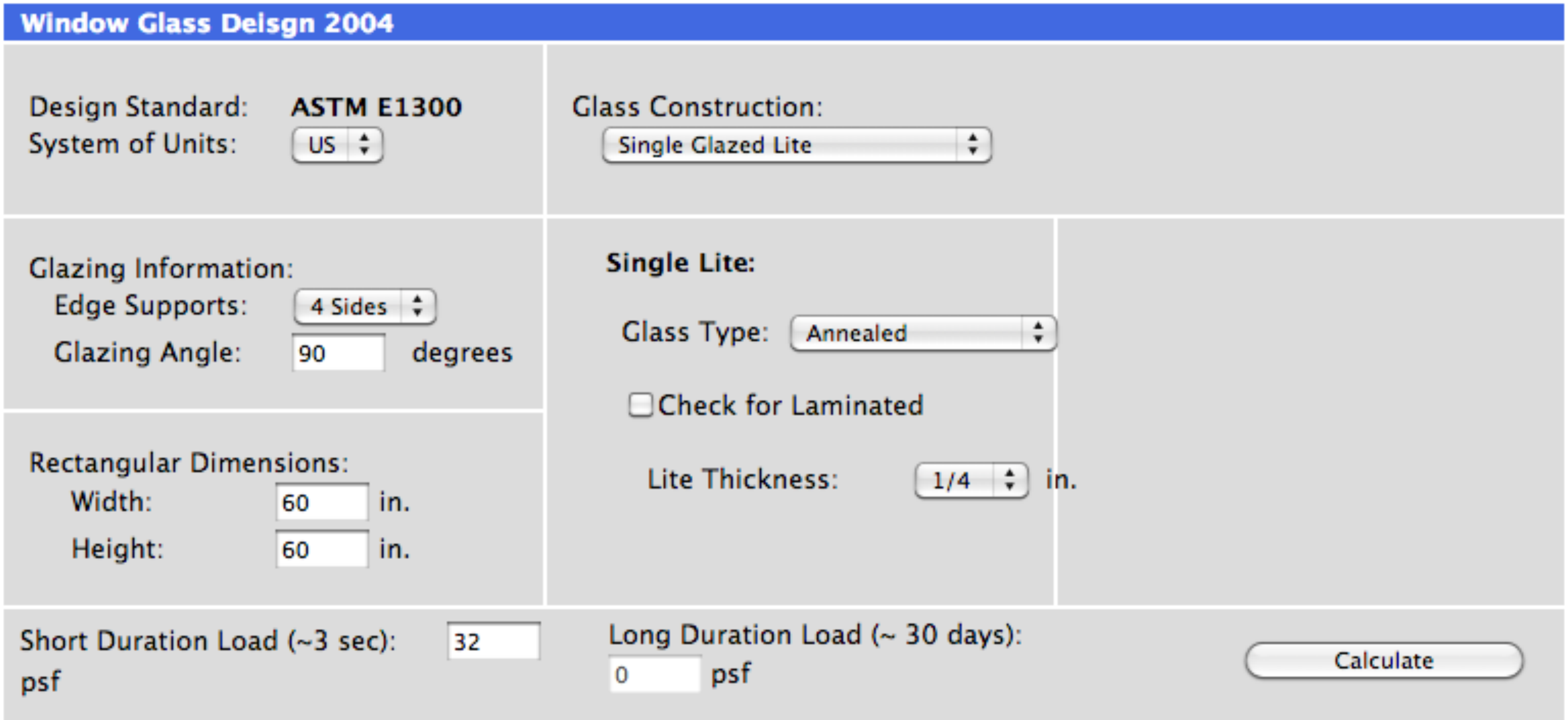
  - This standard describes procedures to determine the load resistance of specified glass types including combinations of glass types used in sealed insulating glass units

Short- and long-duration loads

- ASTM E1300 can be used for both short and long duration loads
  - Short duration loads are 3 sec or less (e.g., wind gusts)
  - Long duration loads are those lasting about 30 days
    - Snow loads are long duration loads

- The load calculation procedure is long and involved
  - But like most things, there's an online calculator
    - http://www.standardsdesign.com/wgd/2004/demos/calculator/wgd2004calculator.aspx

Load calculator



http://www.standardsdesign.com/wgd/2004/demos/calculator/wgd2004calculator.aspx

Load calculator

Results – Single Glazed (Monolithic)

Short Duration Load, Resistance and Deflection Data

Load (~3 sec):	32.0	psf
Load Resistance:	45	psf
Approximate center of glass deflection under the applied load:	0.58	in.

Long Duration Load, Resistance and Deflection Data

Comments

Based on your design information, the load resistance is greater than or equal to the specified loading.

-- Approximate Probability of Breakage (Short Duration Load Only): 2/1000

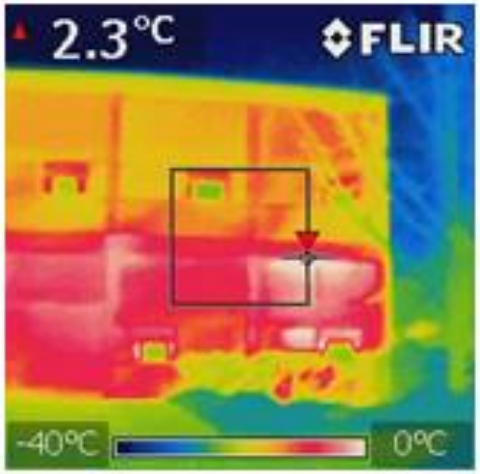
http://www.standardsdesign.com/wgd/2004/demos/calculator/wgd2004calculator.aspx

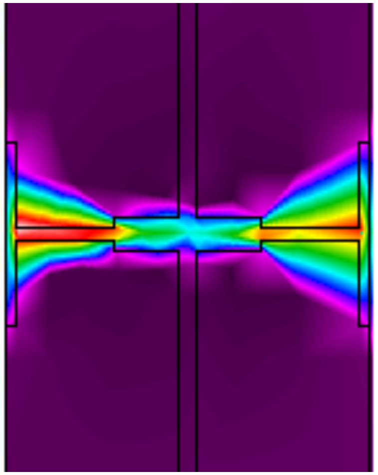
COURSE WRAP-UP

Course information

Course Catalog Description

- Design of building exteriors, including the control of heat flow, air and moisture penetration, building movements, and deterioration. Study of the principle of rain screen walls and of energy conserving designs. Analytical techniques and building codes are discussed through case studies and design projects.





Course objectives

To introduce students to the design of building enclosures (i.e., "building envelopes"), elements of which include walls, floors, roofs, and intentional openings. By taking this course students will be able to:

1. Design and assess building enclosure elements for heat transfer, airflow, and moisture control
2. Be proficient in current building codes as they pertain to building enclosure design
3. Critically analyze designs for advanced building enclosures for their impacts on energy use, airflow, and potential moisture issues
4. Be proficient with several software tools used in building enclosure design

Course re-cap

- Building science review
  - k, L, U, R, h_{conv}, α, ε, T
- Surface energy balances and energy exchanges
- Solar orientation
- Complex conduction
  - Thermal bridges, parallel path, 2-D (THERM), thermal mass, transient conduction
- Moisture flows
  - Hand calculations, WUFI
- Moisture management
- Air movements
  - Infiltration modeling, blower door testing
- Fenestration and designing with glazing
- Energy simulation in enclosure design
  - eQUEST, BEopt + EnergyPlus
- Codes, standards, and applications
- High performance enclosure research reports (next)

Course evaluations

- Available online now in MyIIT
- Very important that you complete the evaluation
  - It's the only way I get graded
  - It's the only way our courses get graded
  - It's one of the best ways for us to improve courses/ teaching
  - It's anonymous

- We usually only get about 50% response rate
  - Let's try to do better than this
    - We're at 55% now
  - If you have an internet connection you can do it right now

Next lecture

- Guest lecture from Bruce Kaskel, Principal, WJE

Bruce S. Kaskel
Principal

PRACTICE AREAS
Leakage Investigation
Glass Performance
Exterior Wall Systems
Curtain Walls and Windows

10 South LaSalle Street
Suite 2600
Chicago, IL 60603
Tel: (312) 372-0555 | Fax: (312) 372-0873
email@wje.com: bkaskel

WJE

Thank you!

- Related upcoming courses for Fall 2016:
  - CAE 515 Building Energy Modeling (Julide Demirdoven)
  - ENVE 576 Indoor Air Pollution (Stephens)
  - CAE 513 Building Science (Stephens)
  - CAE *TBD* DOE Race to Zero Sustainable Home Design Competition