Building Energy Simulation Accuracy

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Outline

- Background
- Predicted / Measured
- History / Context
- Modeling Issues
- Software Testing
- Gaps and Needs
- Future Work
Background

Energy Prediction Accuracy for Existing Homes:

- Preliminary Thinking
- A work in progress
- Your inputs desired
Predicted / Measured
Predicted vs. Actual Total Heating Energy Results-
Oregon set of 173 Homes
Predicted / Measured

Oregon
% Total Therms Discrepancy vs. Year of Construction

Asset ratings
House-by-house:
- Operational ratings
- Utility-bill calibration

Old Buildings
New Buildings
Predicted / Measured

Predicted Use

Actual Use

Asset Rating
- building models
- building characteristics inputs
- standard operational assumptions built-in

Operational Rating
- building models
- building characteristics inputs
- occupant-specific operational inputs
Reduced variance
Utility-bill calibration
- adjusts building/operational characteristics so that predicted use matches actual use
- applied on a house-by-house basis
- not exact for end uses or measure savings (initial building model should be accurate)
Errors / Inadequacies:
1) building models
2) building characteristics inputs
3) standard operational assumptions
If pre-retrofit energy use is over-predicted …

… then there is the possibility (likelihood) that savings will be over-predicted.

\[
\text{Energy Savings} = (\text{Energy Use})_{\text{Before}} - (\text{Energy Use})_{\text{After}}
\]
Predicted/Measured

Realization rates include effects of operational changes with retrofit (e.g., take-back).

<table>
<thead>
<tr>
<th>Measure</th>
<th>Electricity kWh Savings</th>
<th></th>
<th>Realization Rate</th>
<th></th>
<th>Realization Rate</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Tracking System Estimates</td>
<td>Impact Assessment Results</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Program Year 2003</strong></td>
<td></td>
<td></td>
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<tr>
<td>CFL</td>
<td>601,282</td>
<td>517,021</td>
<td>86%</td>
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<tr>
<td>Water Heater^</td>
<td>46,852</td>
<td>32,878</td>
<td>70%</td>
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<tr>
<td>Gas Furnace</td>
<td>95,155</td>
<td>47,212</td>
<td>50%</td>
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<tr>
<td>Heat Pump</td>
<td>4,521</td>
<td>3,173</td>
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<tr>
<td>Heat Pump Tune Up^</td>
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<td>Ceiling Insulation</td>
<td>215,664</td>
<td>138,302</td>
<td>64%</td>
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<td>Floor Insulation</td>
<td>154,485</td>
<td>99,068</td>
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<td>Wall Insulation</td>
<td>50,362</td>
<td>32,296</td>
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<td>Duct Insulation</td>
<td>17,850</td>
<td>5,403</td>
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<td>Duct Sealing^</td>
<td>10,132</td>
<td>7,110</td>
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<td>Window</td>
<td>63,028</td>
<td>40,419</td>
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<td>Air Sealing^</td>
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<td><strong>Total Program Year 2003</strong></td>
<td>1,259,330</td>
<td>922,882</td>
<td>73%</td>
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<tr>
<td>Gas</td>
<td>Tracking System Estimates</td>
<td>Impact Assessment Results</td>
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<tr>
<td></td>
<td>198,576</td>
<td>138,567</td>
<td>70%</td>
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</table>
History / Context
**Question:** How can energy prediction tools that have been developed over many years be significantly wrong?

**Answer:** Existing-home energy analysis is a niche application. Building energy calculations (and research) have historically been focused on:

1) Equipment sizing
2) Commercial buildings
3) New buildings
History/Context

Sizing Calculations
- Conservative “worst case“ assumptions

Energy Predictions
- Representative “typical“ assumptions
Commercial Buildings

- Simple geometry
- Limited shading
- Limited wind shielding
- Multiple conditioned zones

Residential Buildings

- Articulated geometry
- Increased shading
- Increased wind shielding
- Multiple buffer zones (garage, attic, crawl space)
**History/Context**

**New Buildings**

- Inside
  - \( R - 0.68 \)

- Outside
  - \( R - 0.19 \)

- Low-E

- \( R_{\text{gap}} = 3.13 \)

**Old Buildings**

- Inside
  - \( R - 0.68 \)

- Outside
  - \( R - 0.19 \)

- Single-glazed

- \( R_{\text{glass}} = 0.03 \)

*Increased sensitivity to boundary conditions*
Modeling Issues
Errors / Inadequacies:
1) building models
2) building characteristics inputs
3) standard operational assumptions

Analysis Tool
(BEopt, HESpro)

Internal Inputs:
• defaults
• calculated
• built-in
• models, modes

Simulation Engine
(DOE-2, EnergyPlus)

Models:
• algorithm
• coefficients
Modeling Issues

- Exterior: infrared
  - landscaping, neighbors
  - insect screens
- Exterior: convection
  - landscaping, neighbors
  - insect screens
- Interior: infrared
  - partition walls
  - blinds, drapes
- Interior: convection
  - blinds, drapes
- Solar gains
  - landscaping, neighbors
  - Insect screens
  - blinds, drapes
- Infiltration
  - landscaping, neighbors
  - conduction heat recovery

- Unfilled-cavity R-values
  - Infiltration
- Thermal mass
  - non-structural
- Thermostat Setpoints
  - before retrofit
  - after retrofit
- Zoning
  - Interior temperatures
  - solar gain
  - Internal gains
- Interior Temperature
  - stratification
- Insulation R-value
  - temperature-dependence
- HVAC size
  - under-sized before retrofit
  - over-sized after retrofit
Modeling Issues

Interior Radiation:

**DOE-2**

**EnergyPlus**
Software Testing
Software Testing

Software-to-Software Comparisons:
• BESTEST_EX
• BEopt Test Suite

Objectives:
• Validation
• Diagnostics
BESTEST-EX Document
- Defines a representative existing home and several retrofit measures
- Provides inputs necessary to model existing home and retrofits
- Presents average retrofit energy savings predictions using state-of-the-art detailed simulation programs (EnergyPlus, DOE2.1E, SUNREL)

Inputs
- R-wall = 5.1
- ELA = 196 in²
- Tstat = 68°F
- etc.

Audit Software Provider
- Creates model of existing home using inputs from test
- Predicts retrofit energy savings

Results
- Energy Savings
  - Retrofit Measure A, B, C, D, etc.

Energy Savings
- Retrofit Measure A, B, C, D, etc.
BESTEST-EX: “Utility Bill Calibration” Cases

**BESTEST-EX Document**
- Defines a representative existing home and several retrofit measures
- Provides input ranges for key model inputs

  R-wall = 4.5–6.2
  ELA = 137–216 in\(^2\)
  Tstat = 60–75°F
  etc.

- Presents utility bills that were generated by:
  A) randomly selecting key model inputs within ranges (values remain hidden)
  B) running test cases with selected inputs in EnergyPlus, DOE2.1E, and SUNREL

**Audit Software Provider**
- Creates model of existing home knowing input ranges from test
- Calibrates model inputs using utility bills
- Predicts retrofit energy savings

**Input Ranges**

**Utility Bills**

**Results**

Reference results remain hidden for utility bill calibration cases
New Construction: ~400 options (in ~50 categories)

The U-values and SHGC's are air-to-air for the entire window assembly including frame and glazing (including edge spacer effects).

User-options require specifying the Glass-Type-Code (from DOE-2 window library), frame U-value, window framing factor, and frame spacer type (for multiple pane windows).

Argon-filled windows may not be available at higher altitudes (above approximately 3500 feet), due to issues with atmospheric pressure differences between the installation and manufacturer’s locations.
Minimal Tests
Simulation Differences (DOE-2 versus EnergyPlus)
Atlanta, GA
Minimal Tests
Simulation Differences (DOE-2 versus EnergyPlus)
Phoenix, AZ
Minimal Tests
Simulation Differences (DOE-2 versus EnergyPlus)
Chicago, IL
BEopt Test Suite

![Diagram showing Lighting Energy Use (MMBtu/yr)]

- **Energy Use (MMBtu/yr)**

**Categories:**
- Heating (G)
- Hot Water (G)
- Misc (E)
- Heating (E)
- Heating (O)
- Heating (P)
- Cooling (E)
- Hot Water (E)
- Hot Water (O)
- Hot Water (P)
- Lighting (E)
- Appl (G)
Air Conditioner

Energy Use [MMBtu/yr]

- Heating (G)
- Hot Water (G)
- Misc (E)
- Heating (E)
- Heating (O)
- Heating (P)
- Cooling (E)
- Hot Water (E)
- Hot Water (O)
- Hot Water (P)
- Lighting (E)
- Appl (G)
BEopt Test Suite

The chart titled "Furnace" shows energy use [MMBtu/yr] across different energy sources and Appliance (G). The chart includes categories such as Heating (G), Hot Water (G), Misc (E), Heating (E), Heating (O), Heating (P), Cooling (E), Hot Water (E), Hot Water (O), Hot Water (P), Lighting (E), and Appliance (G). The y-axis represents energy use in MMBtu/yr, while the x-axis lists various energy sources and appliances.
Gaps and Needs
Gaps and Needs

Gaps:
• Current tools do not reliably predict:
  ➢ pre-retrofit energy use
  ➢ retrofit energy savings

Needs:
• Identification of potential sources of discrepancies
• Investigation / resolution of modeling issues
• Validation of improved inputs/models against field data
• Development of analysis best practices
• Updated standard test procedures
Future Work
Residential Energy Simulation -- Test and Improvement Process

1. Identify Modeling Issues:
   - Models/Coefficients
   - Asset Inputs
   - Operational Inputs

2. Literature Review
3. Sensitivity Testing
4. Prioritize:
   - Discrepancy size
   - Level of effort

Define Question

Technical Approach

Develop Solution

Test:
   - Empirical
   - Numerical

NREL Working Group

Advisory Experts

Recommended Best Practice

Updated Test Procedures:
   - ASHRAE 140

Aggregate Solution Testing:
   - Software-to-Empirical
   - Software-to-Software