CAE 463/524
Building Enclosure Design
Fall 2012

Lecture 11: November 12, 2012
Energy use and the enclosure

Dr. Brent Stephens, Ph.D.
Department of Civil, Architectural and Environmental Engineering
Illinois Institute of Technology
brent@iit.edu
Built Environment Research Group
www.built-envi.com

Housekeeping: campus projects

- Campus projects due today
  - Email me PDF copy if you haven't already
    - Or upload to BB digital dropbox
    - Or give me a USB flash drive, CD, or DVD

Team	Member 1	Member 2	Member 3	Architect
1 - Siegel Hall	Angulo, Melissa	Diaz, Nestor	El Orch, Zeineb	Mies, 1956
2 - Alumni Hall	Russo, Lynda	Daras Ballester, Alejandro	Kayo, Luciana	Mies, 1945
3 - Crown Hall	Sebastian, Dan	Gomez Soriano, Maria	Gonzalez, Arturo	Mies, 1950
4 - Hermann Hall	Vagner, Inna	Diaz, Giovanni	Espinoza, Juan	SOM, 1962
5 - Stuart	Mcgreal, Tommy	Mejia, Jennifer	Morris, Frank	Goldsmith, 1971
6 - Life Sciences	Huo, Yechen	Wright, Mike	Zwang, Stuart	Goldsmith, 1966
7 - MTCC	Gonzalez, Alvaro	Foley, Patrick	Zylstra, Robert	Koolhaas, 2003

Housekeeping: Final project due in 2 weeks

- Final project report due 11/26 in class (35% of your grade)
  - Expectations are on Blackboard
  - Goal is to produce professional 8-page (single-spaced) conference paper with clear and concise text and figures
    - Can be longer, but additional items go in an appendix
    - Grade primarily comes from main document (not appendices)
    - Turn in one report per team
  - **Submit one electronic copy in PDF to me (or BB) on 11/26**

Final Report **-** There is a strict limit of 8 pages (maximum 12 pt font, single spaced, 1" margins), including all figures and tables. The page limit does not include references. Appendices are allowed, but will not improve your grade. **250/350**

Evaluation:	Creativity and innovation	10%
	Follows specified format	10%
	Clear justification and explanation of your ideas and motivation	20%
	Quality of references	10%
	Solid technical basis for your project	20%
	Depth of investigation	30%

Housekeeping: final project presentations

- Each group will present one 12-minute presentation
  - With a few minutes for Q&A (15-minute blocks)

Oral Presentation – Your group will give a 12-minute oral PowerPoint presentation to the class (12 minute presentation, 3 minutes for questions) on your topic. Ideally, both of you will share the presentation. For those of you that can attend class regularly but may be working with an online student who cannot, think early about how to share the workload. It is fine for only one person to present, but if that is the case, the other should take a larger share of some of the project report. **100/350**

Evaluation:	Quality of visuals	20%
	Quality of speaking	20%
	Response to questions	20%
	Depth of presentation	20%
	Explanation of logic and motivation	20%

Both members of a group will receive the same grade on all portions. However, individual grades will be adjusted depending on your partner's evaluation of your level of effort on the project. Any disputes will be handled prior to submitting final grades.

Housekeeping: final project presentations

- 12-minute presentations
  - Some in class on 11/26 in class
  - Some during finale exam period on 12/3, 7:30-9:30 PM
    - In our regular classroom, Stuart 204
- Presentation schedule:

Team	Member	Member	Topic	11/26 or 12/3?
1	Russo	Foley	Green roofs	
2	Vagner	Diaz	Electrochromic windows	12/3
3	Espinoza	Wright	Cool roofs	
4	Angulo	Huo	Double skin facades	12/3
5	Sebastian	Morris	Phase change materials	11/26
6	Kayo	Gonzalez, Alv	Building integrated photovoltaics	11/26
7	Zwang	Gomez Soriano	Exterior insulated finish systems	11/26
8	El Orch	Gonzalez, Ar	Strawbale construction	11/26
9	Mcgreal	Diaz	Conventional construction	12/3
10	Daras Ballester	Zylstra	High performance glass	11/26
11	Mejia	n/a	Sun shading and thermal mass	12/3

Today's lecture

- Last time:
  - Heat transfer in floors and roofs
    - Below-grade and on-grade floors
    - Roof temperature model
    - Attic heat transfer
  - Began thermal mass
- Today:
  - Finish thermal mass
  - Energy use and the enclosure
    - Energy modeling + meeting energy codes and standards

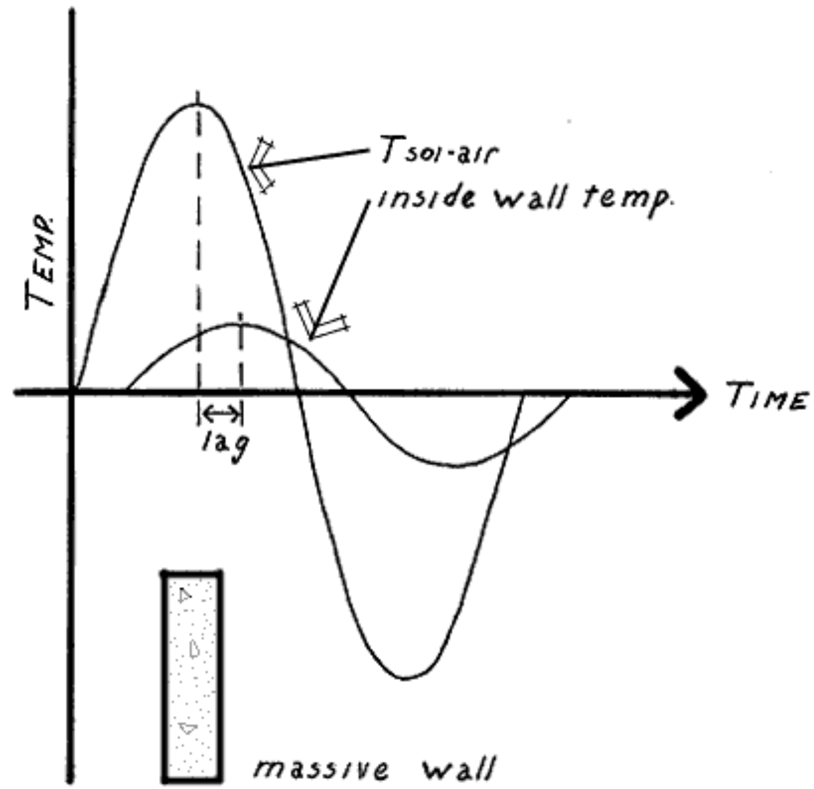
(FINISHING) THERMAL MASS

Heat storage and release

Thermal mass

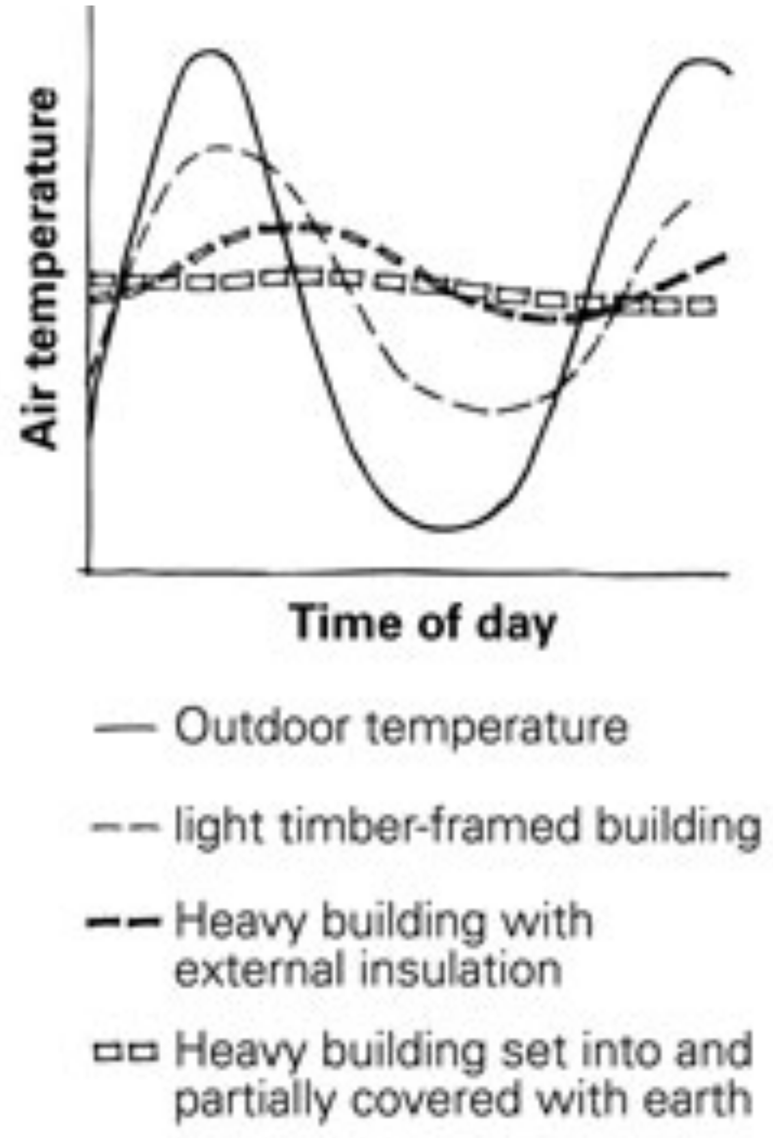
- Thermal mass refers to materials that have the capacity to store thermal energy for extended periods of time

- Thermal mass can be used effectively to absorb daytime heat gains
  - Reduces peak cooling load
  - Releases heat during the night (can reduce heat load)
  - Can be both useful and detrimental to maintaining thermal comfort



Thermal mass: Why do we care?

- A high thermal mass will be slow to heat up
  - But also slow to cool down
  - Can store large amounts of heat
- The result is that exterior temperatures can fluctuate greatly
  - But the interior temperature will fluctuate less
  - It is interior surface temperatures that ultimately impact HVAC loads and energy use



Heat Capacity, HC

- The heat capacity (HC) of a material is the product of the density, specific heat capacity, and width of the material:
  - $HC = \rho L C_p$ [J/m^{2}K]
  - HC is a measure of the ability of a material to store energy per unit area
    - L = length [m]
    - ρ = density [kg/m^3]
    - C_p = specific heat capacity [J/kgK]
  - You sometimes also see $HCA = \rho L C_p A = \rho C_p V$ [J/K]
- Heat capacity is important to thermal mass, but needs to be compared with thermal conductivity to get the whole story

Thermal Diffusivity, α

- Thermal diffusivity, α, is the measure of how fast heat can travel through an object
- α is proportional to conductivity but inversely proportional to density and specific heat:

$$\alpha = \frac{k}{\rho C_p} \quad [\mathrm{m}^2/\mathrm{s}]$$

- The lower the α, the better the material is as a thermal mass (low conductivity relative to storage ability)
  - The time lag between peak internal and external temperature is related to the diffusivity of the walls
  - Steel has a high ρC_p but also a high k so it is not as good a thermal mass as concrete or masonry

Thermal properties

- All three material properties can be found in ASHRAE HOF chapter on thermal transmission data (Ch. 25 in 2005)
  - Thermal conductivity (k), density (ρ), and specific heat (C_p)

Description	Density, kg/m^3	Conductivity[b] (k), W/(m·K)	Conductance (C), W/(m^2·K)	Resistance[c] (R): $1/k$, (m·K)/W	Resistance[c] (R): For Thickness Listed ($1/C$), (m^2·K)/W	Specific Heat, kJ/(kg·K)
Gypsum partition tile						
75 by 300 by 760 mm, solid	—	—	4.50	—	0.222	0.79
75 by 300 by 760 mm, 4 cells	—	—	4.20	—	0.238	—
100 by 300 by 760 mm, 3 cells	—	—	3.40	—	0.294	—
Concretes[o]						
Sand and gravel or stone aggregate concretes (concretes	2400	1.4-2.9	—	0.69-0.35	—	—
with more than 50% quartz or quartzite sand have	2240	1.3-2.6	—	0.77-0.39	—	0.8-1.0
conductivities in the higher end of the range)	2080	1.0-1.9	—	0.99-053	—	—
Limestone concretes	2240	1.60	—	0.62	—	—
	1920	1.14	—	0.88	—	—
	1600	0.79	—	1.26	—	—

Modeling thermal mass and its impacts

- There are several ways to model conduction and thermal mass together
  - Goal is to find how interior surface temperatures fluctuate with changing exterior surface temperatures
- **Lumped capacitance model:**

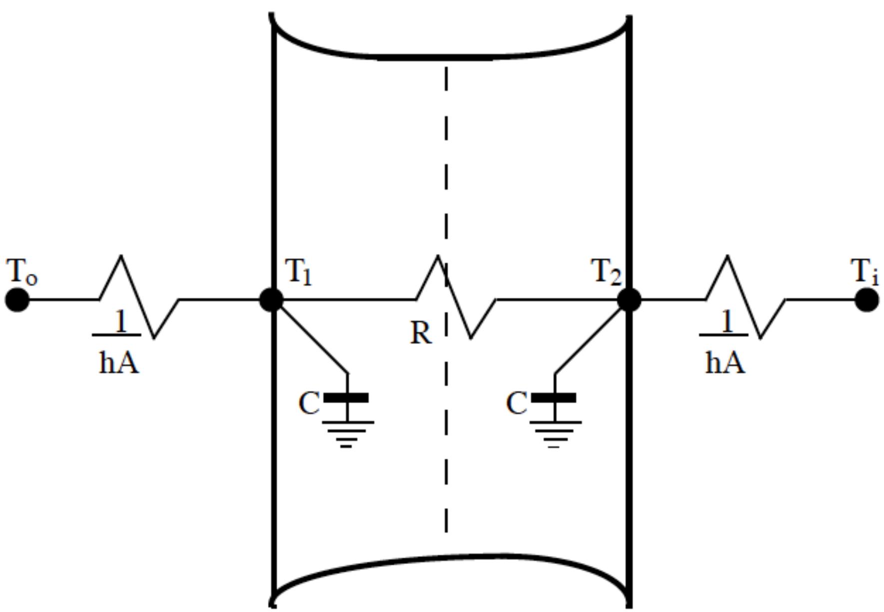


Figure 9. Two Node State Space Example.

Outdoor surface balance:

$$C\frac{dT_1}{dt} = hA(T_o - T_1) + \frac{T_2 - T_1}{R}$$

Indoor surface balance:

$$C\frac{dT_2}{dt} = hA(T_i - T_2) + \frac{T_1 - T_2}{R}$$

where:

$$R = \frac{\ell}{kA},$$

$$C = \frac{\rho c_p \ell A}{2}$$

Modeling thermal mass

- Lumped capacitance: wall example

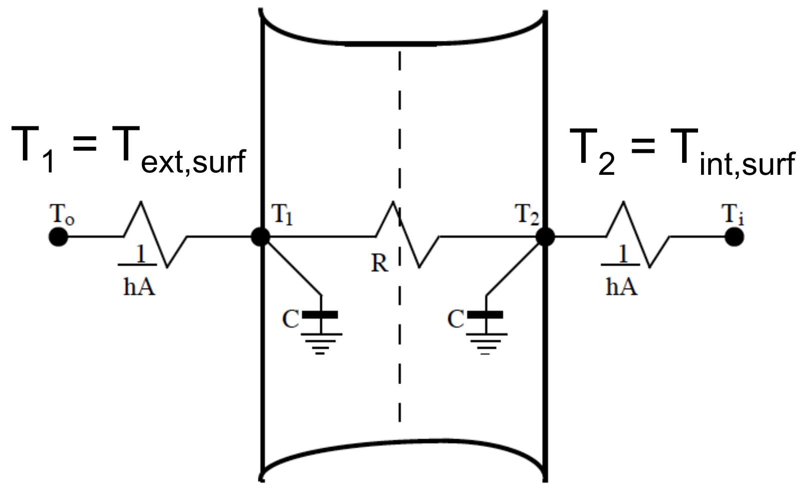


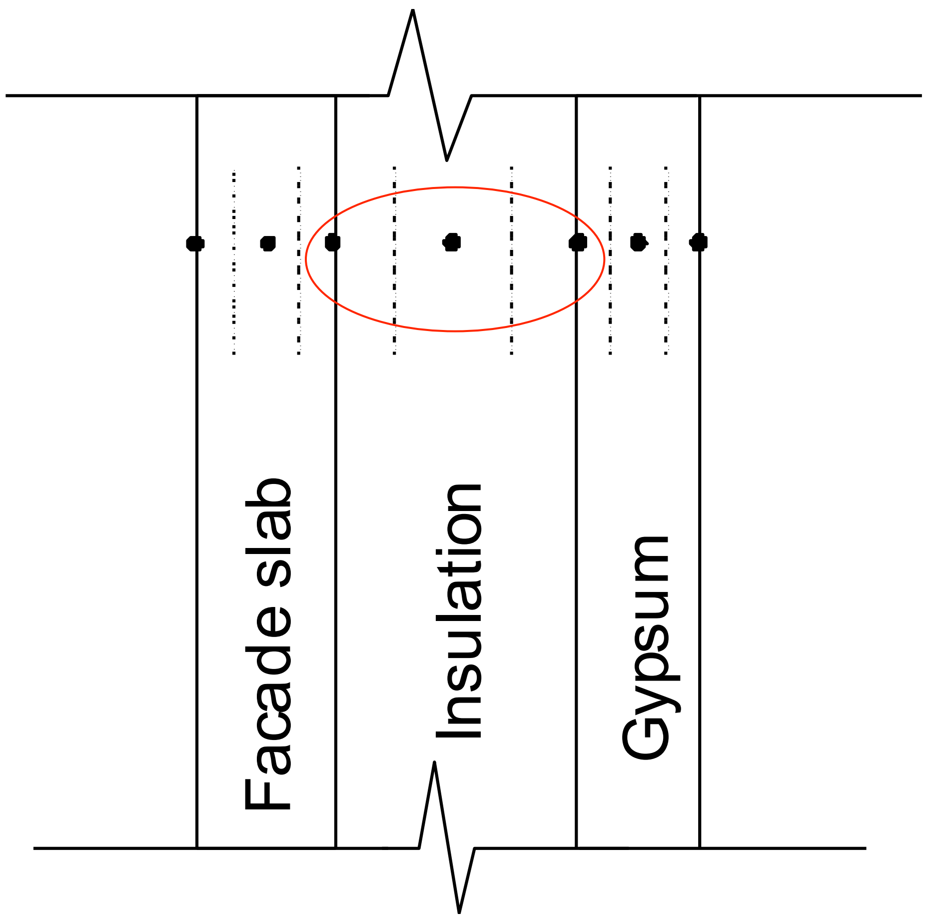
Figure 9. Two Node State Space Example.

Time-varying surface energy balance:

$$\frac{\rho C_p L}{2}\left(\frac{T_{ext} - T_{ext}^{n-1}}{\Delta t}\right) = I_{tot}\alpha_{sw} + h_{conv}(T_{out} - T_{ext}) + \varepsilon F\sigma\left(T_{sky}^4 - T_{ext}^4\right) - \frac{k}{L}(T_{ext} - T_{int})$$

Modeling thermal mass

- Conduction and thermal mass together can also be modeled using discrete nodes:

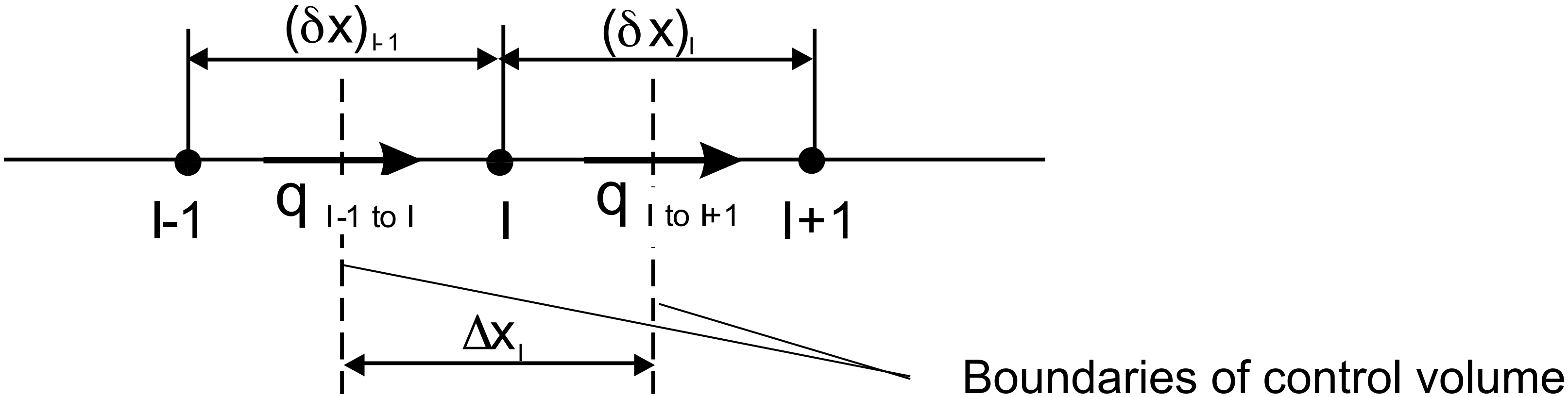


Discretization in space

$$\frac{\partial T}{\partial \tau} = \frac{k}{\rho c_p}\left(\frac{\partial^2 T}{\partial x^2}\right)$$

Discretization in time

Internal node heat balance: finite volume

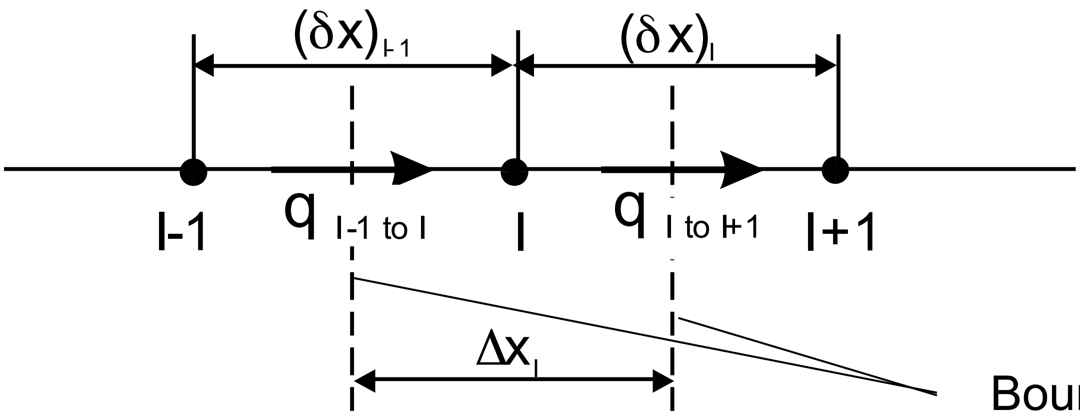


$$\rho c_p \frac{\partial T}{\partial \tau} = k\left(\frac{\partial^2 T}{\partial x^2}\right)$$

For node "I" - integration through the control volume

$$\rho_I c_{pI} \int_{I-\Delta X_I/2}^{I+\Delta X_I/2} \int_{\tau}^{\tau+\Delta\tau} \frac{\partial T}{\partial \tau} d\tau dx = \int_{\tau}^{\tau+\Delta\tau} \int_{I-\Delta X_I/2}^{I+\Delta X_I/2} k\left(\frac{\partial^2 T}{\partial x^2}\right) dx d\tau$$

Internal node heat balance: finite volume



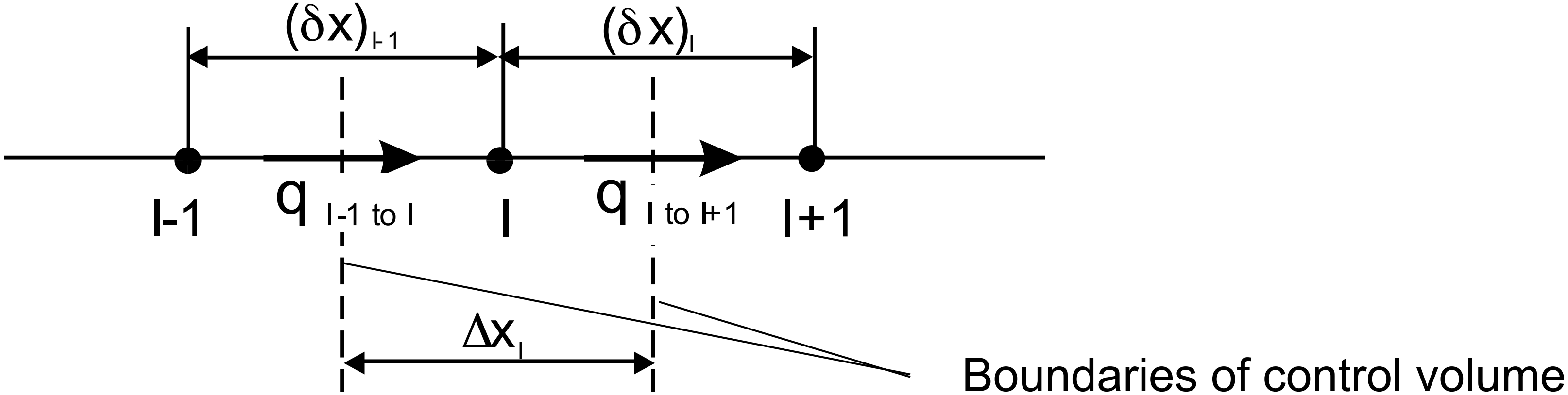
$$\rho c_p \frac{\partial T}{\partial \tau} = k\left(\frac{\partial^2 T}{\partial x^2}\right) + q_{source}$$

Heat source or loss term
(e.g., phase change)

For node "I" - integration through the control volume

$$\rho_I c_{pI} \int_{I-\Delta X_I/2}^{I+\Delta X_I/2} \int_{\tau}^{\tau+\Delta\tau} \frac{\partial T}{\partial \tau} d\tau dx = \int_{\tau}^{\tau+\Delta\tau} \int_{I-\Delta X_I/2}^{I+\Delta X_I/2} k\left(\frac{\partial^2 T}{\partial x^2}\right) dx d\tau + \int_{\tau}^{\tau+\Delta\tau} \int_{I-\Delta X_I/2}^{I+\Delta X_I/2} \dot{q}' dx d\tau$$

Internal node heat balance: finite volume explicit



We can discretize the last equation:

Explicit method

$$\frac{\rho_I c_I \Delta x_I}{\Delta \tau}\left(T_I^{\tau+\Delta\tau} - T_I^{\tau}\right) = \frac{k_I\left(T_{I+1}^{\tau} - T_I^{\tau}\right)}{\Delta x_I} - \frac{k_{I-1}\left(T_I^{\tau} - T^{\tau}\right)}{\Delta x_I} + q^{\tau}$$

$$T_I^{\tau+\Delta\tau} = f(T_{I-1}^{\tau}, T_I^{\tau}, T_{I+1}^{\tau})$$

Time lags and decrement factors

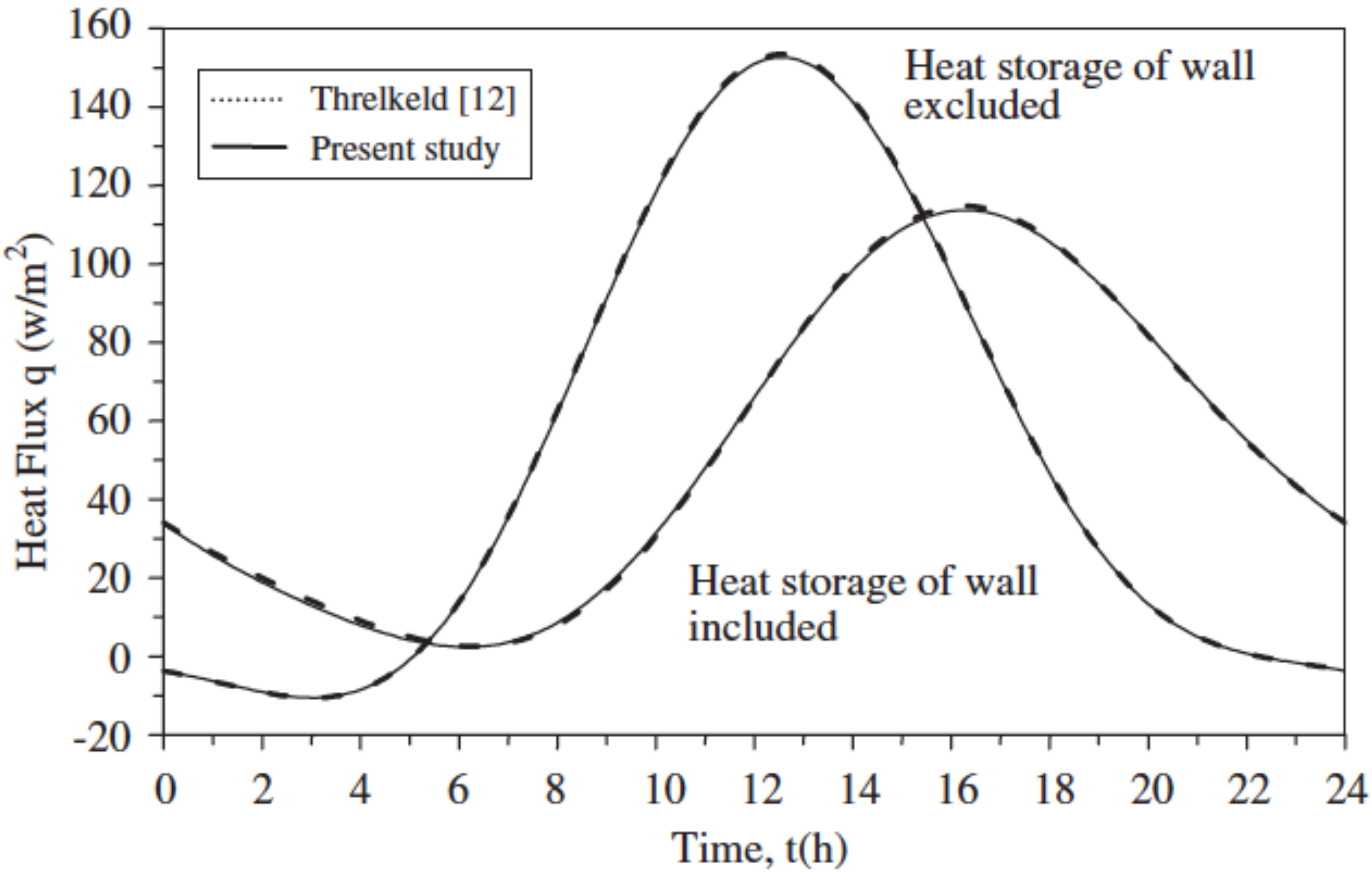
- These models (and measurements) can be used to describe **time lags** and **decrement factors**

- **Time lag** tells you:
  - For a given peak exterior surface temperature at a certain time
  - How much later does the peak interior surface temperature actually occur?
    - Shift due to thermal lag effects

- **Decrement factor** tells you:
  - How much lower is the peak temperature swing (amplitude) with an enclosure with high thermal mass relative to no thermal mass
    - e.g., How squished is the peak temperature profile?

Modeling thermal mass impacts

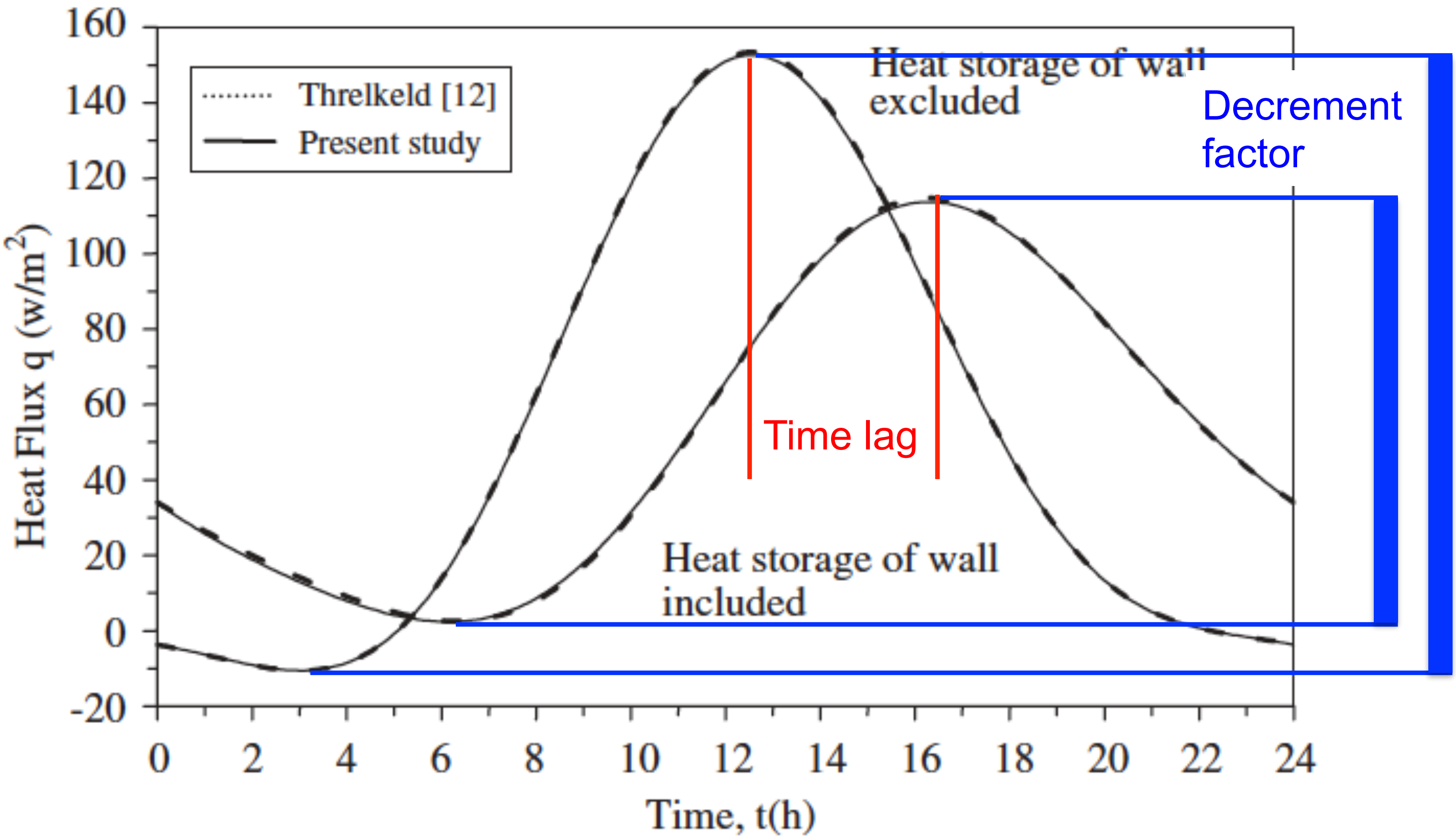
Decrement factors and time lags



Asan, H. 2006. Numerical computation of time lags an decrement factors for different building materials. *Building and Environment* 41:615-620.

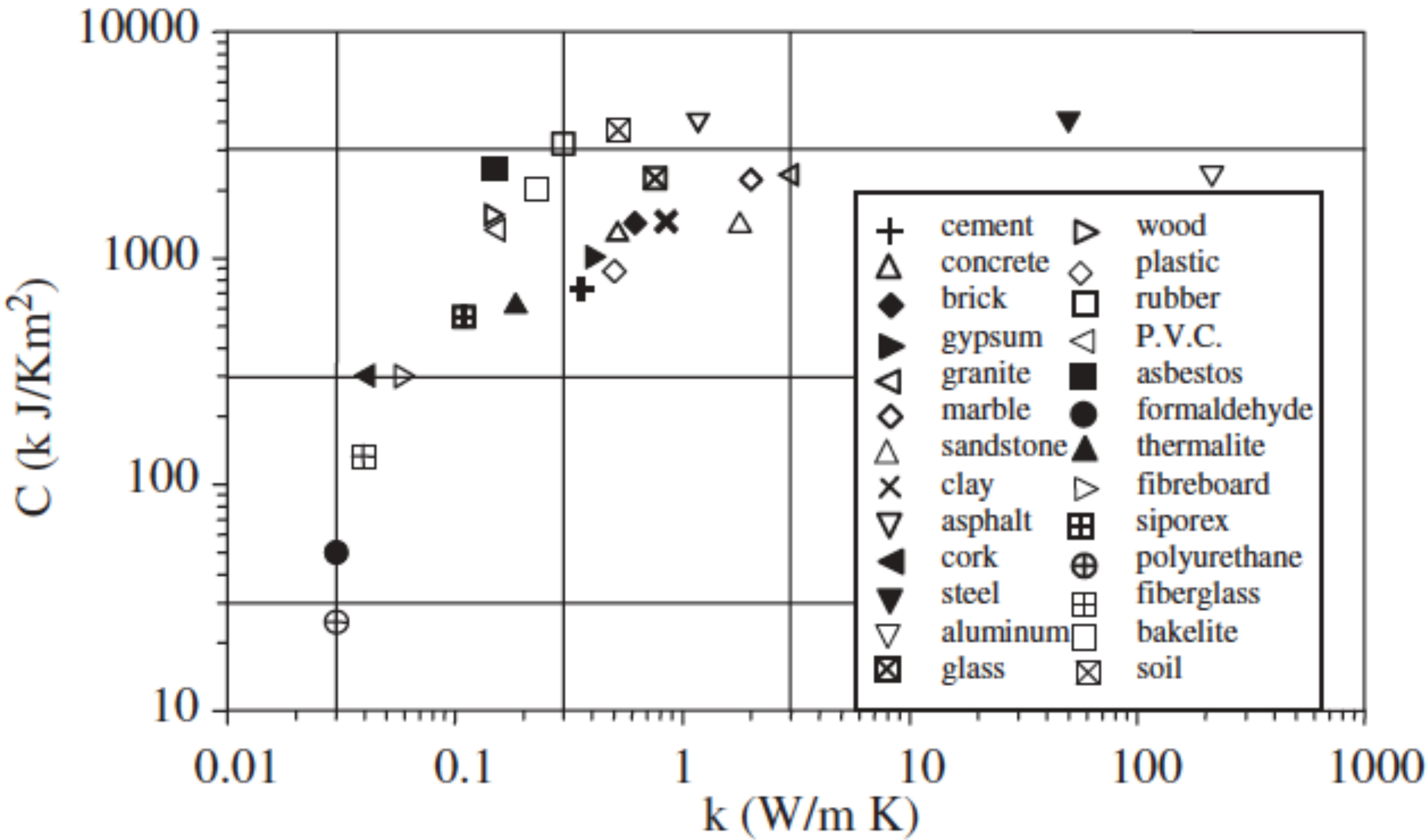
Modeling thermal mass impacts

Decrement factors and time lags



Asan, H. 2006. Numerical computation of time lags an decrement factors for different building materials. *Building and Environment* 41:615-620.

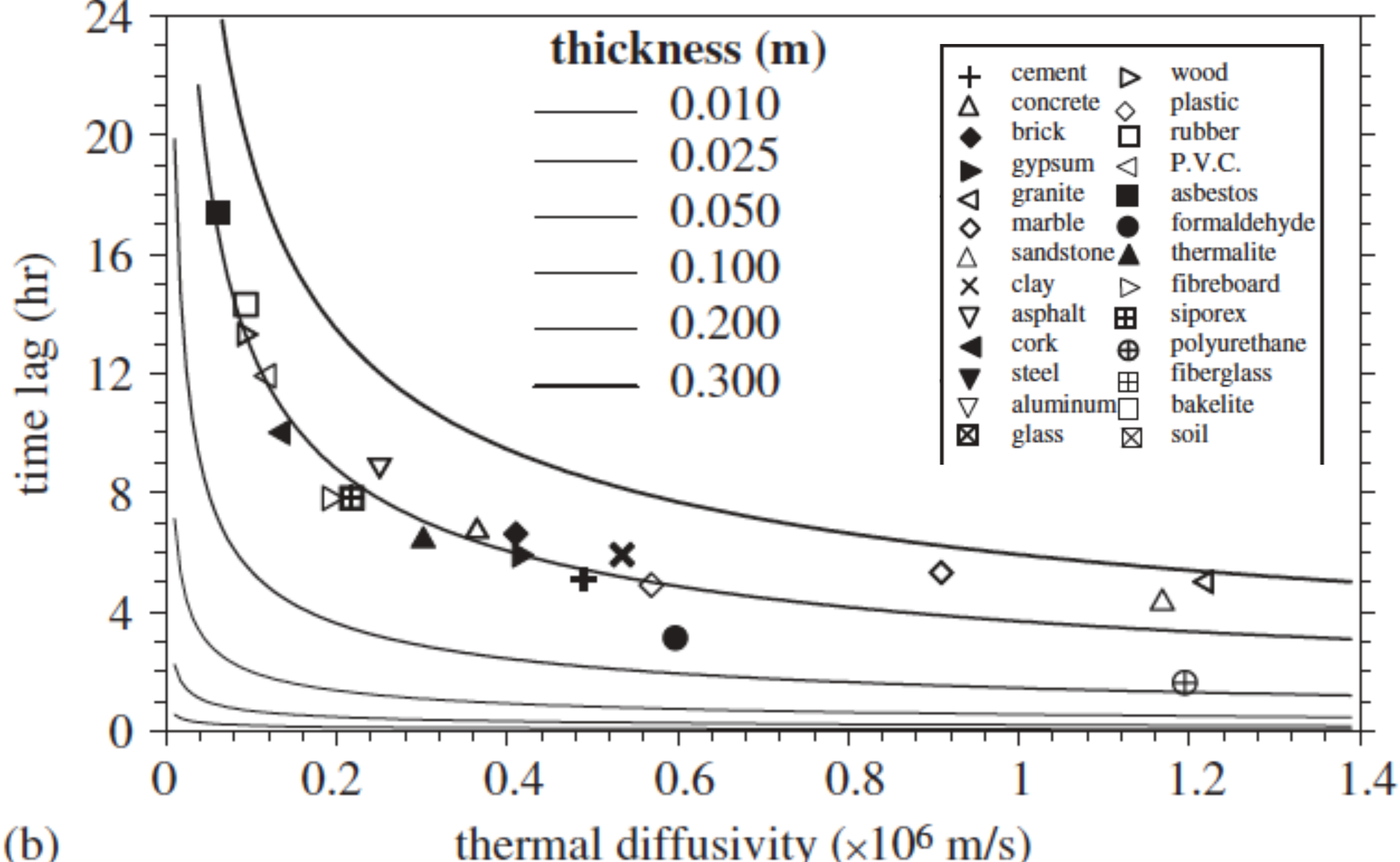
Modeling thermal mass impacts for different materials



Asan, H. 2006. Numerical computation of time lags an decrement factors for different building materials. *Building and Environment* 41:615-620.

Modeled time lag of several materials with varying thickness

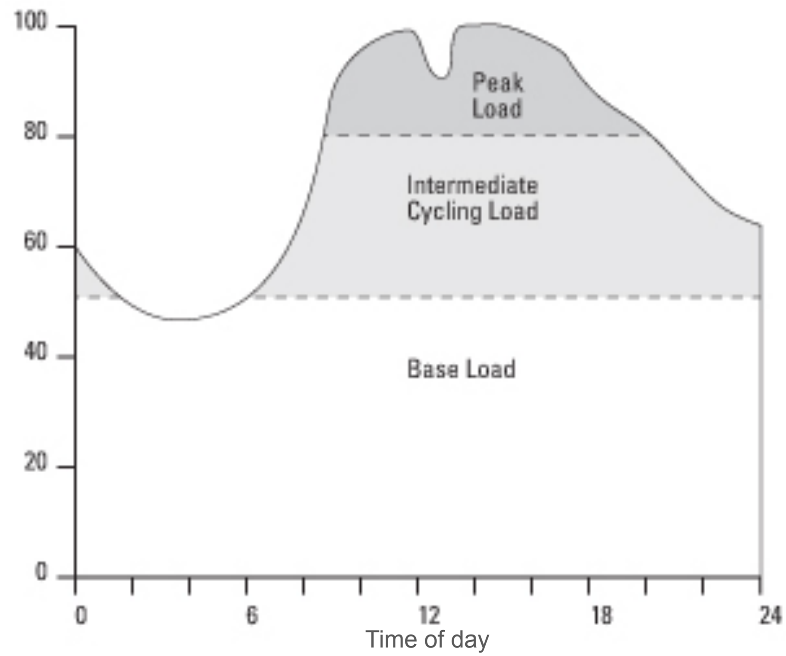
L = 0.2 m = ~8 inches



Asan, H. 2006. Numerical computation of time lags an decrement factors for different building materials. *Building and Environment* 41:615-620.

Why are these important?

- Time lag
  - Only indirectly impacts energy use
    - But impacts time of energy use
  - Can shift peak loads
  - Meaningful for peak loads on aggregate basis
    - Also for energy markets with dynamic pricing



Why are these important?

- Decrement factor
  - Directly impacts energy use and costs
    - Dampens rate of conduction through enclosure
  - Can allow for smaller HVAC equipment
    - Lower upfront costs
    - Important to explore in design phase

Simplified metric: Thermal time constant (TTC)

- The thermal time constant is defined as the sum of the product of the heat capacity of a layer i and the cumulative thermal resistance up to layer i
  (starting from outside)

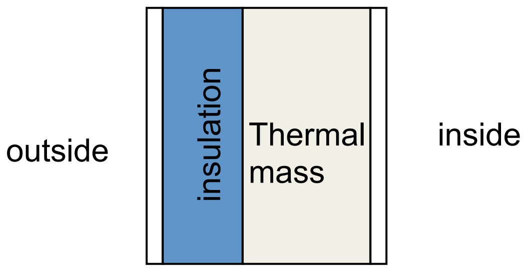
$$TTC = \sum_i \rho_i L_i C_{pi} R_{o \to i}$$

Units of time [sec]

- *TTC* is a measure of time it takes heat to propagate through the wall and is a kind of "effective" thermal insulating capability
  - The higher the TTC, the longer it takes for conduction to occur
  - High TTC can lower the overall heat transfer through the structure

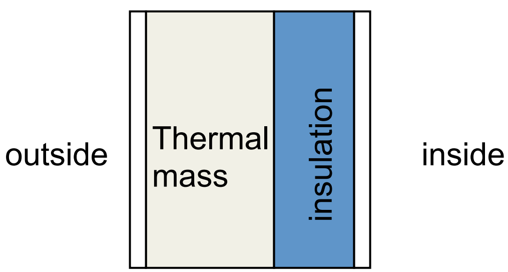
Example TTC calculation

Wall 1: exterior insulation



TTC = 43.8 hours

Wall 2: interior insulation



TTC = 7.8 hours

TABLE 3-8. CALCULATION OF THE THERMAL TIME CONSTANT OF 2 WALLS (METRIC)

Wall #1

LAYER	THICK l_i(m)	DENSITY ρ_i(Kg/m³)	RESIST. r_i	CUMULAT. RESIST.	HC ρ*c	QR_i Hr
Ext. surface						0.03
Ext. plaster	0.02	1800	0.025	0.0425	414	0.35
Polystyrene	0.025	30	0.71	0.41	12	0.12
Concrete	0.10	2200	0.06	0.795	506	40.2
Int. plaster	0.01	1600	0.014	0.832	368	3.1
Wall's TTC						43.8

Wall #2

LAYER	THICK l_i(m)	DENSITY ρ_i(Kg/m³)	RESIST. r_i	CUMULAT. RESIST.	HC ρ*c	QR_i Hr
Ext. surface						0.03
Ext. plaster	0.02	1800	0.025	0.0425	414	0.35
Concrete	0.10	2200	0.06	0.085	506	4.3
Polystyrene	0.025	30	0.71	0.47	12	0.14
Int. plaster	0.01	1600	0.014	0.832	368	3.1
Wall's TTC						7.8

Example TTC calculation

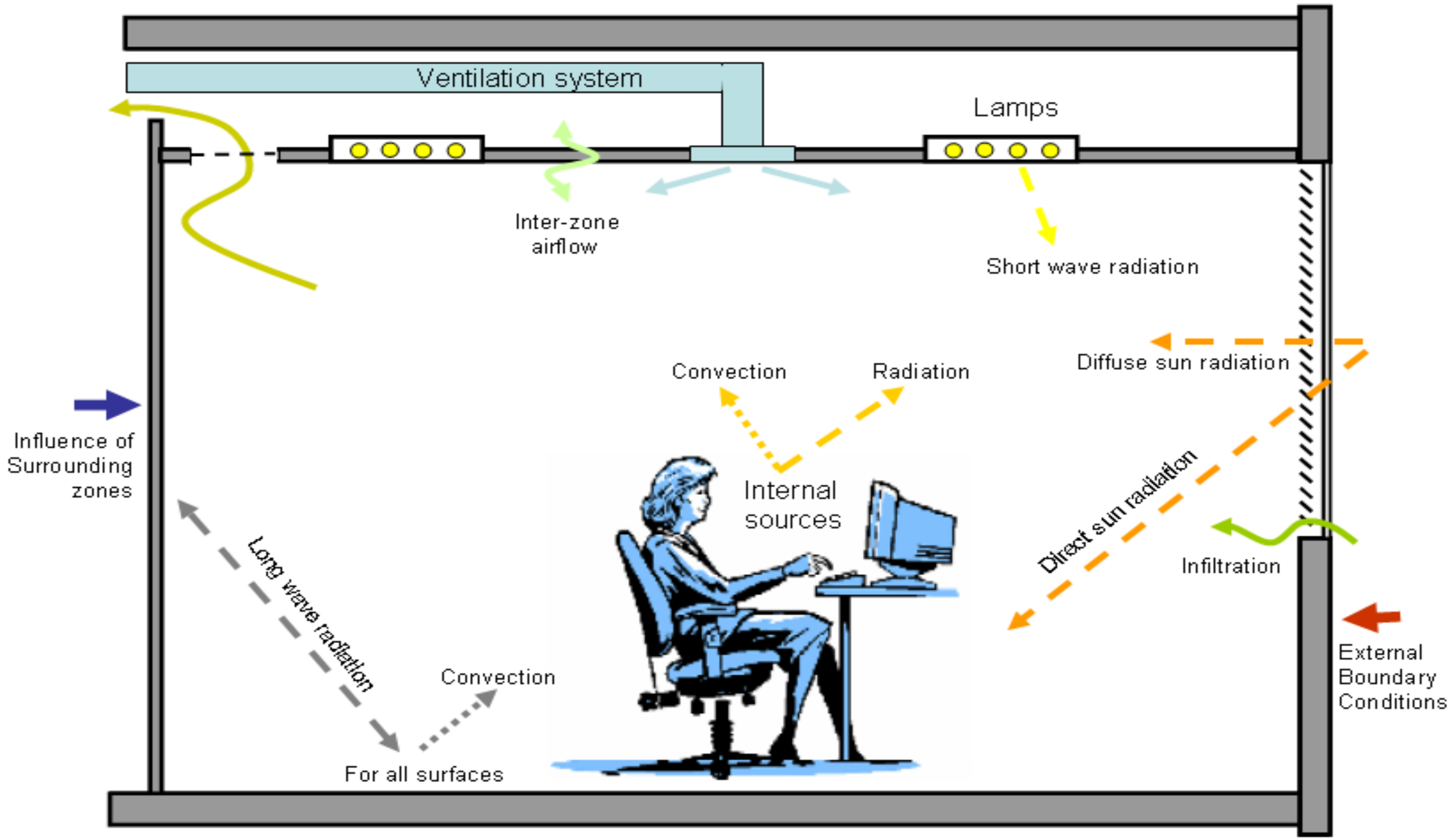
- The Thermal Time Constant (TTC) of the concrete wall with exterior insulation is nearly 5x larger than the concrete wall with interior insulation
  - This means the wall with exterior insulation will be a better thermal mass
- The assembly with the interior insulation has the large thermal mass directly exposed to the large temperature swings of the outdoors
  - By placing the insulation between the exterior air and the thermal mass, it takes longer to “charge” and “discharge” the thermal mass with heat
- To accurately estimate the impacts on overall energy use and time of energy use, whole building energy modeling is required

WHOLE BUILDING ENERGY SIMULATION

Building energy simulation

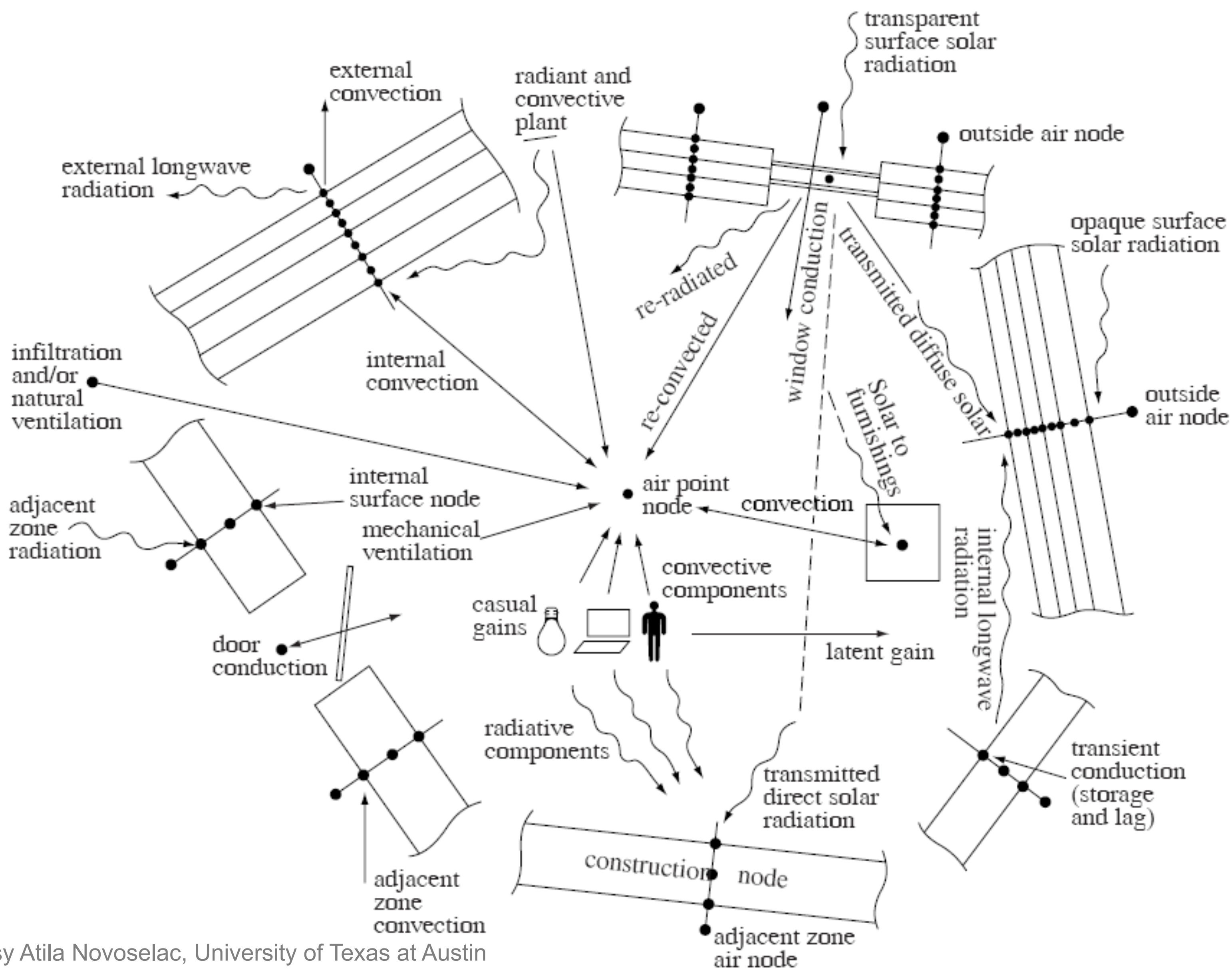
- We've covered surface heat balances
- Last week with attic heat transfer we touched on how surfaces are all connected
  - Relies on a system of equations linking heat balances at a series of "nodes"
    - Each node has an equation accounting for all modes of heat transfer
- Whole building energy simulation is similar
  - With indoor air temperatures (and thus HVAC loads) as the primary variable to predict
    - Include HVAC system capacity and efficiency to get HVAC energy
  - Also includes interior heat gains
    - People, lights, equipment, etc.
    - Direct power draw + indirect heat gains

Building energy simulation



Slide courtesy Atila Novoselac, University of Texas at Austin

Building energy simulation



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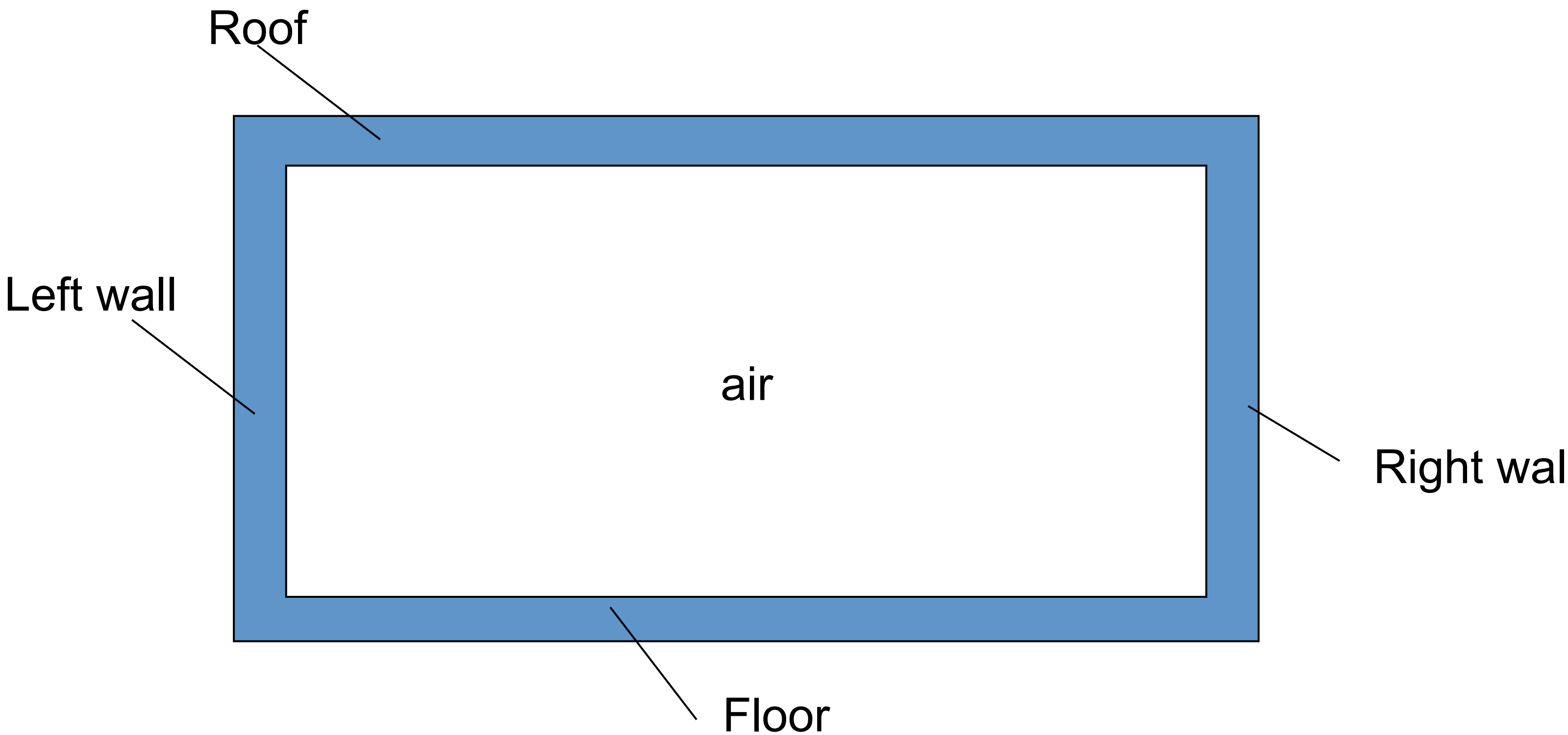
Modeling steps

- Define the domain
- Analyze the most important phenomena and define the most important elements
- Discretize the elements and define connections
- Write the energy and mass balance equations
  - Include any assumptions for indoor sources
- Solve the equations
  - Use numeric methods or discrete solutions
  - Time-varying analysis over an entire year
- Present the results
  - kWh electricity; BTU or MJ of other fuels
  - Hourly, daily, monthly, yearly

Simplest ‘box’ model



Elements are connected by:

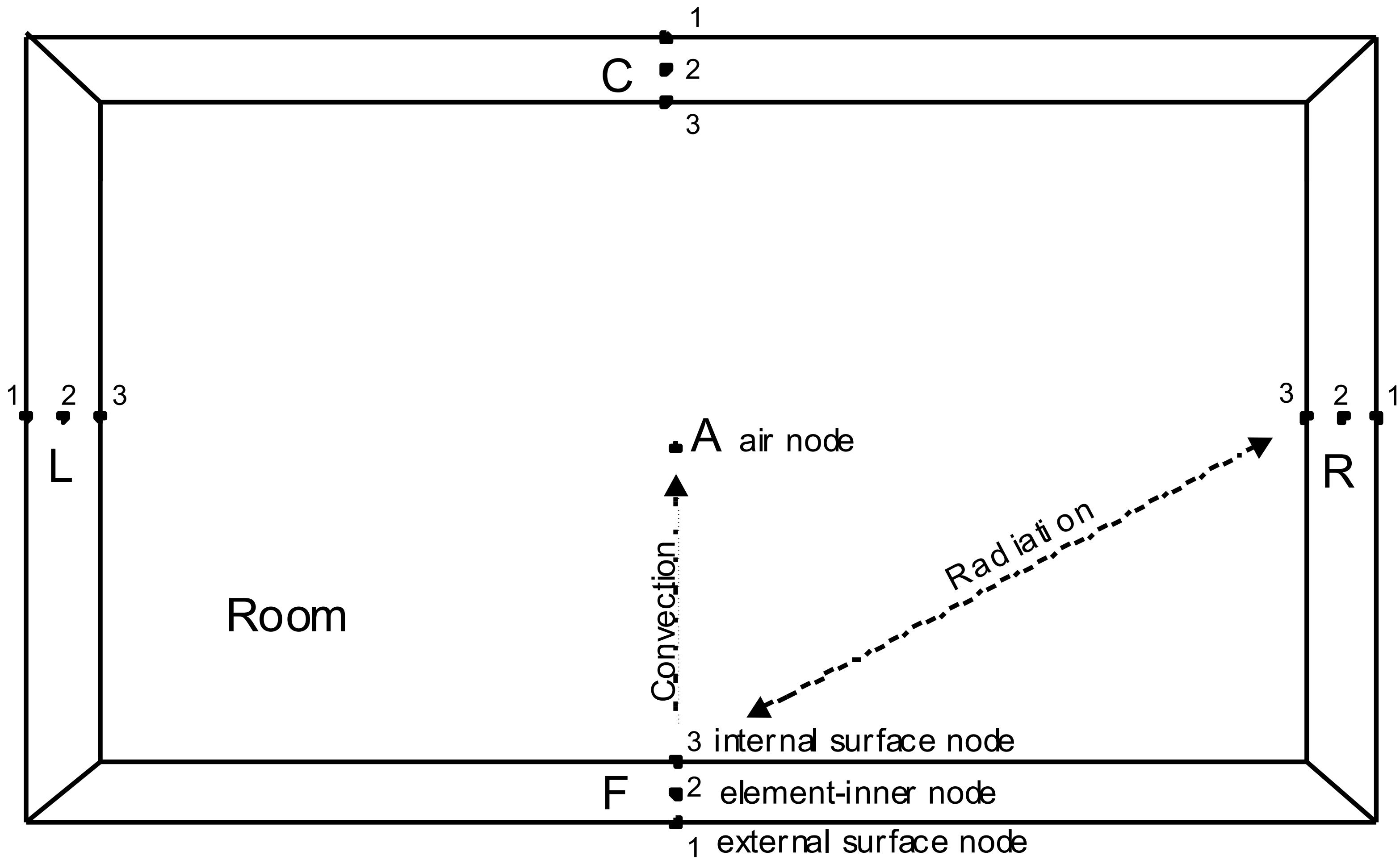
1) Convection – air node
2) Radiation – surface nodes

Slide courtesy Atila Novoselac, University of Texas at Austin

Unsteady energy balance for air node

System of equations for 2-D room with 13 nodes:

L –left wall , C ceiling, F – floor, R – right wall, A – air node



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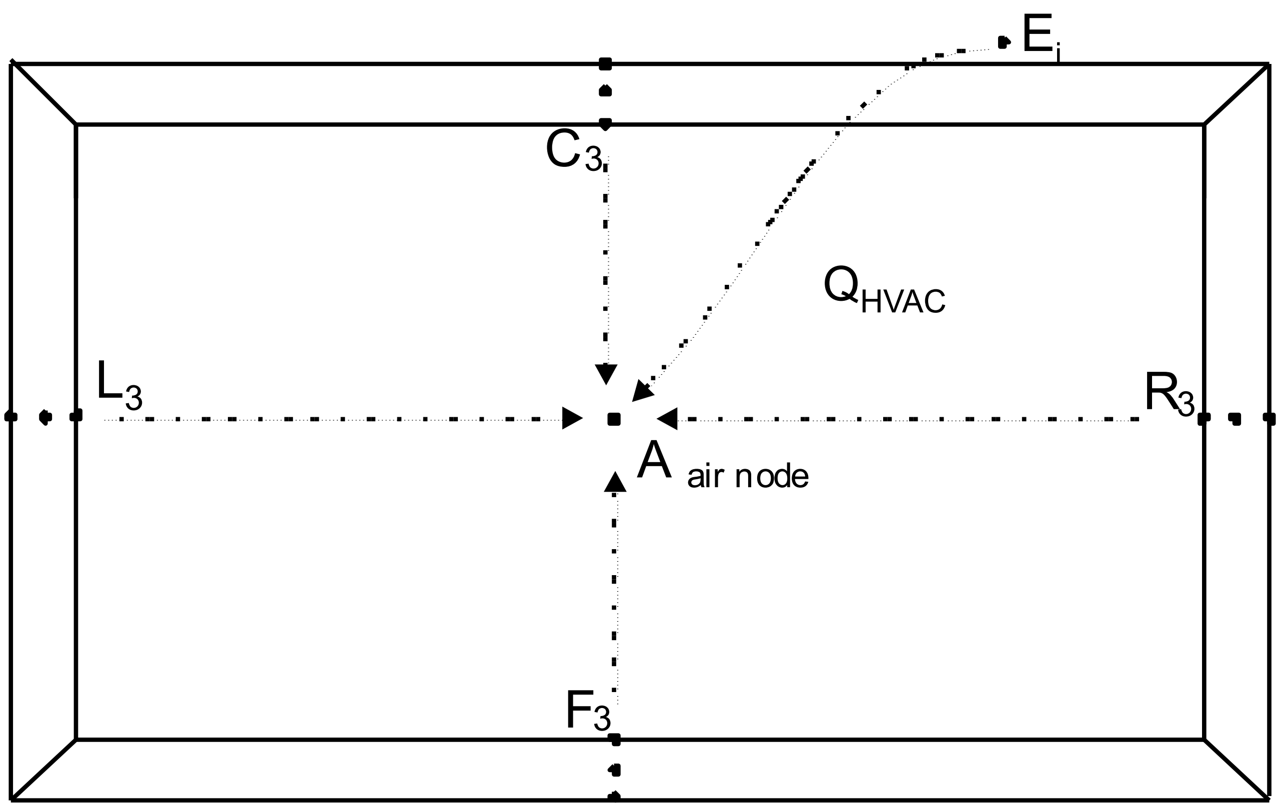
Unsteady energy balance for air node

Convection to/ from all interior surfaces — **Air infiltration/ exfiltration** — **HVAC supply to counter-balance**

$$\frac{\partial (V_{room} \rho c_p T_{air})}{\partial \tau} = \sum_{i=1}^{n} h_i A_i \left(T_{S,i} - T_{air}\right) + \sum_{i=1}^{n} m c_{p_i} \left(T_{ext\_air,i} - T_{air}\right) + \sum Q_{HVAC}$$



Slide courtesy Atila Novoselac, University of Texas at Austin

Important input parameters

- Conduction (and storage) solution method
  - Finite difference (explicit, implicit)
  - Response functions techniques
- Time steps
  - Too short and calculations take forever
  - Too long and solutions diverge
- Meteorological data
  - Temperature, wind speed, solar radiation, cloud cover
- Radiation and convection models
  - Internal and external
- Windows and shading
- Air infiltration models
- Conduction to the ground
- HVAC system and control models

ENERGY SIMULATION (ES) PROGRAMS

Energy simulation (ES) programs

- A large variety of programs exists
  - http://apps1.eere.energy.gov/buildings/tools_directory/subjects_sub.cfm
  - Different levels of functions, user interfaces, and pricing
  - Some have very good GUIs with less functionality
    - Some have the exact opposite

- Most commonly used ES programs:
  - eQUEST (DOE2 engine; free; easy GUI)
  - ESPr (free; difficult to use; research grade)
  - TRNSYS (modular; requires extensive inputs; expensive)
  - TRACE 700 (from Trane; HVAC focus; expensive)
  - EnergyGauge USA (residential only; user-friendly; cheap)
  - EnergyPlus (free; excellent capabilities; modular; difficult to use)
    - Ease of use is improving with DesignBuilder USA and OpenStudio (free)

Example engineering reference for ES program

- These programs rely on the same equations we've been using

$$C_z \frac{dT_z}{dt} = \sum_{i=1}^{N_{sl}} \dot{Q}_i + \sum_{i=1}^{N_{surfaces}} h_i A_i \left(T_{si} - T_z\right) + \sum_{i=1}^{N_{zones}} \dot{m}_i C_p \left(T_{zi} - T_z\right) + \dot{m}_{\inf} C_p \left(T_\infty - T_z\right) + \dot{Q}_{sys}$$

where:

$\sum_{i=1}^{N_{sl}} \dot{Q}_i$ = sum of the convective internal loads

$\sum_{i=1}^{N_{surfaces}} h_i A_i \left(T_{si} - T_z\right)$ = convective heat transfer from the zone surfaces

$\dot{m}_{\inf} C_p \left(T_\infty - T_z\right)$ = heat transfer due to infiltration of outside air

$\sum_{i=1}^{N_{zones}} \dot{m}_i C_p \left(T_{zi} - T_z\right)$ = heat transfer due to interzone air mixing

$\dot{Q}_{sys}$ = air systems output

$C_z \frac{dT_z}{dt}$ = energy stored in zone air

$C_z = \rho_{air} C_p C_T$

ρ_{air} = zone air density

C_p = zone air specific heat

EnergyPlus Engineering Reference, 2012

Example engineering reference for ES program

- Rearrange to solve for instantaneous HVAC system capacity:

$$-\dot{Q}_{sys} = \sum_{i=1}^{N_{sl}} \dot{Q}_i + \sum_{i=1}^{N_{surfaces}} h_i A_i \left(T_{si} - T_z\right) + \sum_{i=1}^{N_{zones}} \dot{m}_i C_p \left(T_{zi} - T_z\right) + \dot{m}_{\inf} C_p \left(T_\infty - T_z\right)$$

- Instantaneous HVAC sensible capacity also equals:

$$\dot{Q}_{sys} = \dot{m}_{sys} C_p \left(T_{\sup} - T_z\right)$$

- Once you have Q_{sys} at each time step, you can calculate the energy required to deliver that rate of bulk heat transfer by knowing the efficiency/COP of your equipment

$$COP = \frac{Q_{sys}}{P_{sys}} \longrightarrow P_{sys} = \frac{Q_{sys}}{COP}$$

EnergyPlus Engineering Reference, 2012

Example engineering reference for ES program

- Discretizing for time t versus time $t - \delta t$:

$$C_z \frac{T_z^t - T_z^{t-\delta t}}{dt} + T_z^t \left(\sum_{i=1}^{N_{surfaces}} h_i A_i + \sum_{i=1}^{N_{zones}} \dot{m}_i C_p + \dot{m}_{\inf} C_p + \dot{m}_{sys} C_p \right) =$$

$$\sum_{i=1}^{N_{sl}} \dot{Q}_i^t + \dot{m}_{sys} C_p T_{\text{supply}}^t + \left(\sum_{i=1}^{N_{surfaces}} h_i A_i T_{si} + \sum_{i=1}^{N_{zones}} \dot{m}_i C_p T_{zi} + \dot{m}_{\inf} C_p T_\infty \right)^{t-\delta t}$$

- If there is any thermal mass at any element, link to surface T:

$$C_p \rho \Delta x \frac{T_i^{j+1} - T_i^j}{\Delta t} = \frac{1}{2} \left[\left(k_W \frac{\left(T_{i+1}^{j+1} - T_i^{j+1}\right)}{\Delta x} + k_E \frac{\left(T_{i-1}^{j+1} - T_i^{j+1}\right)}{\Delta x} \right) + \left(k_W \frac{\left(T_{i+1}^{j} - T_i^{j}\right)}{\Delta x} + k_E \frac{\left(T_{i-1}^{j} - T_i^{j}\right)}{\Delta x} \right) \right]$$

EnergyPlus Engineering Reference, 2012

Example engineering reference for ES program

Outside Surface Heat Balance

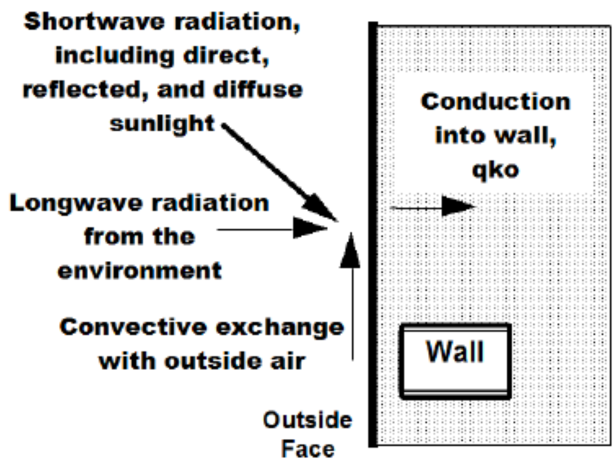


Figure 17. Outside Heat Balance Control Volume Diagram

The heat balance on the outside face is:

$$q''_{\alpha sol} + q''_{LWR} + q''_{conv} - q''_{ko} = 0 \qquad (64)$$

where:

$q''_{\alpha sol}$ = Absorbed direct and diffuse solar (short wavelength) radiation heat flux.

q''_{LWR} = Net long wavelength (thermal) radiation flux exchange with the air and surroundings.

q''_{conv} = Convective flux exchange with outside air.

q''_{ko} = Conduction heat flux (q/A) into the wall.

- We know how to model all of these elements now
- Programs differ in how they select inputs, particularly heat transfer coefficients…

EnergyPlus Engineering Reference, 2012

Example engineering reference for ES program

Simple Combined

The simple algorithm uses surface roughness and local surface windspeed to calculate the exterior heat transfer coefficient (key:SimpleCombined). The basic equation used is:

$$h = D + EV_z + FV_z^2 \qquad (82)$$

where

h = heat transfer coefficient

V_z = local wind speed calculated at the height above ground of the surface centroid

D, E, F = material roughness coefficients

The roughness correlation is taken from Figure 1, Page 22.4, ASHRAE Handbook of Fundamentals (ASHRAE 1989). The roughness coefficients are shown in the following table:

Table 6. Roughness Coefficients D, E, and F.

Roughness Index	**D**	**E**	**F**	**Example Material**
1 (Very Rough)	11.58	5.894	0.0	Stucco
2 (Rough)	12.49	4.065	0.028	Brick
3 (Medium Rough)	10.79	4.192	0.0	Concrete
4 (Medium Smooth)	8.23	4.0	-0.057	Clear pine
5 (Smooth)	10.22	3.1	0.0	Smooth Plaster
6 (Very Smooth)	8.23	3.33	-0.036	Glass

EnergyPlus Engineering Reference, 2012

Example engineering reference for ES program

Inside Heat Balance

The heart of the heat balance method is the internal heat balance involving the inside faces of the zone surfaces. This heat balance is generally modeled with four coupled heat transfer components: 1) conduction through the building element, 2) convection to the air, 3) short wave radiation absorption and reflectance and 4) longwave radiant interchange. The incident short wave radiation is from the solar radiation entering the zone through windows and emittance from internal sources such as lights. The longwave radiation interchange includes the absorption and emittance of low temperature radiation sources, such as all other zone surfaces, equipment, and people.

The heat balance on the inside face can be written as follows:

$$q''_{LWX} + q''_{SW} + q''_{LWS} + q''_{ki} + q''_{sol} + q''_{conv} = 0 \qquad (92)$$

where:

q''_{LWX} = Net longwave radiant exchange flux between zone surfaces.

q''_{SW} = Net short wave radiation flux to surface from lights.

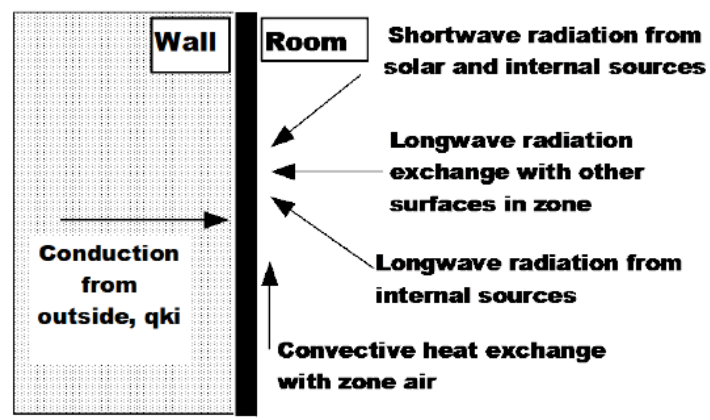
q''_{LWS} = Longwave radiation flux from equipment in zone.

q''_{ki} = Conduction flux through the wall.

q''_{sol} = Transmitted solar radiation flux absorbed at surface.

q''_{conv} = Convective heat flux to zone air.

Each of these heat balance components is introduced briefly below.



EnergyPlus Engineering Reference, 2012

Example engineering reference for ES program

- Choice of interior convection coefficients is complicated
  - Still a topic of ongoing research
  - Remember: Forced vs. laminar? Orientation? Cold or hot surface?

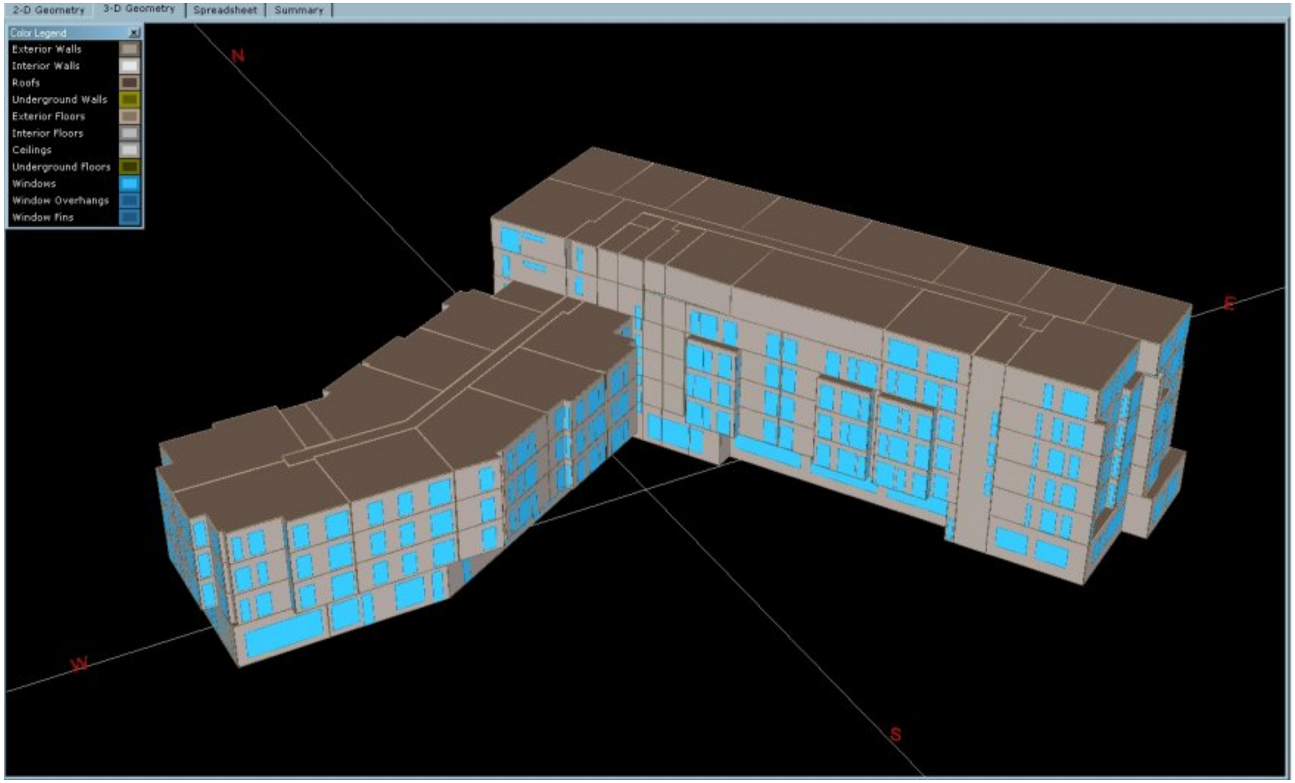
- Different equations for different surfaces
  - Simple buoyancy
    - Vertical walls, tilted surfaces, windows, etc.
  - In-floor heating or in-ceiling cooling
    - Vertical walls, heated floors, chilled ceilings, windows
  - Forced flow near diffusers
    - Ceiling diffusers, floor diffusers, near heated or cooled windows
  - Central mechanical fan circulation
    - Walls, horizontal flow

- EnergyPlus documentation has a great review of all of these

EnergyPlus Engineering Reference, 2012

Demonstration of ES program

- eQuest demonstration
  - Launch program



http://www.buildingenergyexperts.com/wp-content/uploads/2010/08/Equest.jpg

Cost analysis during design

- Were any of those enclosure design changes worth it financially?
- For any energy efficiency improvement, you expect lower energy bills
  - But that improvement also had an upfront (capital) cost

- Payback periods
  - How long will it take for energy savings to cover the initial cost?
  - Several methods to calculate
    - Simple payback
    - Cash flow analysis
    - Net present value
    - Internal rate of return
    - Return on investment

Cost analysis during design

- Simple payback
  - Say you are considering a $5,000 improvement
  - Your energy simulations predict $350 per year in savings on energy bills
    - Assuming rates stay constant
  - The simple payback period is: $Payback = \dfrac{\$5000}{\$350\ /\ year} = 14.3\ years$
  - After ~14 years, you will have covered your upfront costs

- Rate of return on investment
  - Inverse of payback period

$$ROI = \frac{1}{14.3\ years} = 7\%$$

Cost analysis during design

- Cash flow analysis and net present value methods
  - If you take out a loan to pay for efficiency improvements, you need to factor in the interest rate on that loan/mortgage
    - Will likely extend the payback period to cover principal + interest
- Other considerations:
  - Inflation
    - Somewhat predictable
  - Changes in energy costs
    - More variable
    - Most assume energy costs will rise at a constant rate
    - Not always the case (e.g., natural gas prices today)
    - If energy costs rise above predicted, payback period shortens
      - Vice versa for falling energy costs
- Overall: who pays capital costs and who pays for energy costs?

ENERGY USE, CODES, AND STANDARDS: ASHRAE STANDARD 90.1

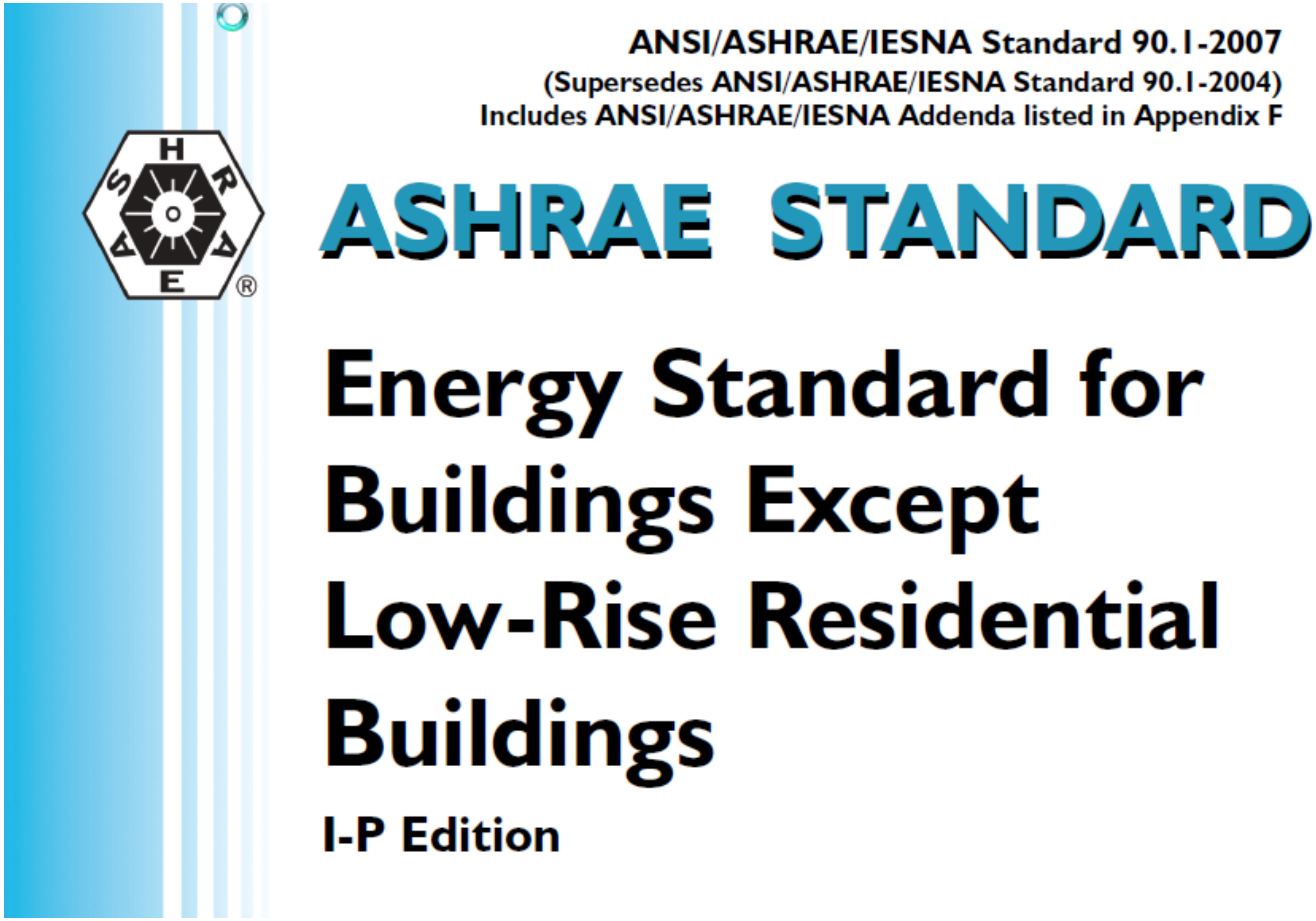
“Energy standard for building except low-rise residential buildings”

Energy standards

- Building Codes have had minimum energy standards for some time
  - Designed to reduce energy misuse and waste
- 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

- 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


ANSI/ASHRAE/IESNA Standard 90.1-2007
(Supersedes ANSI/ASHRAE/IESNA Standard 90.1-2004)
Includes ANSI/ASHRAE/IESNA Addenda listed in Appendix F

ASHRAE STANDARD

Energy Standard for Buildings Except Low-Rise Residential Buildings

I-P Edition

- ASHRAE 90.1-2007, & 2010, *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
    - 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)

- 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
- 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/

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 (link)
  - You can download the full text of the Energy Efficiency code here
    - 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

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

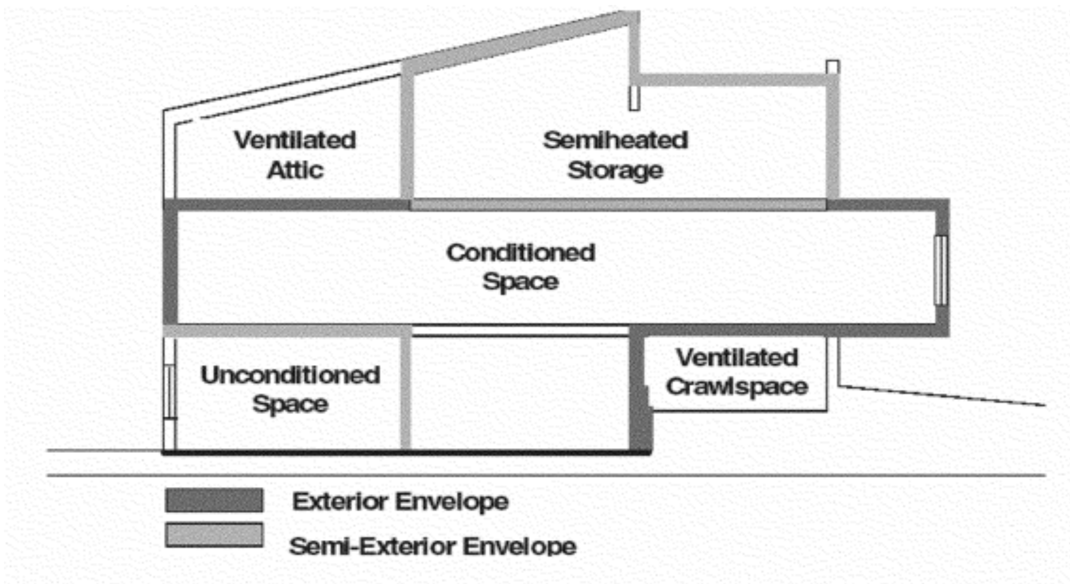
90.1 table of contents

CONTENTS

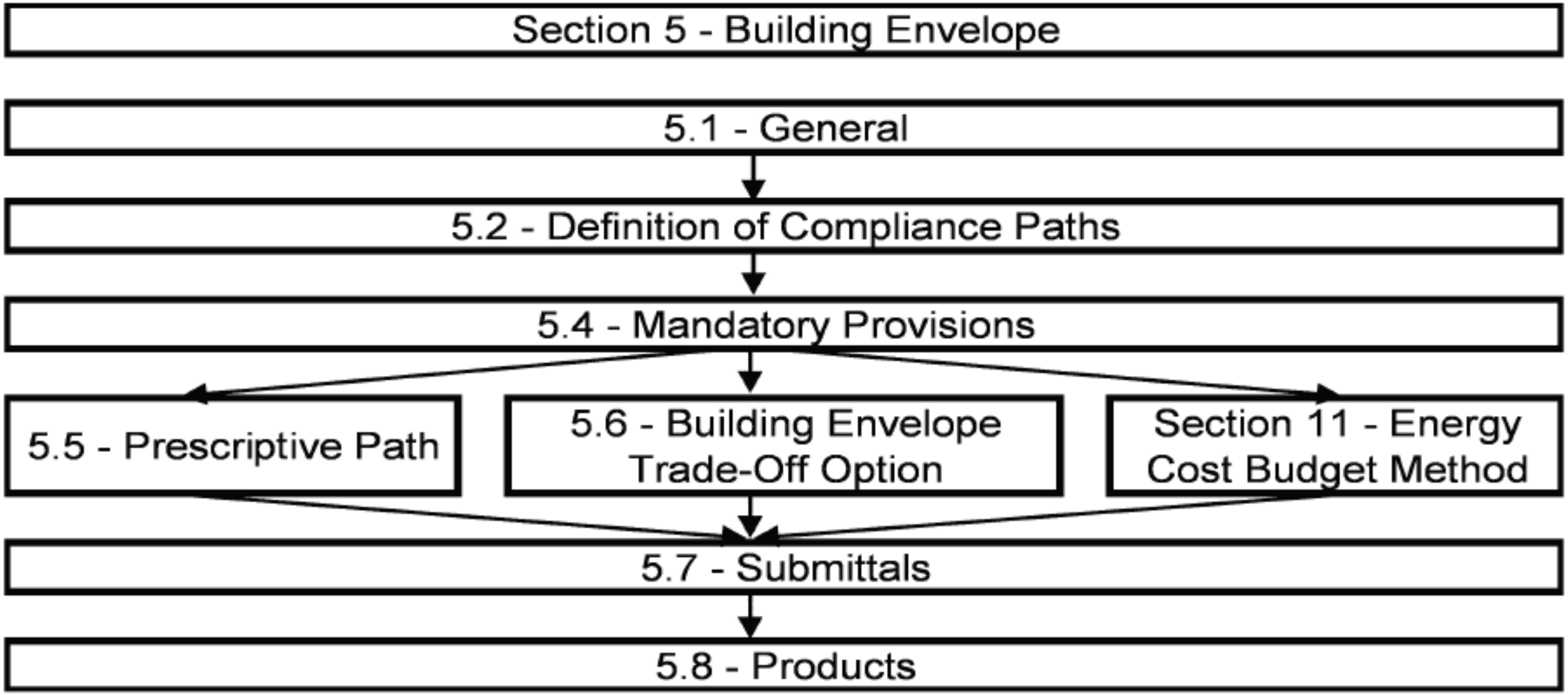
ANSI/ASHRAE/IESNA Standard 90.1-2007
Energy Standard for Buildings Except Low-Rise Residential Buildings

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



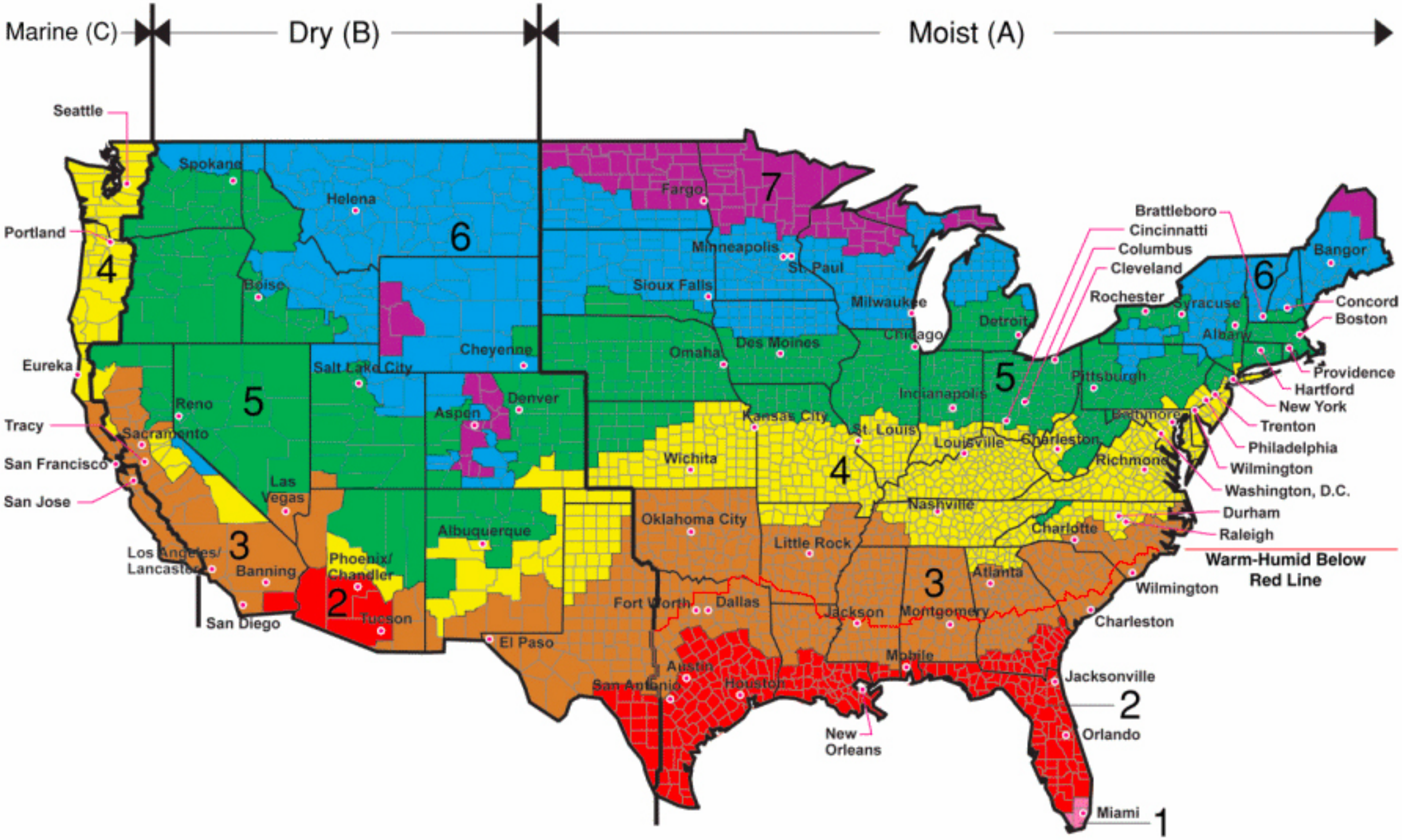
5.1 General

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

5.4.3.4 Vestibules

- All entrances to conditioned spaces <u>must</u> 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		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-20.0 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

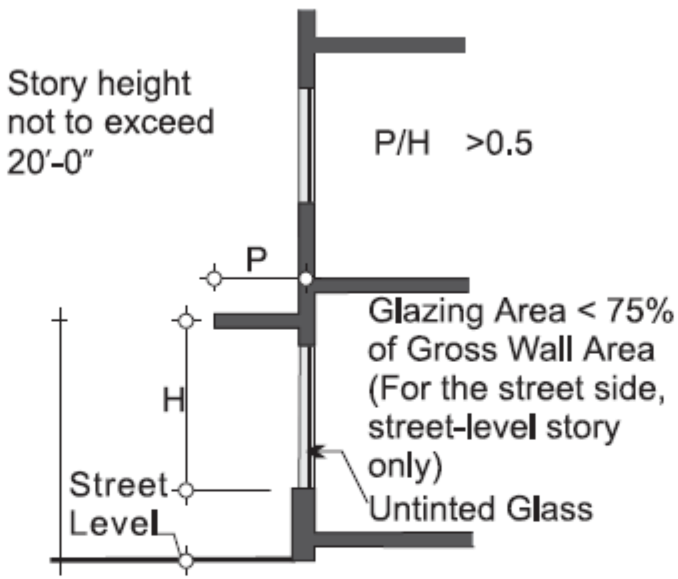
5.5.4.2.1 Vertical Fenestration Area. The total *vertical fenestration area* shall be less than 40% of the *gross wall area.*

- 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



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

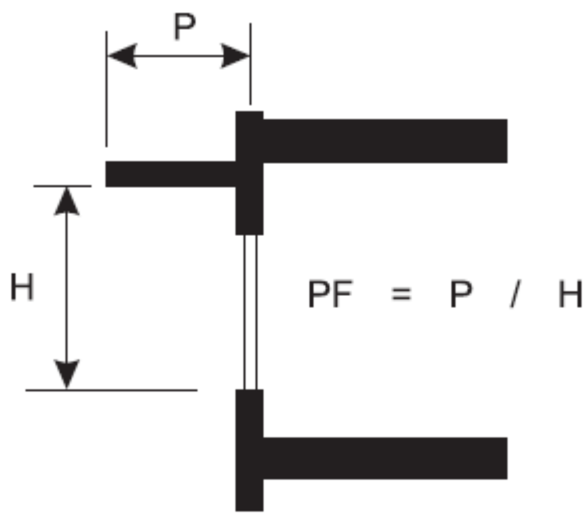


TABLE 5.5.4.4.1 SHGC Multipliers for Permanent Projections

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

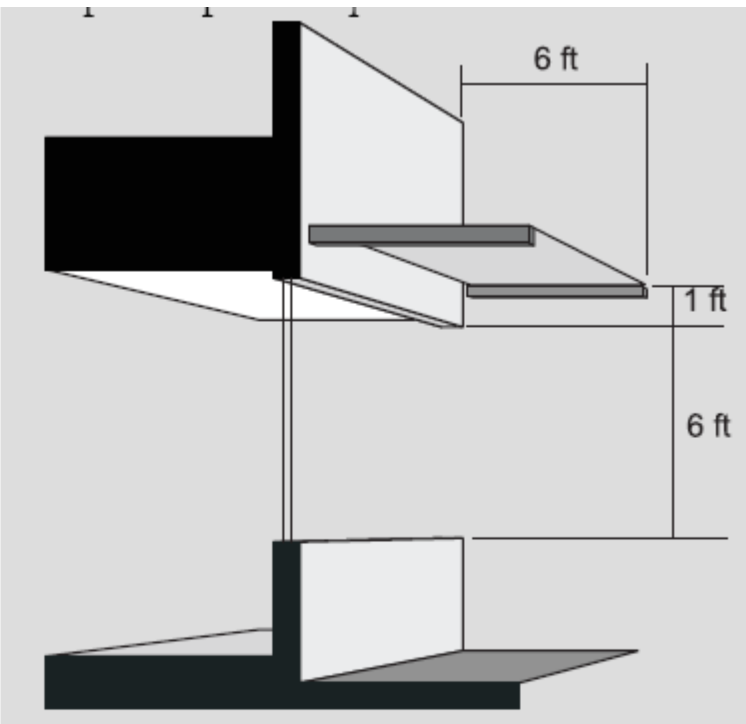
O_i = percent opacity of the infill—for glass O_i = (100% – T_s), where T_s is the solar transmittance as determined in accordance with NFRC 300; for perforated or decorative metal panels O_i = percentage of solid material

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 6 ft wide 30% transparent shading what is the adjusted SHGC?



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

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

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

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

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

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

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 maximum energy use requirements
  - 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 Energy 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
- 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

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 HDD65 and CDD50

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

EPF algorithms

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

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

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

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

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

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

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

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

$$CLC = Area$$

No one does this by hand! Just use software!

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

ed using some
of 90.1

$+ CLXUO +$

$0 + CU2 \times CDH80^2$

$J4 \times DR]$

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

Software to help you out

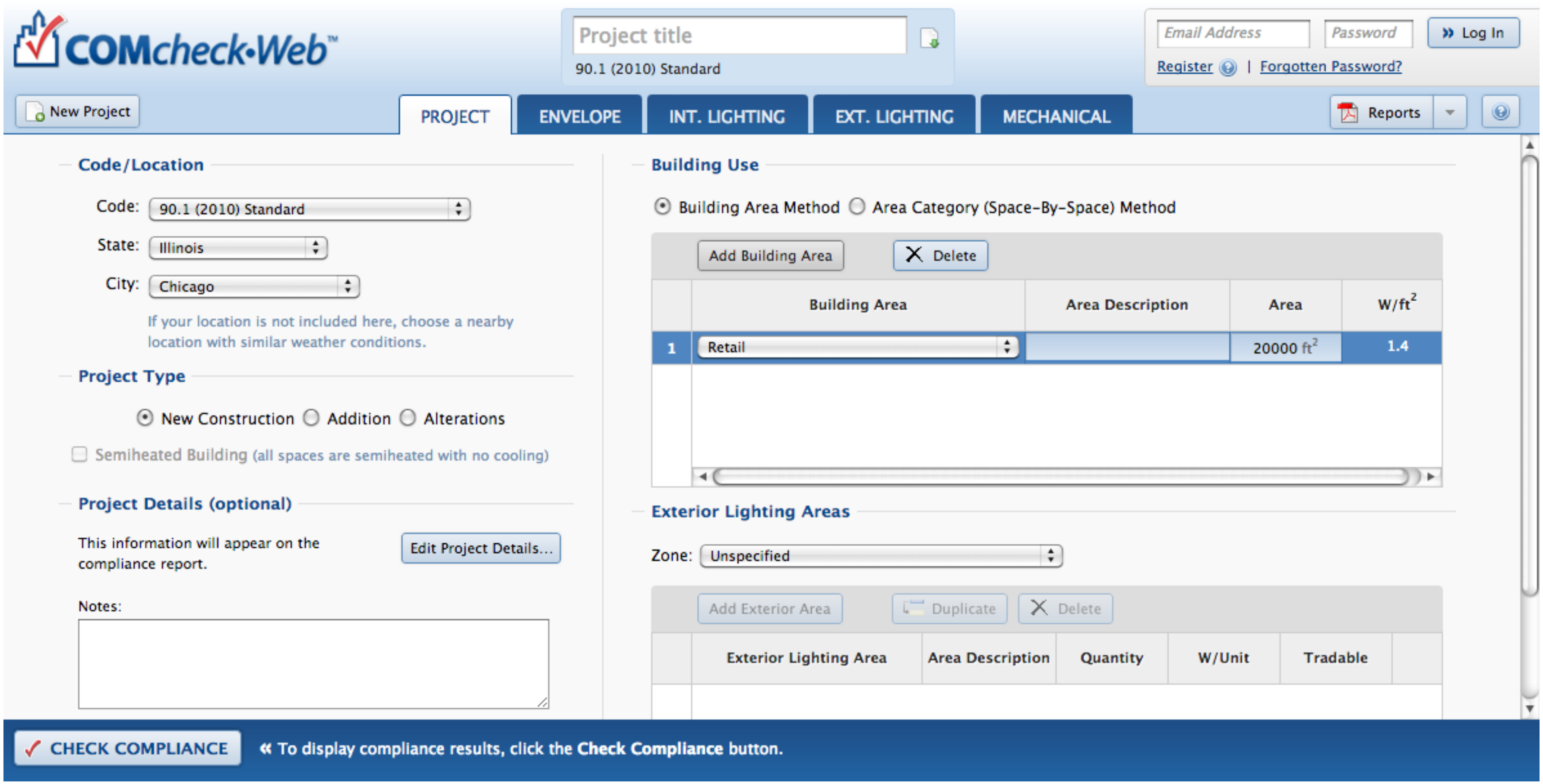
COM*check* and RES*check* from DOE

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

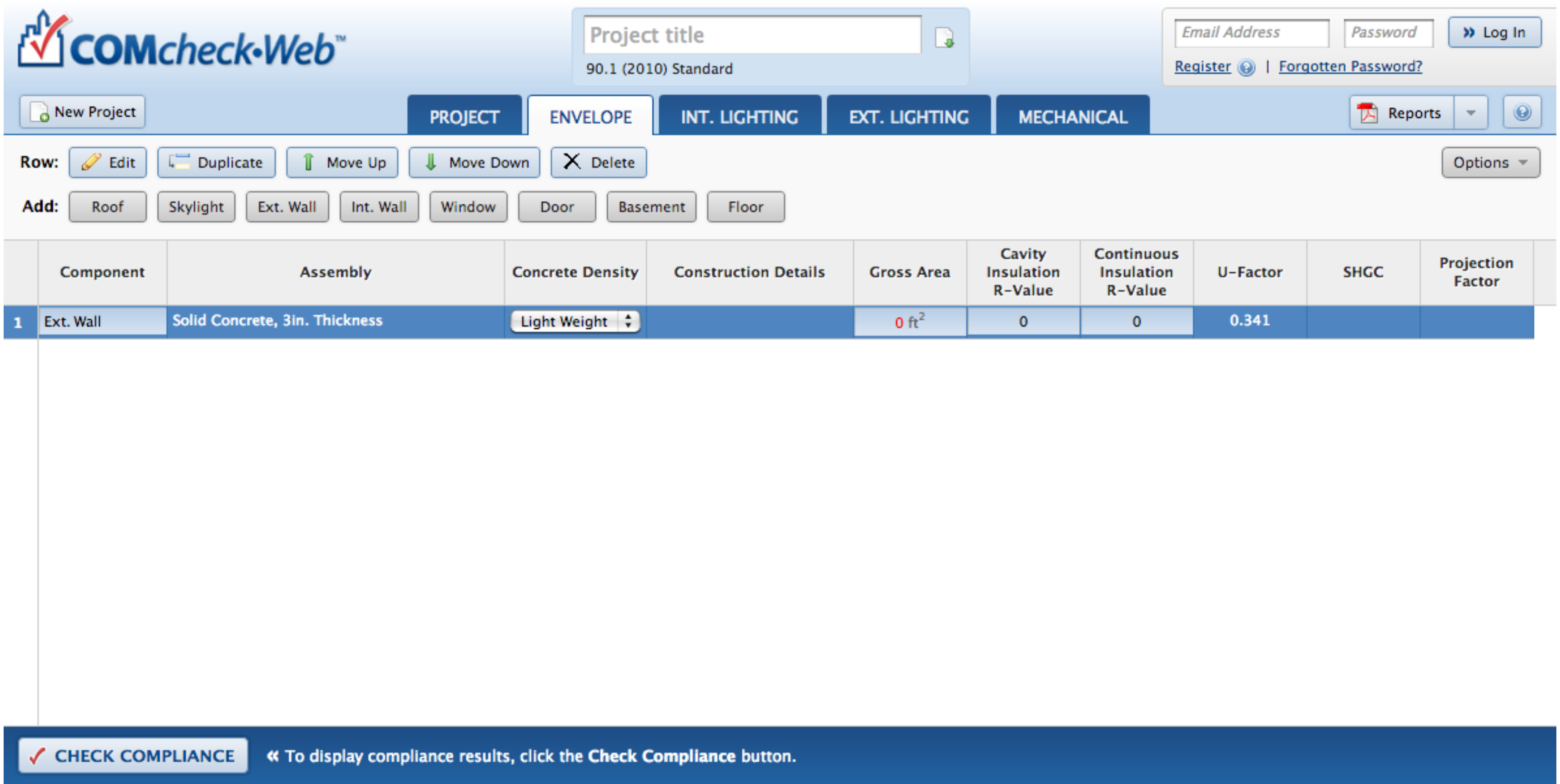
COM*check*

- 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 performance requirement
  - Can be used in lieu of the prescriptive requirements
- Allows for far more flexibility 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 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

LEED and energy use

- 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

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

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