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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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ACI Spring 2012 Convention

American Concrete Institute, Dallas, Texas
March 19, 2012

U.S. Department of Energy
Energy Efficiency and Renewable Energy

The State of the Art in Building Modeling Software

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Outline

- Scope of Building Modeling
- Performance Criteria
- Modeling Heat Conduction
- Application Examples
- Summary

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Scope of Building Modeling

- DOE Building Energy Software Tools Directory with 405 tools. By subjects:
  - Whole building analysis
    - Energy Simulation
    - Renewable Energy
    - Retrofit Analysis
    - Sustainability/Green Buildings
  - Codes and Standards
  - Materials, Components, Equipment and Systems
  - Other applications
- Building energy modeling (whole building energy simulation) is a subset of the energy simulation

http://apps1.eere.energy.gov/buildings/tools_directory/

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Scope of Building Modeling

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Scope of Building Modeling

- Evaluate energy efficiency measures
- Show design compliance, Energy Cost Budget in ASHRAE Standard 90.1

$$design\ energy\ cost \leq energy\ cost\ budget$$

- Show performance rating, LEED

$$\%\ improvement = \frac{Baseline\ bldg.\ perf. - proposed\ bldg.\ perf.}{Baseline\ bldg.\ performance}$$

- Conduct virtual experiments as research tools, eg. HVAC control, day-lighting…

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Performance Criteria (90.1 Appendix G)

- 8760 hours per year
- Hourly variations in occupancy, lighting, plugload, T setpoints, and HVAC operation
- Thermal mass effects
- Ten or more thermal zones
- Part-load performance curves for mechanical equipment

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Performance Criteria (90.1 Appendix G)

- Capacity and efficiency correction curves for mechanical equipment
- Economizers with integrated control
- Baseline building design characteristics
- Performing design load calculations to determine equipment sizes
- Tested according to ASHRAE Standard 140 (Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs)

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Common Software

- EnergyPlus
- EnergyPro
- EnerSim
- eQuest
- HAP
- IES-VE
- TRACE 700
- VisualDOE

*From USGBC (2011). Advanced Energy Modeling for LEED - Technical Manual v2.0 U.S. Not a complete list. http://apps1.eere.energy.gov/buildings/tools_directory/ Provides a short description and estimated user number

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Modeling Heat Conduction - EnergyPlus

- Conduction Transfer Function (CTF) – default method
  - Heat flux at a surface is determined using the flux history, surface temperature history and CTF coefficients of the wall element.
  - Thermal mass is accounted
- Finite Difference Solution Algorithms (for PCM)
  - Material properties (k, ρ, Cp) are T-dependent Computation intensive
- Heat and Moisture Transfer Algorithms

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Modeling Heat Conduction - EnergyPlus

- Define material
  - Thickness
  - Density
  - Conductivity
  - Specific heat capacity
- Define wall assembly (example)
  - 1st layer: 7 ¼” concrete panel
  - 2nd layer: R13 cavity insulation, 3.5 in. depth steel studs, 16” o.c.
  - 3rd layer: ½” gypsum board

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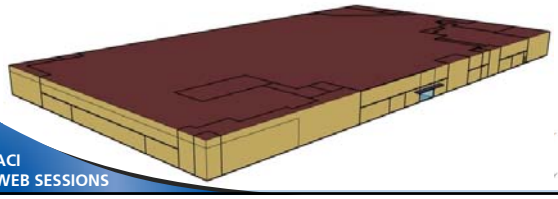
Example 1: Retrofit EEM Evaluations

- Operation and occupancy are known
- Historical energy use are available
- Energy audit was conducted
- Calibrated energy model: assess the savings potential of energy efficiency measures (EEM) and their interactions

Location	Virginia
Building type	Retail
Built	1987
Area	~100,000 ft²
No. of stories	1 level



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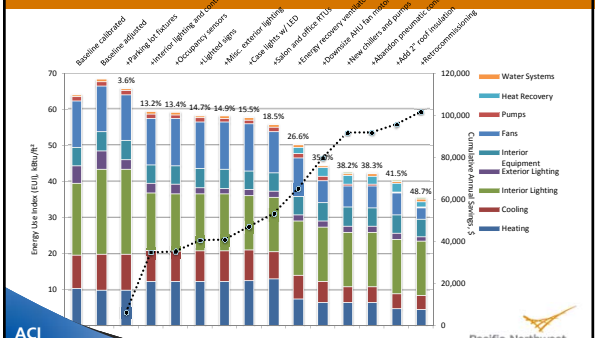
Example 1: Retrofit EEM Evaluations



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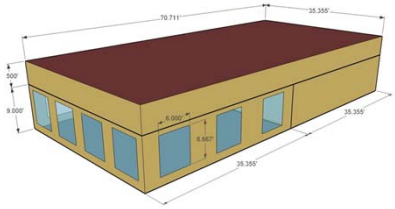
Example 2: 50% Savings for QSR

- ASHRAE AEDG (Advanced Energy Design Guide)
- Quick-service restaurant, new construction
- Baseline meets ASHRAE 90.1-2004
- Climate specific advanced design packages - envelope, lighting, kitchen appliance and HVAC



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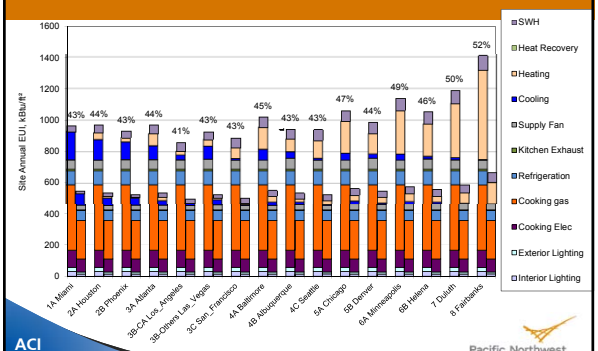
Example 2: 50% Savings for QSR



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Example 3: Code Development

- ANSI/ASHRAE/IESNA Standard 90.1 under continuous maintenance process
- ASHRAE had a goal of 30% savings for 90.1-2010 comparing to 90.1-2004.
- This project measures progress toward the 30% goal
- Book by book comparison

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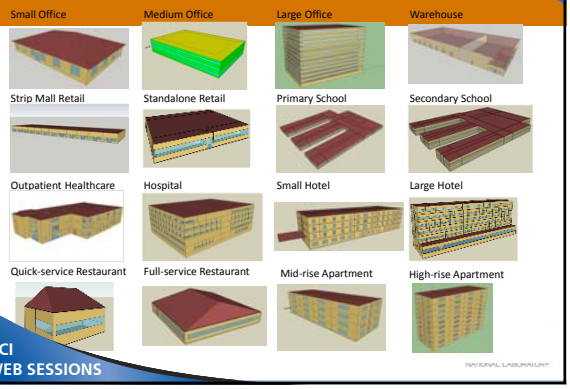
Example 3. Code development



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Example 3: Code development

Climate Zone	Climate Zone Type	Representative City
1A	Very Hot - Humid	Miami FL
1B	Very Hot - Dry	Riyadh, Saudi Arabia
2A	Hot - Humid	Houston, TX
2B	Hot - Dry	PhoenixAZ
3A	Warm - Humid	Memphis, TN
3B	Warm - Dry	El Paso, TX
3C	Warm - Marine	San Francisco, CA
4A	Mixed - Humid	Baltimore, MD
4B	Mixed - Dry	Albuquerque NM
4C	Mixed - Marine	Salem OR
5A	Cool - Humid	Chicago IL
5B	Cool - Dry	Boise ID
5C	Cool - Marine	Vancouver, BC
6A	Cool - Humid	Burlington VT
6B	Cool - Dry	Helena MT
7	Very Cold	Duluth, MN
8	Subarctic	Fairbanks, AK

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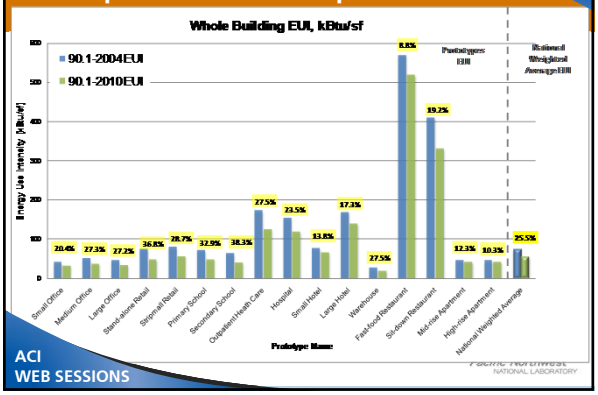
Example 3: Code development



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PNNL Prototype Building Models

- Progress Indicator methodology and prototype building models are documented in PNNL's published report
- 90.1 prototype building models (EnergyPlus input/output files) are published at DOE's Building Energy Codes Program web site
  - 16 prototype buildings
  - 17 climate locations
  - 90.1-2004, 90.1-2007 and 90.1-2010 code-compliant models
  - Scorecards (building basic modeling information)
  - National aggregated site energy savings results
  - EnergyPlus weather files

Download PNNL Report at:
http://www.pnl.gov/main/publications/external/technical_reports/PNNL-20405.pdf

Download the 90.1 Prototype Building Models:
http://www.energycodes.gov/commercial/901models/

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Summary

- Building energy simulation programs are tools for
  - EEM evaluation
  - Code compliance
  - Performance rating
- Performance criteria have been established to ensure confidence in results
- Current programs are capable to account for thermal mass and moisture transfer but they may require
  - Detailed inputs
  - Computational time
  - Convergence issue
- Important decisions are being made based on simulations

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QUESTIONS?

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