Energy Modeling Applications for Existing Buildings

Presented by:

Clark Denson
PE, CEM, BEMP, LEED® AP BD+C

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Learning Objectives

1. List available methods and tools for energy modeling

2. Explain how energy modeling can be used at different times during the life of a building

3. Identify appropriate steps for using energy models to explore energy use in existing buildings

4. Understand how energy models can be used to estimate savings of ECMs/FIMs

5. Identify how energy models can be used as a part of an M&V plan to measure actual savings of ECMs/FIMs and ensure those measures are persisting.
What is an Energy Model?

- **Energy Model**
  - A mathematical representation of how building energy systems react to external or internal loads.
- **Whole-building simulation**
  - “An energy model that represents the operations of all building systems simultaneously as opposed to a specific system or area of a building.”
Why Do We Use Energy Modeling?

- Comparative Analysis - Decision-making tool
- Find areas of highest potential impact/savings
- Identify synergies to reduce equipment size
- Identify counter-intuitive building performance relationships
- Green Building certifications and labels
- Utility Rebates/Incentives
Energy Simulation Methods and Tools

• “Determining the most appropriate calculation methodology and energy analysis tool is perhaps one of the most challenging and important steps in the energy audit process.”
  ▫ ASHRAE Procedures for Commercial Building Energy Audits, 2nd Edition

• 2009 ASHRAE Fundamentals says to consider the following factors:
  ▫ Accuracy
  ▫ Sensitivity
  ▫ Versatility
  ▫ Speed and cost
  ▫ Reproducibility
  ▫ Ease of use

• More critical decisions require more accurate tools
Spreadsheet-based Calculators

Measure M1: Reduce supply air pressure setpoint for VAV system

**Inputs**
- Orig. SP: 1.5 in w.g.
- New SP: 1.00 in w.g.
- ΔP: 0.50 in w.g.
- \( \eta_{\text{Fan}} \): 0.6
- \( \eta_{\text{Motor}} \): 0.95

**Demand and Energy Savings**

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**Equations:**

- **[A]** \( \text{CFM} = 412 \times \text{OAT} + 33,511 \) (See trended data below)
- **[B]** \( \text{Delta BHP} = \text{CFM} * \frac{(p/p_{\text{std}})}{(s_{\text{original}} - s_{\text{new}})} \times 6356 / \eta_{\text{Fan}} \) (\( p/p_{\text{std}} = 0.83 \) in Denver)
- **[C]** \( \text{kW}_{\text{save}} = (\text{Delta BHP})^* 0.746 / \eta_{\text{Motor}} \)
- **[D]** \( \text{kWh}_{\text{save}} = (\text{kW}_{\text{save}} \times \text{hours}_{\text{run}}) \)
- **[E]** Peak kW savings = kW savings at 97 F OAT

**Trend Data:**

**Supply Air Flow vs. OAT**

\( y = 412x + 33511 \)

Peak demand savings:
Spreadsheets vs. Whole-building Simulation

• Spreadsheets
  ▫ Simpler to understand and review
  ▫ Encouraged by several utility incentive programs
  ▫ Limited in their applicability

• Whole-building simulation
  ▫ More comprehensive measures
  ▫ Accounts for interactive effects
  ▫ More training to master
Energy Simulation Approaches and Tools

• Steady-state calculations
  ▫ Degree-day method
  ▫ Balance-point Temperature
  ▫ Limited to thermal performance & plant efficiency

• Bin Method
  ▫ Provides reasonable savings for preliminary assessments
  ▫ Using a more detailed tool will not always result in more accurate results if based on estimated operation
  ▫ Limited in its application

• Whole-building modeling/simulation
  ▫ Captures the dynamic nature of commercial buildings
  ▫ Complexity of an hourly simulation model may be required for projects where deeper level of analysis is required, such as:
    • Building Envelope measures
    • Comprehensive projects with interactive measures
    • Documenting tax incentives or green ratings
    • Effect of building massing on cooling load
    • Capability of program to model specific features and technologies such as VRF, daylighting, thermal ice storage, etc.
Whole-Building Energy Simulation

- eQUEST
- Trane TRACE
- Carrier HAP
- EnergyPlus
- EnergyPro
- VisualDOE
- TRNSYS
- IES <VE>
- AECOsim
- ESP-r
- Many others...

http://apps1.eere.energy.gov/buildings/tools_directory/
Anatomy of an Energy Model

• External Loads
  ▫ Shell Geometry and Thermal Performance
  ▫ Weather Data

• Internal Loads
  ▫ Lighting, Occupancy, Plug Loads
  ▫ Utilization Profiles

• Mechanical Equipment
  ▫ HVAC
  ▫ Service Water Heating

• Utility Rates
Shell Geometry and Thermal Performance

REALITY

Simplify

ENERGY MODEL

Text-based Entry

2-D CAD (dwg files)

3-D BIM Import
Weather Data - Annual Weather Files

- Necessary for annual energy and economic analysis
- Useful for developing HVAC design strategies
- Must include 8760 hours
- Generally from sets of averaged data (TMY)
- Actual weather data may be preferred in EBCx

*RMI Building Energy Modeling Workshop*
Lighting, Occupancy, & Plug Loads

Peak Power and Occupancy
- Total watts of all connected power
- Peak number of occupants
- Can be input with density values

Fraction of Heat Gain to space
- Assign proportional amounts of heat to space vs. plenum

Fractional Schedules
- Daily/Weekly/Annual Occupancy Schedules
- Hourly fractional multiplier for peak values
- Daylight Dimming or Occupancy Sensors
Mechanical Equipment

**Chilled Water Cooling Systems**
- Air-cooled chillers or closed-loop cooling towers serving chillers
- Water-cooled chillers served by open-loop cooling towers
- Evaporatively-cooled chillers

**Heating Systems**
- Central boiler plant
- Steam boilers
- Hot water boilers

**Distribution Systems**
- Air handlers with chilled water cooling coils and/or hot water heating coils
- Fan coils
- Radiators
- Chilled beams / radiant panels
Mechanical Systems
Part-load Performance Curves

• Fan power = f(airflow) for VAV systems
• “Canned” & custom curves

**Fan Curve Issues:**
- “Canned” VSD fan curves are often optimistic
- If creating a custom curve, plot it and check it, set appropriate minimum value

• Similar curves for pumps, chillers, boilers

Source: DOE2.2 Volume 2 Dictionary
Utility rates
Types of Charges and Rate Structures

- **Monthly Charge**: Fixed fee for providing energy services
  - $35 per month

- **Energy Charge**: Unit cost for total quantity of energy consumed
  - $0.06 per kWh

- **Demand Charge**: Fee for highest or peak amount of energy used
  - $7.53 per kW

- **Power Factor Charge**: Penalty for lower than optimum power factor
  - $0.40 per KVAR

- **Block Charge**: Unit charge based on different blocks of energy use or demand
  - 0–350 kWh: $0.06 per kWh
  - 350–700 kWh: $0.04 per kWh
  - 700+ kWh: $0.02 per kWh

- **Time of Use Rate**: Prices change during peak and off-peak times
  - Peak Time: $0.24 per kWh
  - Off Peak Time: $0.06 per kWh
Life-Cycle of a Building

New Construction

- Schematic Design
- Design Development
- Construction Documents

Existing Buildings

- Operations
- Existing Building Commissioning
- Measurement & Verification
New Construction: When Do We Use Energy Modeling?

Typical energy modeling timeframe

Level of Effort

Performance Impact

Level of Effort

Project Start

Project Finish

Time
New Construction: Setting Energy Target/Goals

• “If you aim at nothing, you’ll hit it every time.” – Zig Ziglar

• An OPR, written during the pre-design phase, is essential to establishing energy targets for the design team to strive for.

• Energy modeling facilitates setting your target
New Construction: Energy Modeling Process

Schematic Design
- “Wizard” level models
- Load Reduction Analysis
- System Comparisons
- Combination Runs

Design Development
- System Optimization
- Fine-tuning of details
- Further Development of ECMs

Construction Documents
- Value Engineering
- Final Model
- Document for LEED, Utility rebates, etc.
Existing Buildings: AABC Energy Management Guidelines

1. Project Assessment
   ▫ Goal Setting
2. Energy Use Exploration
   ▫ Annual Energy Balance
   ▫ Model Development
3. Site Investigation
   ▫ Data Collection and Calibration
4. ECM/FIM and EBCx Analysis
5. Implementation
6. Final Acceptance
   ▫ Measurement and Verification
7. Continuous Energy Management
   ▫ Update model as a part of Ongoing Commissioning
**Project Assessment:**
**Setting Energy Efficiency Goals**

**Use Energy Modeling to Quantify Targets**

- kBTU/sf/yr
- % reduction below ASHRAE 90.1
- No mechanical cooling

**Goal Setting Charrette**

### Types of Goals

**Overall Target Values**
- EISA 2007
- EUI < 35 kBTu/sf/yr
- Net Zero operating carbon
- Demand < 3 W/sf

**Comparative**
- 55% better than ASHRAE 90.1-2007
- Lowest EUI of any U.S. museum
- 80% water reduction from current use

**Certifications**
- LEED Platinum
- Energy Star score
- ASHRAE Building Energy Quotient
- Living Building Challenge

**End Use Specific**
- 80% reduction in lighting energy from natural daylight
- 100% of heating from waste heat and solar thermal

*RMI Building Energy Modeling Workshop*
Project Assessment: Observation of Potential Measures

- Similar to ASHRAE Level 1 (Walk-through) Audit
- Estimate rough energy cost savings and payback
- No energy modeling necessary
Energy Use Exploration: Annual Energy Balance

- Based on available energy data
- May not require energy model
- Created by estimating, measuring, or modeling each energy end-use
- Energy Model Development
  - Helpful in verifying results of the utility consumption analysis
  - Outputs are only as good as the inputs
  - Useful for analysis of potential ECMs/FIMs
  - Should be calibrated to utility bills
Site Investigation: Data Collection

- On-site data collection serves two purposes:
  - Identify actual building operation for use in model calibration
  - Identify potential Energy Conservation Measures

- Areas of Interest
  - Building Geometry/Envelope
  - Internal Loads
  - Airside Systems
  - Waterside Systems
  - Controls and Operation
Site Investigation: Data Collection

• Building Geometry/Envelope
  ▫ Building Orientation
  ▫ Window-to-Wall Ratio
  ▫ Effective R-value
  ▫ Mass Effects
  ▫ Building Infiltration

2D drawings
Satellite images
Google Earth
Site Investigation: Data Collection

Internal Loads

- Concentrated Process Loads
  - Kitchens
  - Servers
  - Elevators
  - DHW
- Unoccupied Loads
  - Lighting
  - Equipment
  - Process
- Frequency of Use

*Gathering Data for Building Simulation Model Calibration*
Site Investigation: Data Collection

**Airside & Waterside Systems**
- Many moving parts
- Integrated Control Strategies
- Check visible conditions of equipment
- Analyze trend data for proper operation of controls

**Data Most Relevant to Calibration**
- Schedules
  - On/Off Status
  - Unoccupied setpoints
  - Fan cycling?

![Frozen Damper Linkage](image)
Site Investigation: Data Collection

Airside & Waterside Systems

Data Most Relevant to Calibration

- **Air-side**
  - Outside Air Settings
  - Economizer Function
  - VAV box Airflow Reset
  - Supply Air Temperature Reset

- **Equipment Efficiency**
  - Fans
  - Pumps
  - RTUs
  - Boilers
  - Chillers

Outside Air, Anyone?
Site Investigation: Data Collection

Airside & Waterside Systems

Data Most Relevant to Calibration

- **Water-side**
  - Hydronic Loop Flow & Pressure & Reset Controls
  - Chilled Water Temperature & Reset Controls
  - Condenser Water Temperature & Reset Controls

- **Boiler & Chiller loading/cycling**
ECM/FIM and EBCx Analysis

- Energy Model Calibration
- Estimate Energy Savings of ECMs/FIMs
- Validate savings estimates
- Bundle measures to maximize payback
What is Model Calibration?

• A process where model inputs are adjusted so that the model outputs correlate better to actual performance

• Goals:
  ▫ Enhanced model accuracy
  ▫ Increased level of confidence in simulation results
ECM/FIM and EBCx Analysis: Model Calibration

- **Step 1: Calibrate to known data**
  - 1a: **Energy Demand**
    - Installed lighting power, plug loads, peak occupants
    - Equipment capacities
  - 1b: **Energy Consumption**
    - BAS trends and setpoints
    - Known equipment or occupant schedules
    - Weather data

- **Step 2: Calibrate to unknown data**
  - Adjust unknown load schedules, infiltration, efficiencies, and part-load performance for fine tuning
ECM/FIM and EBCx Analysis: Model Accuracy Criteria

- ASHRAE Guideline 14, IPMVP, and FEMP all provide various accuracy criteria
- Mean Bias Error (ERR)
  - A measure of the model accuracy relative to the mean of the data set
- Coefficient of variation of the Root Mean Squared Error [CV(RSME)]
  - A measure of the residuals of the data set not accounted for by the model

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Model Calibration

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ECM/FIM and EBCx Analysis: Calculating and Validating Savings

- Using the calibrated energy model as a baseline, apply ECMs/FIMs and calculate savings.
- Validate estimated savings against previous experience of actual savings or case studies.
- Based on project financing, group/bundle measures to meet project energy goals.

*Figure 1. Site Energy Savings and Simple Payback Period by Measure Type*

*A Study on Energy Savings and Measure Cost Effectiveness of Existing Building Commissioning*
Final Acceptance: Measurement & Verification

**Possible Causes**

- Differing Weather
- Differing Building Usage
- Differing Control
- Equipment Installation and O&M
- Sub-optimal System Operations
Final Acceptance: Measurement & Verification

- To measure the actual savings of each ECM, consider sub-metering and data trending.

- IPMVP, ASHRAE 14, and FEMP provide multiple ways to develop and implement an M&V plan

- More energy model calibration may be needed
  - Calibrate Pre-retrofit and Post-retrofit models to actual weather and operational data

- M&V can help to identify systems that are not operating as intended
Continuous Energy Management: Measure Persistence

- Use the energy model to estimate impact on savings for ECMs/FIMs found not to be persisting.

- Coupling sub-metered data with updating the model can help to ensure that the savings from previously installed measures are persisting.
Continuous Energy Management: Measure Persistence
Continuous Energy Management: Measure Persistence
Continuous Energy Management: Energy Model Maintenance

- The energy model is an investment for ongoing commissioning and continuous improvement.

- In the hands of a skilled modeler, the model can be used to simulate specific conditions, operating schedules, different utility rates.

- A calibrated energy model can be a valuable decision-making tool, both for new and existing buildings.
Resources

- DOE Building Energy Software Tools Directory
- Rocky Mountain Institute BEM Workshop
- ASHRAE Procedures for Commercial Building Energy Audits, 2nd Edition
- AABC Energy Management Guideline
- Calibrating Simulation Models for Existing Buildings
- A Study on Energy Savings and Measure Cost Effectiveness of Existing Building Commissioning
Thank you!