Guidelines for Verifying Savings from Commissioning Existing Buildings
Method 3: Energy Models Using Interval Data
David Jump, Ph.D., P.E.
September 20, 2012
Welcome!

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Today’s Speaker

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Agenda

- Method 3 Overview
- Measurement Boundary
- M&V Procedure
- Model Types
- Modeling Procedure
- Modeling Considerations
- Application to Demand Savings
- Example
- Method Costs
Energy models are empirical relationships between the dependent (energy) and independent (i.e. ambient temperature, solar load, occupancy, etc.) variables.

Most often dry-bulb ambient temperatures are used as it is typical of California’s climate.

Interval data are typically measured at 15 minute intervals or less.
- main building meter frequency is typ 15-min
- system energy use typ. 5 mins. and logged through the EMS
- Guideline describes roll-up to hourly or daily time intervals – more later

Method accounts for all impacts downstream of the energy meter
- all ECMs, but in addition:
  - occupant behavior, equipment shut-downs, added load, etc.
  - these are factors to account for when using this method

Method may be used to estimate savings uncertainty
- shows accuracy of method

Bonus is that the method may be used to continually track energy performance
This method may be applied to building subsystems as well as to the building as a whole.

It may be used to adhere with IPMVP Option B Retrofit Isolation or Option C Whole Building M&V options.
Method 3 may be applied at the whole building or building subsystem level.

At the Whole Building level, there is often only one meter for electricity and one for a heating fuel such as natural gas and steam.

Larger buildings – typically with 200 kW peak use and above, have TOU electric meters in California.

Short-time interval natural gas meters are not yet common.

With more installations of SmartMeters, short-time interval meter data for all energy sources will soon be more common.

For building subsystems, data sources are more difficult. Each component in a building subsystem must be monitored. The EMS is the best source of this data, but energy meters and trend logs must be started early in the project.

Often additional building submeters are present and may be used to isolate subsystems.

Motor control centers (MCCs) should also be considered for metering, as all required components to a subsystem may be powered through the MCC, and only one monitored point may be necessary.
The EMS is a good source of data for the Interval Data Method.

Feedback status signals are typically among the points on an EMS. These may be trended over time.

These signals may be translated to energy variables.

Constant load status signals may indicate on or off status. Spot measurements of power may be used to convert the status signal into an energy monitoring variable.

Similarly with variable load equipment, except that power measurements of the equipment at various load levels are used to develop a relationship between the equipment load and power. This is the same concept as that of a proxy energy variable, as described for Method 2.
Proxy Variables

- VFD Speed for kW

\[ y = 38.5x^{2.6} \]

\[ R^2 = 0.7 \]
This chart broadly outlines the process to set up the savings verification process – to determine whether the interval data method is suitable for verifying the EBCx project’s savings.
Method 3 Process

1. Implement EBCx measures
2. Post-installation period data
3. Calculate savings
4. Report results
The Guideline discusses linear regressions and change-point models, however other types of regressions or empirical methods may be used, as long as it can be shown that the models accurately predict the data upon which they are built.
2-P Model (Linear Regression)

- \( E = C + B1 \times T \)
- Energy use varies linearly throughout year
  - Extremely warm or cold climates
- Seasonal energy use
  - Summer only
  - Winter only

\[
\begin{align*}
\text{Energy use} & \quad \text{Ambient Temp} \\
C & \quad B1 \\
\text{C = constant} & \quad \text{B1 = slope}
\end{align*}
\]
Note that there are different models for heating than for cooling.

Heating models are based on heating fuels: natural gas and steam.

Cooling models are based on electricity usually.

Note there can be different models for the different fuel sources.
3-Parameter CP Example
4-P Models

- Heating in VAV or dual-duct systems with hot deck reset schedules

\[ E = C + B_1 \times (B_3 - T)^+ - B_2 \times (T - B_3)^+ \]

- Buildings with multiple stages of cooling:
  - Economizers
  - Chillers

\[ E = C - B_1 \times (B_3 - T)^+ + B_2 \times (T - B_3)^+ \]

4-p cooling models are typical for buildings in California
Model ‘fit’ (how well the model fits the data on which it is built) is assessed using these statistical indexes.
This is the general process for determining the best fitting model.

It can get complicated quickly when models get more complicated, such as when change-points are introduced.

This process is arduous without tools. In spreadsheets, the regression tool is not enough to eliminate hours of analysis time.
There are other examples of change-point modeling software, this is not a comprehensive list.

There may be other energy modeling methods in tools, not all must be change-points.
In seeking the best model fit, additional variables may be needed.

Keep it simple however. Less complication is always better – less data requirements, less analysis.
Multivariate Modeling - Example

- $E = C_2 \times [C_1 + B_1 \times T] + C_3 \times [C_4 + B_2 \times T]$
  - Build weekday and weekend/holiday models separately

![Graph showing energy use vs. ambient temperature for weekday and weekend/holiday](image)
The 15-min energy data is typically rolled up to hourly or daily time intervals before starting the modeling process.

Independent variables are usually averaged over the time period, but for daily time intervals, maybe a peak temperature or average temperature over the operating period may produce a better model fit.
In California’s mild coastal climates, there may not be as large a variation in temperature and energy use throughout the year as compared to inland and more extreme climates.

The monitoring period duration may be less in coastal climates than inland.

A good way to check is to obtain TMY weather data sets and examine the maximum and minimum temperatures, and then select the time period where one can expect to monitor 90% of that range to occur.
To assess the interval data method’s ability to verify the savings expected from an EBCx project (or any savings project), its uncertainty must be estimated.

ASHRAE introduced the fractional savings uncertainty framework, which is described in the Guideline.

The fractional savings uncertainty may be estimated prior to implementation of the EBCx measures. This allows one to assess whether the specific modeling approach is adequate to verify savings and allows one a chance to make adjustments to the approach before measures are installed.
Fractional savings uncertainty may be estimated once a baseline model is developed and an estimate of the expected savings have been made.

\[ \frac{\Delta E_{\text{save,m}}}{E_{\text{save,m}}} = t \cdot \frac{1.26 \cdot CV \left[ \frac{n}{n'} \left( 1 + \frac{2}{n'} \right) \frac{1}{m} \right]^{1/2}}{F} \]

- State as: Savings = \( E_{\text{save,m}} \pm 0.5 \cdot \Delta E_{\text{save,m}} \)

Correlated residuals: Each point has a relationship with the previous point. There is a higher potential for correlated residuals when time unit is short.
Uncertainty Assessment

- ASHRAE GL14: 50% at 68% confidence
  - “68% confident savings are between 75,000 and 125,000 kWh” (for 100,000 kWh savings estimate)
  - Acceptable?

- Project sponsors should decide what uncertainty to accept
  - Specify confidence and precision levels
Demand Savings

- Two main methods:
  - Average Peak Period Demand Reduction
    - Calculate reductions in total kWh use during the peak period and divide by total peak period hours
    - Peak period defined by utility peak demand periods
      - e.g., noon to 6pm non-holiday weekdays, May through September
  - Coincident Peak Demand Reduction
    - Calculates reduction for actual hour of peak
    - Requires hourly model
# Example – EBCx Project

<table>
<thead>
<tr>
<th>#</th>
<th>Issue</th>
<th>Measure Description</th>
<th>Estimated Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Simultaneous CHW pump operation with nearly closed balance valves</td>
<td>Rebalance CHW pumps to run in lead/lag mode.</td>
<td>68,849 kWh</td>
</tr>
<tr>
<td>2</td>
<td>Simultaneous CW pump operation with nearly closed balance valves</td>
<td>Balance CW pumps to run in lead/lag mode.</td>
<td>68,849 kWh</td>
</tr>
<tr>
<td>3</td>
<td>CHW outside air temperature lockout not operating</td>
<td>Repair lockdown temperature function.</td>
<td>361,181 kWh</td>
</tr>
<tr>
<td>4</td>
<td>Raise OHWDA lockout temperature from 60 F</td>
<td>Per OHW specification, raise chiller lockout set point to 85 F</td>
<td>113,767 kWh</td>
</tr>
<tr>
<td>5</td>
<td>Several leaky valves in pre-heat coil bank causing unnecessary heating</td>
<td>Repair leaking valves and faulty control module.</td>
<td>101,775 kWh, 10,543,991 lbs steam</td>
</tr>
</tbody>
</table>

- Estimated Savings:
  - 653,575 kWh
  - 10,543,991 lb
Example – EBCx Project

Electric

Steam
Example, cont.

Electric

Steam
The example shows that the estimated electric savings are within the confidence intervals of the verified savings.

However, the estimated steam savings was under-estimated. Even though the model fit was not great, because the expected steam savings was very high, the resulting uncertainty was low.
M&V Costs

- Meters + hardware and maintenance
- Added Labor
  - Measurements
  - Analysis
  - Reporting
For the three RCx project where Method 3 M&V was performed, evaluation results showed realization rates at or above 100%. 
Where to find the Guideline

- [http://cacx.org/resources/vos-guidelines/](http://cacx.org/resources/vos-guidelines/)
Q&A

• Please submit questions via the Q&A box
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### 2012 Meeting Dates

<table>
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<th>Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>October 18, 2012</td>
<td>Webinar – Lighting Systems</td>
</tr>
<tr>
<td>December 6, 2012</td>
<td>In-person, host SoCal Gas in Downey, CA</td>
</tr>
</tbody>
</table>
Thank you for participating!

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