American Concrete Institute®
Advancing concrete knowledge

The Art of Thermal Mass Modeling for Energy Conservation in Buildings, Part 1

ACI Spring 2012 Convention
March 18 – 21, Dallas, TX

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Modeling Energy Use in Buildings with Thermal Mass

Implications for Energy Modelers & Their Needs

Medgar Marceau, PE, ASHRAE
Building Science Engineer
Morrison Hershfield

2012 March 19

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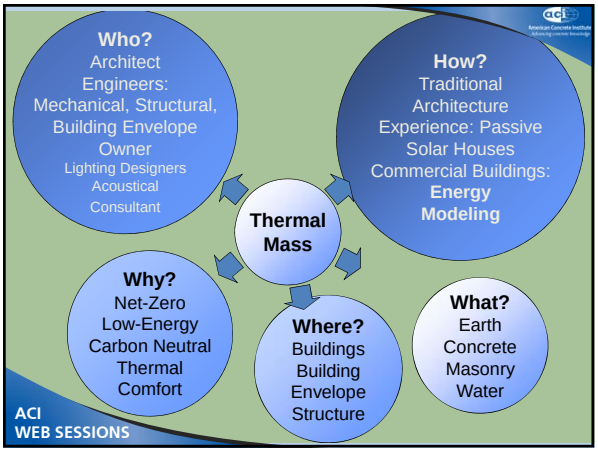

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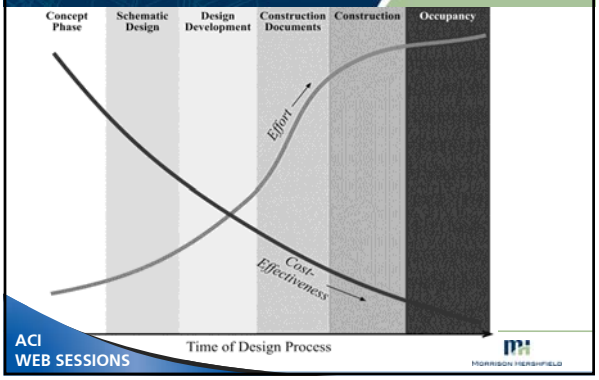
Energy Modeling: When To Do It?



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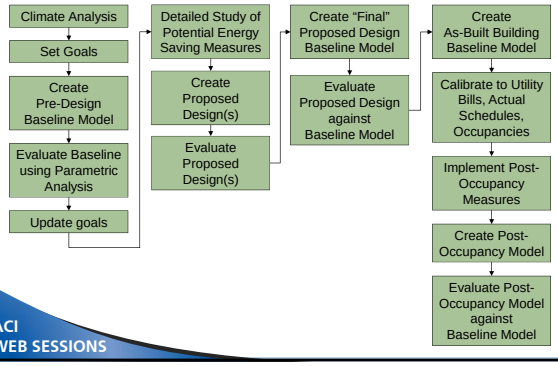
Energy Modeling Process



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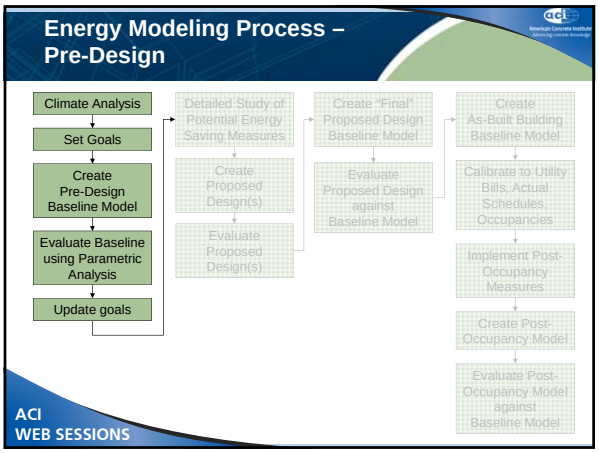
Energy Modeling Process – Pre-Design
Climate Analysis
Set Goals
Create Pre-Design Baseline Model
Evaluate Baseline using Parametric Analysis
Update goals
Detailed Study of Potential Energy Saving Measures
Create Proposed Design(s)
Evaluate Proposed Design(s)
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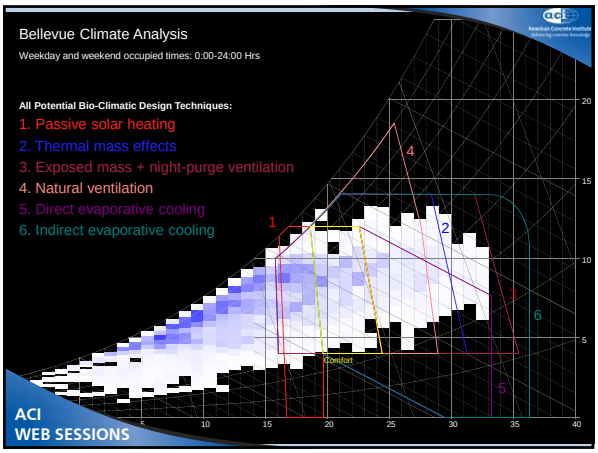
Bellevue Climate Analysis
Weekday and weekend occupied times: 0:00-24:00 Hrs
All Potential Bio-Climatic Design Techniques:
1. Passive solar heating
2. Thermal mass effects
3. Exposed mass + night-purge ventilation
4. Natural ventilation
5. Direct evaporative cooling
6. Indirect evaporative cooling
Comfort
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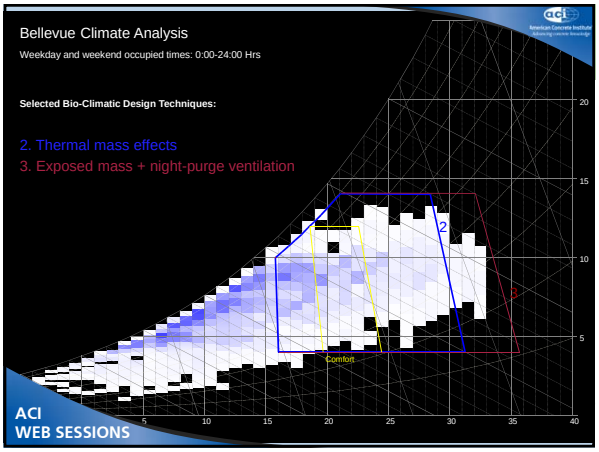
Bellevue Climate Analysis
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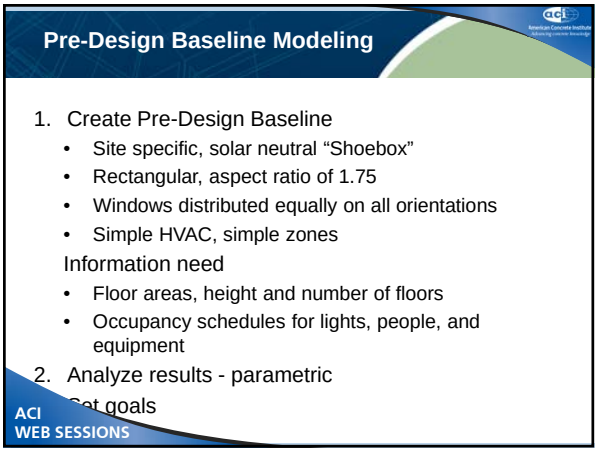
Pre-Design Baseline Modeling
1. Create Pre-Design Baseline
• Site specific, solar neutral "Shoebox"
• Rectangular, aspect ratio of 1.75
• Windows distributed equally on all orientations
• Simple HVAC, simple zones
Information need
• Floor areas, height and number of floors
• Occupancy schedules for lights, people, and equipment
2. Analyze results - parametric
Set goals
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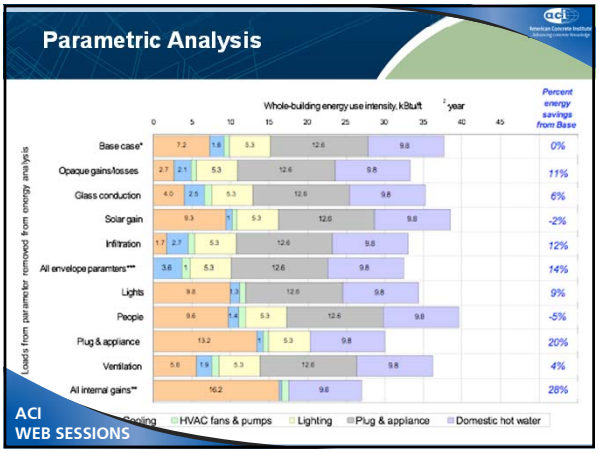
Parametric Analysis
Whole-building energy use intensity, kBtu/ft²/year
Percent energy savings from Base
Base case*
Opaque gains/losses
Glass conduction
Solar gain
Infiltration
All envelope parameters***
Lights
People
Plug & appliance
Ventilation
All internal gains**
Loads from parameter removed from energy analysis
Cooling
HVAC fans & pumps
Lighting
Plug & appliance
Domestic hot water
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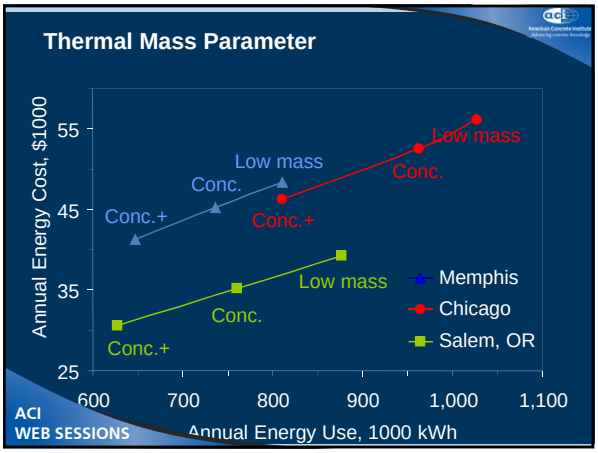
Thermal Mass Parameter
Annual Energy Cost, $1000
Annual Energy Use, 1000 kWh
Low mass
Conc.
Conc.+
Memphis
Chicago
Salem, OR
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Pre-Design Baseline Modeling - Determine Strategies

Perform "elimination parametric analysis" on pre-design baseline:

- Sequentially eliminate loads from baseline to see what effect they have on total energy use
  - Building conduction losses
  - Lighting loads
  - Solar gains
  - Internal gains (people)
  - Internal gains (equipment)
  - Plug loads (computers, photocopiers, etc.)
- Based on what's possible, develop strategies to achieve

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Example Parametric Analysis on Thermal Mass

Conclusion for buildings with thermal mass + R-5 insulation above code + fenestration U-factor 40% better than code:

- Salem:
  - 21% energy cost savings
  - 4 LEED points
- Denver, Chicago:
  - 17.5% energy cost savings
  - 3 LEED points
- Memphis:
  - 14% energy cost savings
  - 2 LEED points

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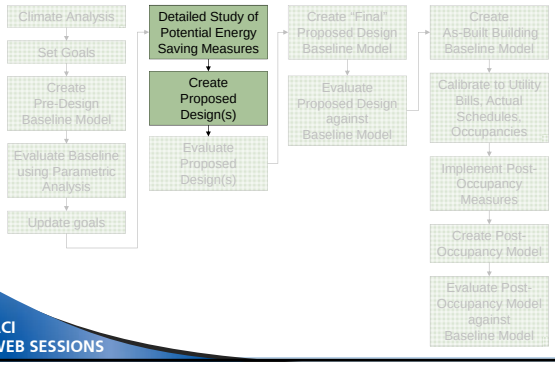
Energy Modeling Process – Schematic Design



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Schematic Design Baseline Modeling – page 1/2

1. Develop diagrammatic building plans
2. **Incorporate building envelope and thermal mass design strategies to reduce loads on energy-using systems**
3. Develop site plan to make best use of orientation and daylighting
4. Select building systems and efficiency level
5. Develop building plans, sections, and details incorporating above strategies

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Schematic Design Baseline Modeling – page 2/2

6. Design review—verify that project meets original goals
7. **Calculate building HVAC loads.**
8. **Match capacity of HVAC systems to design loads.**
9. Perform final coordination and integration of architectural, mechanical, and electrical systems
10. Develop specifications
11. **Integrate commissioning specifications into project manual**

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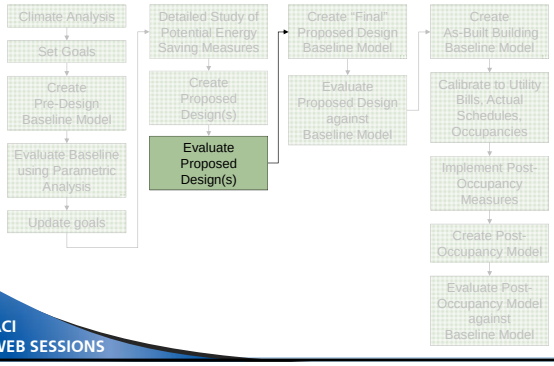
Energy Modeling Process – Design Development



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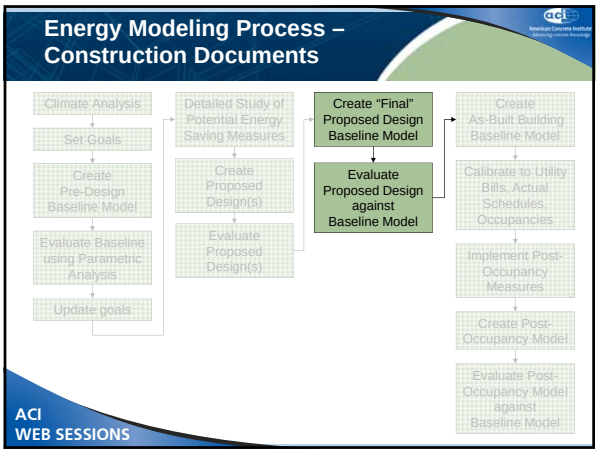
Energy Modeling Process – Construction Documents
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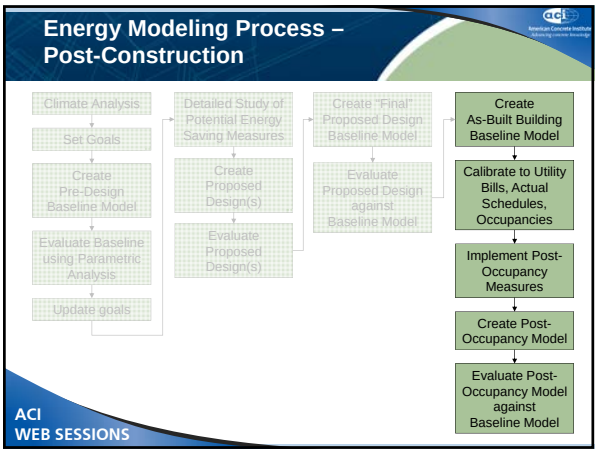
Energy Modeling Process – Post-Construction
Climate Analysis
Set Goals
Create Pre-Design Baseline Model
Evaluate Baseline using Parametric Analysis
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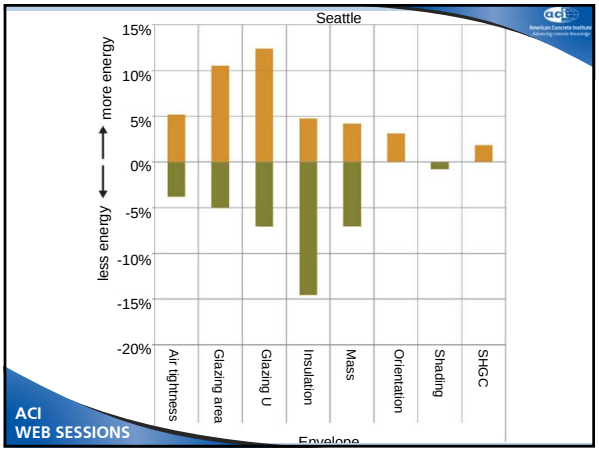
Seattle
less energy
more energy
15%
10%
5%
0%
-5%
-10%
-15%
-20%
Air tightness
Glazing area
Glazing U
Insulation
Mass
Orientation
Shading
SHGC
Envelope
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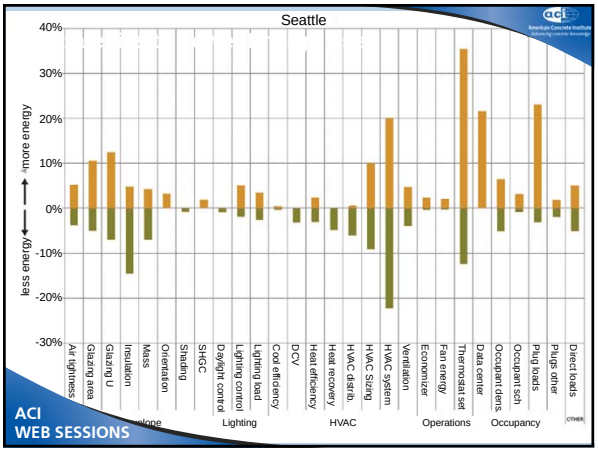
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Glazing U
Insulation
Mass
Orientation
SHGC
Shading
Daylight control
Lighting control
Lighting load
Coil efficiency
DCV
Heat efficiency
Heat recovery
HVAC distrib.
HVAC Sizing
HVAC system
Ventilation
Economizer
Fan energy
Thermostat set
Data center
Occupant dens.
Occupant sch
Plug loads
Plugs other
Direct loads
Envelope
Lighting
HVAC
Operations
Occupancy
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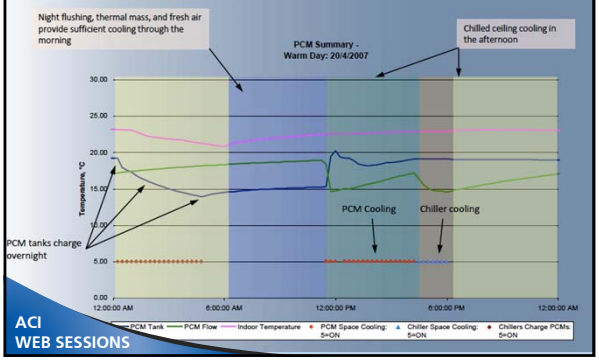
Phase Change Materials – Warm Autumn Day



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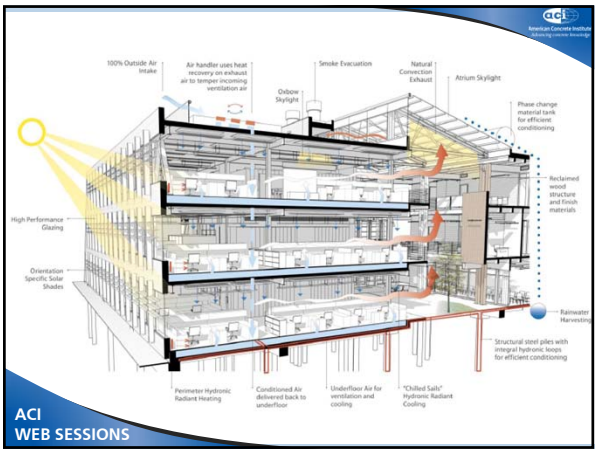

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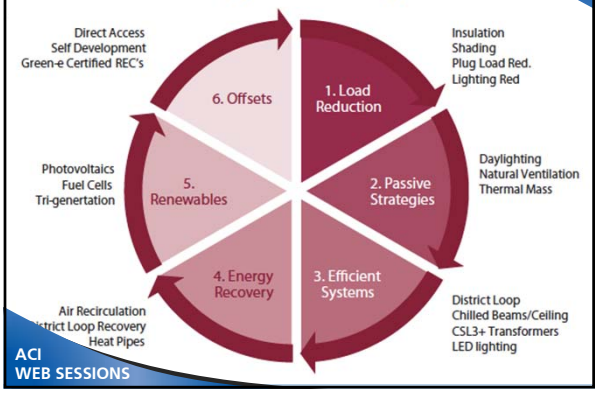
Overall Energy Strategy (Courtesy Arup)



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Strategies to Reduce Energy Use

Minimize heating and cooling loads:

- Minimize glazing on east and west facades
- Minimize solar gains with shading during peak cooling periods
- Optimize R-value for climate and building occupancy
- Eliminate thermal bridges (accounts for significance heat loss)
- Thermal mass reduces energy use in most buildings in most climates
- Maximize southern exposure
- Orient building with long axis East-West
- Use prevailing wind for ventilation

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Needs?

- Energy modeling shows us that thermal mass can save energy
- Integrated design ad post-occupancy data shows us that thermal mass saves energy
- But are we missing something?
- Because energy modeling is still not very accurate

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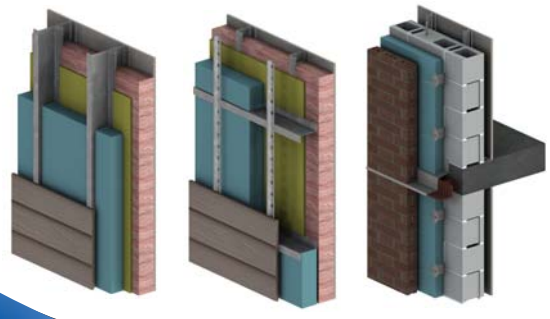
We Live in a 3D World!



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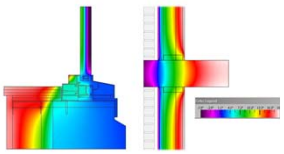
Thermal Bridging

How is Thermal Bridging Typically Evaluated?



2D Computer Modeling

Hand Calculations

Lab Measurement

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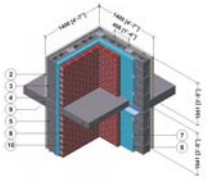
ASHRAE Research Project

Goals and Objectives of the Project

- Calculate thermal performance data for common building envelope details for mid- and high-rise construction
- Develop procedures and a catalogue that will allow designers quick and straightforward access to information
- Provide information to answer the fundamental questions of how overall geometry and materials affect the overall thermal performance



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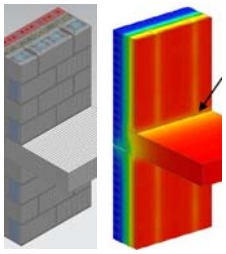
ASHRAE Research Project

Calibrated 3D Modeling Software

- Heat transfer software by Siemens PLM Software, FEMAP & Nx
- Model and techniques calibrated and validated against measured and analytical solutions
- ISO Standards for reference materials/geometry and glazing
- Guarded hot box test measurements, 29 in total

SIEMENS



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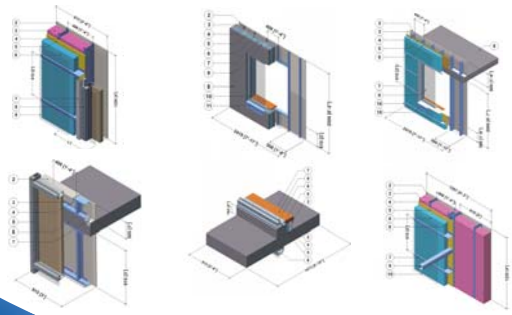
What is ASHRAE Research Project 1365-RP?



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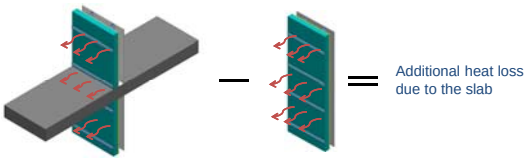
Overall Heat Loss

Q Q_o Q_{slab}



Additional heat loss due to the slab

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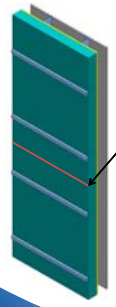
Overall Heat Loss



$$\Psi = Q_{slab} / L$$

The **linear transmittance** represents the additional heat flow because of the slab, but with area set to zero

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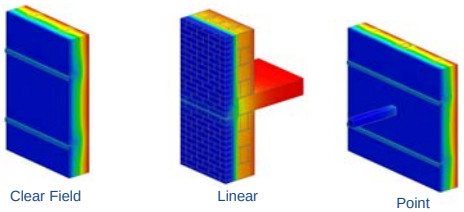
Overall Heat Loss

Types of Transmittances



Clear Field Q_o or U_o

Linear Ψ

Point χ

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Overall Heat Loss, Q

Total heat loss = heat loss due to clear field + Heat loss due to linear anomalies + Heat loss due to point anomalies

$$Q = (U_o \cdot A) + \Sigma(\Psi \cdot L) + \Sigma(\chi \cdot n)$$

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Overall Heat Loss

$$U = \frac{Q}{A_{Total}}$$

or

$$U = \frac{\Sigma(\Psi \cdot L) + \Sigma(\chi \cdot n)}{A_{Total}} + U_o$$

- The assembly U-factor is the clear field U-factor, plus all the linear and point transmittances

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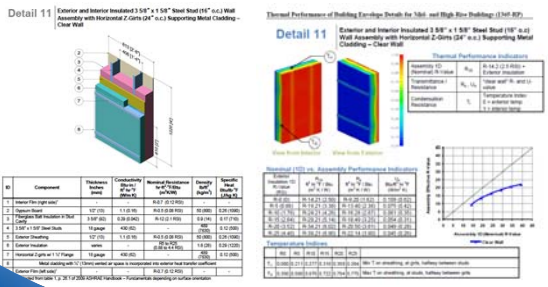
How to Access Results

ASHRAE Data Sheets



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How to Access Results

Nominal (1D) vs. Assembly Performance Indicators

Exterior Insulation 1D R-Value (RSI)	R_{1D} ft² hr °F / Btu (m² K / W)	R_o ft² hr °F / Btu (m² K / W)	U_o Btu/ft² hr °F (W/m² K)
R-0 (0)	R-14.2 (2.50)	R-9.2 (1.62)	0.109 (0.62)
R-5 (0.88)	R-19.2 (3.38)	R-13.4 (2.36)	0.075 (0.42)
R-10 (1.76)	R-24.2 (4.26)	R-16.3 (2.87)	0.061 (0.35)
R-15 (2.64)	R-29.2 (5.14)	R-18.5 (3.25)	0.054 (0.31)
R-20 (3.52)	R-34.2 (6.02)	R-20.5 (3.61)	0.049 (0.28)
R-25 (4.40)	R-39.2 (6.90)	R-22.1 (3.90)	0.045 (0.26)

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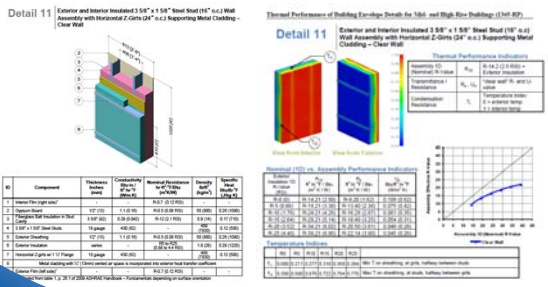
How to Access Results

ASHRAE Data Sheets



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