META-REVIEW OF BEHAVIOR-BASED ENERGY-SAVINGS POTENTIAL ESTIMATES FOR COMMERCIAL BUILDINGS

OCTOBER 22, 2016
Buildings would work perfectly if it weren’t for the people in them.

--Anonymous, ACEEE Conference, circa 1993
Simulations of occupant behavior in private offices show that occupants who are proactive in saving energy … consume 50% less energy than average occupants.

-- Hong and Lin 2013
## Behavior-Based Savings Potential: Residential

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Focus:</td>
<td>Carbon Emissions</td>
<td>Energy Savings Opportunities</td>
<td>Energy Savings</td>
</tr>
<tr>
<td>Savings</td>
<td></td>
<td></td>
<td>Opportunities</td>
</tr>
<tr>
<td>Scope:</td>
<td>17 Household</td>
<td>110 HH Actions (Roughly)</td>
<td>27 HH Actions</td>
</tr>
<tr>
<td>Actions</td>
<td></td>
<td></td>
<td>(Roughly)</td>
</tr>
<tr>
<td>Potential Savings:</td>
<td>20% (of HH Direct</td>
<td>22%</td>
<td>30%</td>
</tr>
<tr>
<td>Residential Sector</td>
<td>Emissions)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potential Savings:</td>
<td>7.4% (of National</td>
<td>9%</td>
<td>11%</td>
</tr>
<tr>
<td>National</td>
<td>Emissions)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Period to Achieve Max.</td>
<td>10 years</td>
<td>5 to 8 years</td>
<td>N/A</td>
</tr>
<tr>
<td>Annual Savings</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Conservative estimates for Residential and Personal Transport only.
BEHAVIOR-BASED SAVINGS POTENTIAL: COMMERCIAL

But what do we know about the energy savings that could be achieved via changes in *occupant* and *operator* behaviors in *commercial* buildings?

Meta-Review
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1. Overview of the Studies
2. Comparisons and Insights
3. Take-Aways
STUDIES OF BEHAVIORAL POTENTIAL

Where we looked:

- Journal articles
- Conference proceedings: ACEEE, ECEEE
- Conference presentations: BECC

The studies we found:

1 – Azar & Menassa 2014
3 – Norton et al. 2013 / Burke & Baker 2008
4 – Wikler et al. 2016
HIGH-LEVEL FINDINGS

4 - 91

Occupant & operator behaviors

<1-7%

Achievable Potential

12-21%

Technical Potential
MEASURES OF BEHAVIOR POTENTIAL

What do we mean by Potential?

**Technical Potential**: The amount of energy savings that would be possible if ALL relevant opportunities to improve energy efficiency are taken immediately.

**Achievable Potential**: The energy efficiency savings that could be expected in response to specific barriers, incentives, influences and other factors that determine participation.

Accounts for eligibility and likely participation rates
"A comprehensive framework to quantify energy savings potential from improved operations of commercial building stocks"  

*Energy Policy* 67 (2014)

**Method:** Commercial building energy modeling is used to emulate existing building conditions. Related studies in literature are used in the building energy modeling process to quantify the energy savings potential from improved building operations. Finally, sampling weights are used to generalize the obtained results to the entire stock of buildings under study.

<table>
<thead>
<tr>
<th>Study</th>
<th>Scope</th>
<th>No.</th>
<th>Types</th>
<th>End Uses</th>
<th>Savings</th>
</tr>
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<tbody>
<tr>
<td>Azar and Menassa 2014</td>
<td>Natl; Office Bldgs; Elec &amp; N.Gas</td>
<td>4</td>
<td>Thermostat setpoints, unoccupied equip use &amp; lighting</td>
<td>HVAC, equipment, lighting</td>
<td>Technical, 21%</td>
</tr>
</tbody>
</table>

1. **CBECS DATA**
   - Commercial Buildings Energy Consumption Survey
     - Building Activities and Building Characteristics
     - Building Count per building type and census division
     - Building Area per building type and census division
     - Energy Intensity per building type and census division

2. **CENSUS DATA**
   - Population and demographic information

3. **LITERATURE REVIEW AND EXPERT INSIGHTS**
   - Technology Saturation
   - Energy consumption by end use and building type
   - Opportunities for energy savings by building type and energy end use

**ESTIMATES OF ACHIEVABLE SAVINGS**
from Occupant and Operator Behaviors
### EHRHARDT-MARTINEZ 2015, 2016

<table>
<thead>
<tr>
<th>End Use</th>
<th>No. of Behaviors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space Heating</td>
<td>15</td>
</tr>
<tr>
<td>Space Cooling</td>
<td>10</td>
</tr>
<tr>
<td>Ventilation</td>
<td>5</td>
</tr>
<tr>
<td>Water Heating</td>
<td>8</td>
</tr>
<tr>
<td>Lighting</td>
<td>12</td>
</tr>
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<thead>
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<th>End Use</th>
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<tbody>
<tr>
<td>Cooking</td>
<td>3</td>
</tr>
<tr>
<td>Refrigeration</td>
<td>11</td>
</tr>
<tr>
<td>Office Equipment</td>
<td>8</td>
</tr>
<tr>
<td>Computers</td>
<td>7</td>
</tr>
<tr>
<td>Other</td>
<td>12</td>
</tr>
</tbody>
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#### Behaviors

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<tr>
<td>Ehrhardt-Martinez 2015, 2016</td>
<td>5 U.S. cities; 9 bldg. types; Elec &amp; N.Gas</td>
<td>A wide range: thermostat set points to computers</td>
<td>All</td>
<td>Achievable 7%</td>
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Method:
1. Extensive primary data collection and metering.
2. Determination of efficient technologies and behaviors for each end use.
3. Enhanced engineering analysis to assess energy usage and waste.

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<td>16</td>
<td>Turn off, settings, maintenance, virtualization</td>
<td>Lighting, cooling, vent, motors, refrigeration, office equip.</td>
<td>Technical, 12-18%</td>
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**Method:** Estimate savings opportunity associated with particular types of behavioral interventions given the existing building stock and equipment stock. Representative programs modeled: building operator certification, lighting controls, building energy management systems, and tenant engagement.

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<td>Bldg. operations, lighting controls, tenant engagement</td>
<td>HVAC, lighting, equip., plug load</td>
<td>Achievable &lt;1%</td>
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2. Comparisons and Insights

3. Take-Aways
# LOOKING ACROSS STUDIES

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INSIGHTS: OFFICES, EDUCATION, RETAIL ARE IMPORTANT

BB Energy Savings Potential by Building Type and City

Top 5 Building Types:
- Office
- Education
- Retail
- Healthcare
- Hotels/Lodging

Source: Ehrhardt-Martinez 2016
INSIGHTS: OFFICES, RETAIL, AND EDUCATION BUILDINGS REPRESENT A LOT OF THE BEHAVIOR-BASED OPPORTUNITY*

<table>
<thead>
<tr>
<th>Building Type</th>
<th>% of City-level Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offices</td>
<td>28%-33%</td>
</tr>
<tr>
<td>Education</td>
<td>22%-24%</td>
</tr>
<tr>
<td>Retail</td>
<td>16%-20%</td>
</tr>
<tr>
<td>Sub-Total</td>
<td>68%-75%</td>
</tr>
<tr>
<td>Remaining 6 Building Types</td>
<td>25%-32%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
</tr>
</tbody>
</table>

Source: Ehrhardt-Martinez 2016

*Of the 9 commercial building types included in the study.
INSIGHTS: LIGHTING, HVAC, AND COMPUTERS ARE GOOD TARGETS

BB Energy Savings Potential by End Use and City

Source: Ehrhardt-Martinez 2016
INSIGHTS: END USE SAVINGS POTENTIAL VARIES DRAMATICALLY BY BUILDING TYPE

BB Energy Savings Potential by End Use and Building Type

Source: Ehrhardt-Martinez 2016
Savings Estimates by Building Size and Vintage

- Large office <1980: 10%
- Large office >1980: 11%
- Medium office <1980: 19%
- Medium office >1980: 22%
- Small office <1980: 26%
- Small office >1980: 27%

Average savings across all U.S. Office Buildings = 21%

Source: Azar and Menassa 2014
INSIGHTS: HVAC-RELATED POTENTIAL IS THE LARGEST

HVAC Savings by End Use:
Large 5-15%
Medium 7.5-17%
Large 10-23%

Equipment Savings ≈ 5-15%
Lighting ≈ 2-3%

Source: Azar and Menassa 2014
INSIGHTS: BEHAVIOR AND TECHNOLOGY-BASED OPPORTUNITIES OVERLAP

Energy Use Classified in Baseline Study

- 21% Efficient Usage 61%
- 12% Shared Waste *
- 6% Behavioral Waste 12-18%
- Technological Waste 21-27%

*Either technology or behavior waste, depending on which is addressed first.

Source: Norton (Opinion Dynamics) 2013
### BB Savings Ranking by End Use

<table>
<thead>
<tr>
<th>Study</th>
<th>HVAC</th>
<th>Lighting</th>
<th>Office Computers &amp; Equip.</th>
<th>Hot Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Azar &amp; Menassa (offices) 2014</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>?</td>
</tr>
<tr>
<td>Norton (C&amp;I) 2013</td>
<td>2</td>
<td>1</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Ehrhardt-Martinez (Comm.) 2015</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Ehrhardt-Martinez (offices) 2015</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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TAKE AWAYS

Technical BB Savings Potential =
• 21% in office buildings; 4 behaviors (Azar & Menassa 2014)
• 12-18% in C&I; 16 behaviors (Norton 2013)

Achievable BB Savings Potential =
• 7% in commercial buildings; up to 91 behaviors (Ehrhardt-Martinez 2015)
• 10% in office buildings; up to 91 behaviors (Ehrhardt-Martinez 2015)
• <1% in commercial buildings; 4 program interventions (Wikler 2016)

Variation is Size and Source of Savings:
• Savings estimates vary by building type, geography, size and vintage.
• Most important building types: offices, schools, retail – healthcare, lodging
• Most important end uses: vary by building type and geography.
REFERENCES


Wikler, Greg; Sathe, Amul; Swamy, Surya; Ehrhardt-Martinez, Karen; Daftari, Aayush; Oztreves, Semih; Pierce, Julie; Menon, Carishma; and Jack Cullen. 2016. “AB802 Technical Analysis: Potential Savings Analysis.” (Ref No.: 174655) Prepared for the California Public Utilities Commission.
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