Investigating a Building Enclosure Performance (BEP) Metric

Envelope Technology Research Team Meeting

Nov. 7, 2018
2 to 3pm ET
Agenda

- Welcome, introductions
- Discussion: Building Enclosure Performance (BEP) Metric
  - Overview of ORNL’s research
  - Gathering ETRT Member feedback
  - Next steps with Field Validation
- Update on ETRT Resources and CY 2019 Plans
  - Technology Showcases
  - Passive Walls Performance Analysis
Introductions…

Your name, organization

Experiences with Enclosure Systems

Name your biggest challenge
Dr. Simon Pallin,
Oak Ridge National Laboratory
Building Enclosure Performance Metric

Do we need another metric to evaluate the performance of buildings?
BEP Metric
Examples from other Industries

Target - Fuel Economy

Variables

- Engine
  - Size
  - # of Cylinders
  - Valve resistance + timing
  - Combustion time
  - etc.
- Fuel System
- Air Supply
- Shape (aerodynamics)
- ...

Performance Indicator
**BEP Metric**

**Examples from other Industries**

**Appliances – Energy Efficiency**

**Performance Indicator**

[Image of energy-efficient appliances and a performance indicator chart]
<table>
<thead>
<tr>
<th>Appliances – Energy Efficiency</th>
<th>Performance Indicator</th>
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<tbody>
<tr>
<td>Light Bulb</td>
<td>Lumens / Watts</td>
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<td>Paint</td>
<td>Service Life</td>
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<td>Fabric</td>
<td>Martindale</td>
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<td>Variables</td>
<td>Performance Indicator</td>
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<td>Target – Energy Efficiency</td>
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<td>Building Type</td>
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<td>Thermostat Setpoints</td>
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<td>Predicted EUI (Simulations)</td>
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BEP Metric

Variables
- R-value
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- Thermal Bridges
- Installation Quality
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- ...

Performance Indicator
- EUI [kBtu/ft²]
- Predicted EUI (Simulations)
- ...

- Only Applicable to Existing Buildings
- One-way Connection
- Highly Influenced by Building Usage
BEP Metric

**Variables**
- R-value
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**Performance Indicator**
- EUI [kBtu/ft²]
- Predicted EUI (Simulations)
- ...

- Complicated
- Time Consuming
BEP Metric Theory

Variables:

- R-value
  - Walls
  - Roof
  - Foundation
  - Fenestration

- Thermal Bridges
  - Installation
    - Joints
    - Penetrations
    - Perforations
  - Airtightness
  - Building Type
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  - …

Heat losses/gains from conductive heat transfer are described through **R-value**.

\[
Q_{\text{cond}}[W, Btu/hr] = \frac{\lambda \cdot A}{d} \cdot (T_e - T_i) = \frac{A}{R} \cdot (T_e - T_i)
\]

\[
Q_{\text{conv}} = R_a \cdot \rho_a \cdot c_a \cdot (T_e - T_i)
\]
BEP Metric
Theory

Variables

- R-value
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\[
R_{\text{eff}} = \frac{1}{(K_{\text{cond}} + K_{\text{conv}}) \cdot A}
\]

\[
K_{\text{cond}} = \frac{\lambda \cdot A}{d}
\]

\[
K_{\text{conv}} = R_a \cdot \rho_a \cdot c_a
\]
**Variables**

- **R-value**
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\[ R_{eff} = \frac{1}{(K_{cond} + K_{conv}) \cdot A} \]
BEP Metric
Theory

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BEP Metric

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Thoughts…
Reactions…

…Tell us what you think
Thermal Mass
Exterior and Interior Loads

Temperature °F

<table>
<thead>
<tr>
<th>AM</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>70</td>
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<tr>
<td>70</td>
<td>60</td>
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<tr>
<td>60</td>
<td>50</td>
</tr>
<tr>
<td>50</td>
<td>40</td>
</tr>
</tbody>
</table>

- **Indoor Temperature**
- **Outdoor Temperature**
Thermal Mass
Exterior and Interior Loads

 Temperature °F

<table>
<thead>
<tr>
<th>Time</th>
<th>AM</th>
<th>12</th>
<th>3</th>
<th>6</th>
<th>9</th>
<th>12</th>
<th>3</th>
<th>6</th>
<th>9</th>
<th>12</th>
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<tr>
<td></td>
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<td>80</td>
<td>70</td>
<td>60</td>
<td>50</td>
<td>40</td>
<td>50</td>
<td>60</td>
<td>70</td>
<td>80</td>
</tr>
</tbody>
</table>

- **Indoor Temperature**
- **Outdoor Temperature**
Thermal Mass
Exterior and Interior Loads

Exterior and Interior Loads

Phase Change ($\varphi$)

Amplitude [$A_e$]

Exterior Loads

Amplitude [$A_i$]

Solar + Interior Loads

Indoor Temperature

Outdoor Temperature
Thermal Mass
Exterior and Interior Loads

Temperature °F

12 3 6 9 12 3 6 9 12

AM PM

80
70
60
50
40

Amplitude $[A_e]$ Exterior Loads
Solar + Interior Loads

Phase Change ($\varphi$)

Indoor Temperature
Outdoor Temperature

Amplitude $[A_i]$
Thermal Mass
Impact of Demand Charges

1. **Energy charges**
   Total amount of energy used

2. **Demand charge**
   Highest 15-minute peak each month
Thermal Mass
Impact of Demand Charges

<table>
<thead>
<tr>
<th>Customer A</th>
<th>Customer B</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 kW load for 50 hours:</td>
<td>5 kW load for 500 hours:</td>
</tr>
<tr>
<td><strong>Usage</strong></td>
<td><strong>Usage</strong></td>
</tr>
<tr>
<td>Energy = 50 kW x 50 hours = 2,500 kWh</td>
<td>Energy = 5 kW x 500 hours = 2,500 kWh</td>
</tr>
<tr>
<td>Demand = 50 kW</td>
<td>Demand = 5 kW</td>
</tr>
<tr>
<td><strong>Bill</strong></td>
<td><strong>Bill</strong></td>
</tr>
<tr>
<td>Energy = 2,500 kWh x $0.15 = $375.00</td>
<td>Energy = 2,500 kWh x $0.15 = $375.00</td>
</tr>
<tr>
<td>Demand = 50 kW x $28.00 = $1,400.00</td>
<td>Demand = 5 kW x $28.00 = $140.00</td>
</tr>
<tr>
<td>Total = $1,775.00</td>
<td>Total = $515.00</td>
</tr>
</tbody>
</table>

Identical energy usage, but very different totals due to PATTERN of energy usage.
BEP Metric
Equation – Work in Progress

\[ BEP = \text{Thermal Resistance} \quad | \quad \text{Peak Demand} \quad | \quad \text{Response Time} = \]

\[ \frac{1}{A_{tot}}(A_{wall} \cdot R_{wall}^{-1} + A_{roof} \cdot R_{roof}^{-1} + A_{fen} \cdot U_{fen} \cdot R_{inf}^{-1}) \]

\[ \lambda_{install} \]

\[ \max(A_i, A_e) \cdot \rho \cdot c \cdot V \]

Time

Phase Change (\(\varphi\))

Temperature °F

40 50 60 70 80

AM  PM

Amplitude \([A_i]\) 
Solar + Interior Loads

Amplitude \([A_e]\) 
Exterior Loads

Oak Ridge National Laboratory
BEP Metric
Equation – Work in Progress

\[ \text{BEP} = \text{Thermal Resistance} \mid \text{Peak Demand} \mid \text{Response Time} = \]

\[ \frac{1}{A_{\text{tot}}}(A_{\text{wall}} \cdot R_{\text{wall}}^{-1} + A_{\text{roof}} \cdot R_{\text{roof}}^{-1} + A_{\text{fen}} \cdot U_{\text{fen}}) + R_{\text{inf}}^{-1} \]

\[ \lambda_{\text{install}} \]

\[ \max(A_i, A_e) \cdot \rho \cdot c \cdot V \]

\[ \text{time} \]

Example:

\[ \text{BEP} = 7.8 \mid 125 \mid 5.5 \]

Overall Thermal Resistance [BTU/(hr\cdot°F\cdotft²)]

Peak Demand [W/ft²]

Time Lag [hr]
BEP Metric
Equation – Work in Progress

\[ \lambda_{\text{install}} \quad - \quad \text{The BEP Installation Defect Factor} \]

\[ \lambda_{\text{install}} = \lambda_{\text{install.walls}} \times \lambda_{\text{install.roof}} \times \lambda_{\text{install.fen}} \times \lambda_{\text{install.inf}} \times \ldots \]
BEP Metric Validation

Simulations — Lab Testing — Field Testing — Real Building

BEP metric
BEP Metric
Validation

Simulations    Lab Testing    Field Testing    Real Building

BEP metric
BEP Metric Validation

Simulations  Lab Testing

BEP metric

Net Energy Transfer Through Building Envelope

-2000 -1500 -1000 -500 0 500
Month

0 2 4 6 8 10 12

Simple Thermal Resistance Model
Complex Thermal Resistance Model
BEP-metric Simple Implementation
BEP-metric Complex Implementation
BEP Metric - Next Steps

Q4 CY’18
- Identifying Partners and data sets
- Gathering data sets

Q1 – Q2 CY’19
- Running simulations
  - Modeled
  - Real building
- Evaluating results
- Assessing potential additional validation needs

Q3 CY ‘19
- Summarize work
  - Guidelines
  - Case studies
  - Tools and resources

• Validate metric against field tests and actual building performance data
• Implement solar radiation (SHGC)
• Sensitivity analyses on BEP input variables
• Gather information for Installation Defect Factor
• Finalize BEP formulation/equation
Data Needed for Field Testing

- Building type
- Location
- Floor area (preferably building envelope surface area)
- Number of floors
- Year of construction
- Wall type and R-value (e.g., mass wall, steel frame)
- Roof type and R-value (e.g., Metal, IEAD)
- Window to wall ratio, including window area (N/S/E/W)

- Window performance (U, SHGC)
- Automated window attachments (e.g., curtain, blinds, etc.)
- Airtightness/air barrier system employed (e.g., 0.4 CFM/ft²)
- Occupancy schedule / Business hours
- Electricity and Gas consumption (monthly/annual)
New ETRT Resources

Enclosure Technologies
- Tech Showcase: Windows and Air Barrier Technologies
- Tech Showcase: Enclosure Systems, Air Barrier Technologies, & Window Attachments

BECx
- Half-Day Workshop: Going Deep on Enclosure Commissioning
- BECx Resources Page (coming soon)

Airtightness
- Airtightness of Commercial Buildings – Where are we and where could we go? D. Hun et al, 2018 ACEEE Summer Study on Efficient Buildings
- ORNL/ABAA/NIST Airtightness Savings Calculator
Categorize common commercial wall assemblies
- Research availability of measured envelope data
- Identify performance indices for control and energy optimization

Identify simulation model deficiencies
- Do the models capture all the real wall assemblies accurately?

Conduct sensitivity analysis
- Light weight wall vs mass wall systems

Compare Performance in Natural Exposure Testing Facility

Wall panel data
- Air leakage
- Pressure distribution
- Temperature
- Relative humidity
- Moisture content
- Heat flux

Seeking ETRT Partner input: Building Envelope Data
Wrap up/Next Steps

- Next Envelope Team Meeting
  - Late winter or early spring 2019
- Get involved
  - BEP Metric field validation
  - Passive Walls research
- Additions to ETRT Website
  - Building Enclosure Commissioning resources page
Lots of great feedback!
Thank you!

Simon Pallin, PhD

pallinsb@ornl.gov
Join the Team!

Members
(includes: Building Owners/Mgrs, Property Managers, A&E, Construction/ Installers)

- Adams 12
- Allegheny County Community College
- Arlington Initiative to Rethink Energy (AIRE)
- Brevard County School Board
- Clark Atlanta University
- Cook County Bureau of Asset Mgmt
- Emory University
- exp US Services, Inc.
- Green Dinosaur Inc.
- Hersha Hospitality Mgmt
- HOK
- Instituto Superior de Engenharia do Porto
- Legacy Health
- MA Dept of Energy Resources

- More
- Newmark Grubb Knight Frank
- Parkway Schools
- SABEY Data Centers
- Schmidt
- SIM²
- Smart Building Strategies LLC
- TN Office of Energy Programs
- Tishman Speyer
- Turner Construction Company
- US Army Corps of Engineers
- z2zero
Join the Team!

Friends
(Includes: Researchers, Academics, Trade Associations, Energy Service Providers, Manufacturers, Subject Matter Experts)

- Air Barrier Assoc of America
- American Institute of Architects
- AppleBlossom Energy, Inc.
- Argonne Nat’l Lab
- Association for Energy Affordability
- BA Consult
- BROAD U.S.A. Inc.
- Building Commissioning Assoc
- Building Envelope Materials (BEM)
- Burns & McDonnel
- Cadmus Group
- Covestro LLC
- Dow
- Dunsky Energy Consulting
- EIFS Industry Members Association
- Guardian Glass
- Humann Building Solutions
- ICF
- NanoPore
- National Fenestration Rating Council
- Northwest Energy Efficiency Alliance
- NRG Insulated Block
- Owens Corning
- QuadLock
- Renovate by Berkowitz
- Rmax Operating, LLC
- SGH®
- Sustainability Consultants LLC
- UNIFRAX
- USG Corporation
- WJE