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

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Outline

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

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/

INPUT
Design
Characteristics
Weather data

Building
Energy
Simulation
Software

OUTPUT
Whole Building
Energy Use
a lot more
**Scope of Building Modeling**

- Evaluate energy efficiency measures
- Show design compliance, Energy Cost Budget in ASHRAE Standard 90.1
  \[ \text{design energy cost} \leq \text{energy cost budget} \]
- Show performance rating, LEED
  \[ \% \text{ improvement} = \frac{\text{Baseline bldg. perf} - \text{proposed bldg. perf}}{\text{Baseline bldg. performance}} \]
- Conduct virtual experiments as research tools, e.g., HVAC control, day-lighting...

**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

**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)

**Common Software**

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


**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

**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
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

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

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
### Example 3: Code development

<table>
<thead>
<tr>
<th>Climate Zone</th>
<th>Climate Type</th>
<th>Representative City</th>
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<tbody>
<tr>
<td>1A</td>
<td>Very Hot - Humid</td>
<td>Miami, FL</td>
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<tr>
<td>1B</td>
<td>Very Hot - Dry</td>
<td>Riyadh, Saudi Arabia</td>
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<tr>
<td>2A</td>
<td>Hot - Humid</td>
<td>Houston, TX</td>
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<tr>
<td>2B</td>
<td>Hot - Dry</td>
<td>Phoenix, AZ</td>
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<td>3A</td>
<td>Warm - Humid</td>
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<td>3B</td>
<td>Warm - Dry</td>
<td>El Paso, TX</td>
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<td>3C</td>
<td>Warm - Marine</td>
<td>San Francisco, CA</td>
</tr>
<tr>
<td>3D</td>
<td>Mixed - Humid</td>
<td>Baltimore, MD</td>
</tr>
<tr>
<td>3E</td>
<td>Mixed - Dry</td>
<td>Albuquerque, NM</td>
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<td>3F</td>
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<td>Subarctic</td>
<td>Duluth, MN</td>
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<tr>
<td>8</td>
<td>Subarctic</td>
<td>Fairbanks, AK</td>
</tr>
</tbody>
</table>

### 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:
[

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

### 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

### Questions?

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