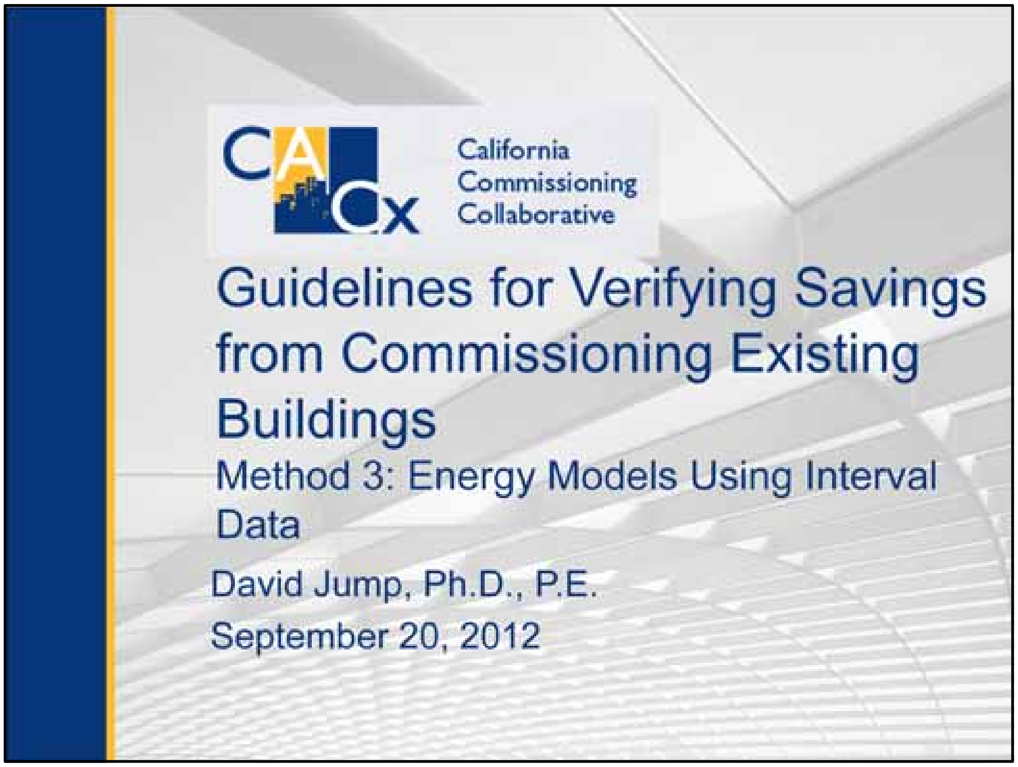


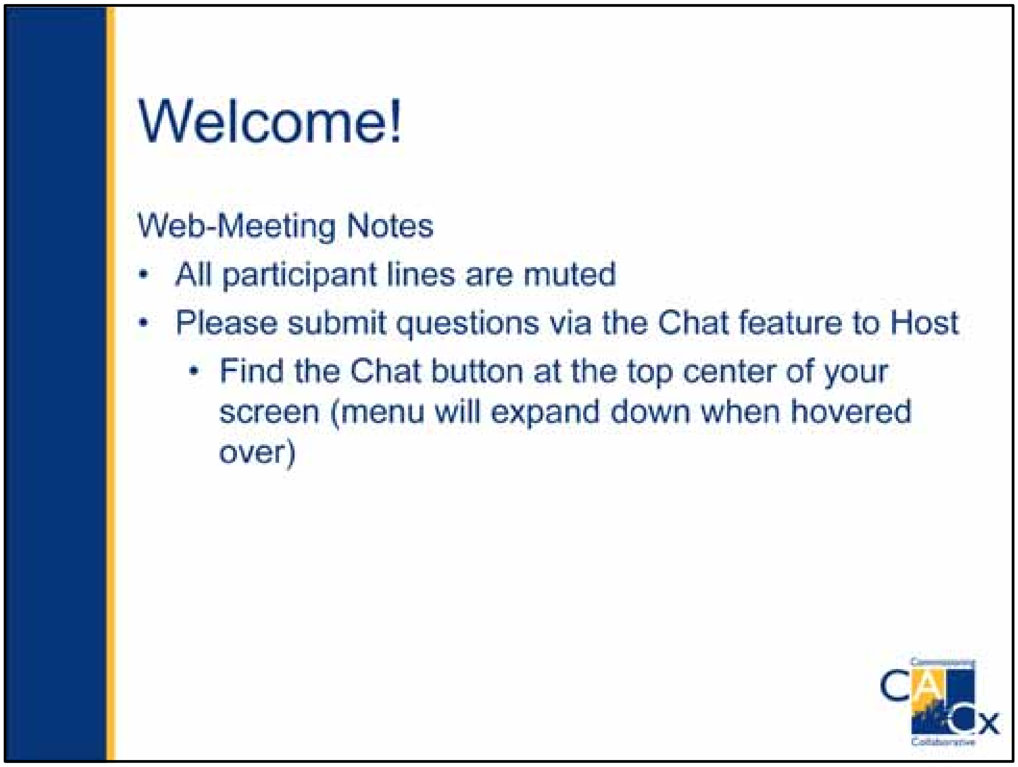
CA Cx California Commissioning Collaborative

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!

Web-Meeting Notes

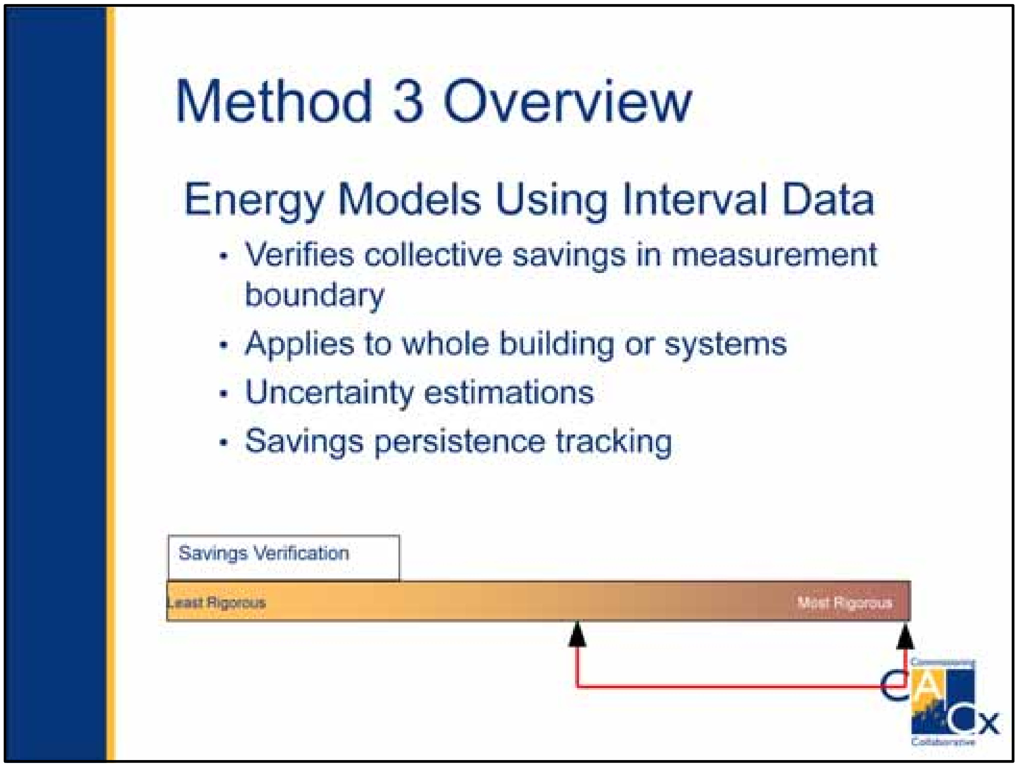
- All participant lines are muted
- Please submit questions via the Chat feature to Host
  - Find the Chat button at the top center of your screen (menu will expand down when hovered over)

Today's Speaker

David Jump, Ph.D., P.E.
Quantum Energy Services & Technologies, Inc.

Agenda

- Method 3 Overview
- Measurement Boundary
- M&V Procedure
- Model Types
- Modeling Procedure
- Modeling Considerations
- Application to Demand Savings
- Example
- Method Costs



Method 3 Overview

Energy Models Using Interval Data

- Verifies collective savings in measurement boundary
- Applies to whole building or systems
- Uncertainty estimations
- Savings persistence tracking

Energy models are empirical relationships between the dependent (energy) and independent (i.e. ambient temperature, solar load, occupancy, etc.) variables.

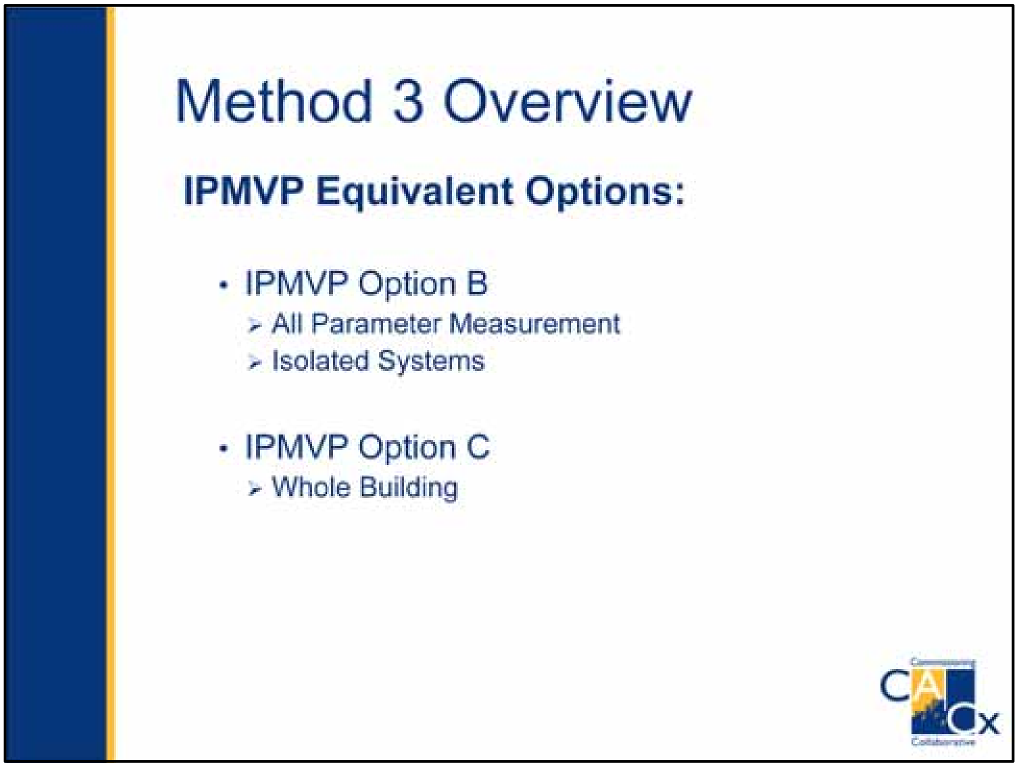
Most often dry-bulb ambient temperatures are used as it is typical of California's climate.

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



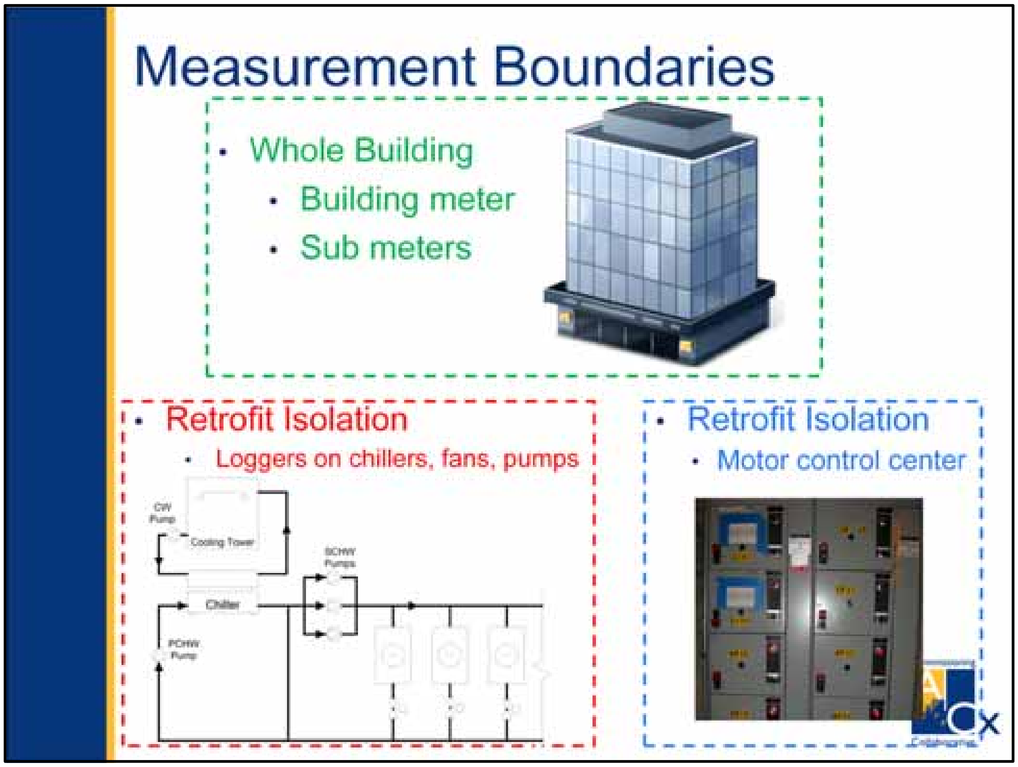
Method 3 Overview

IPMVP Equivalent Options:

- IPMVP Option B
  - All Parameter Measurement
  - Isolated Systems
- IPMVP Option C
  - Whole Building

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.



Measurement Boundaries

- Whole Building
  - Building meter
  - Sub meters
- Retrofit Isolation
  - Loggers on chillers, fans, pumps
- Retrofit Isolation
  - Motor control center

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.

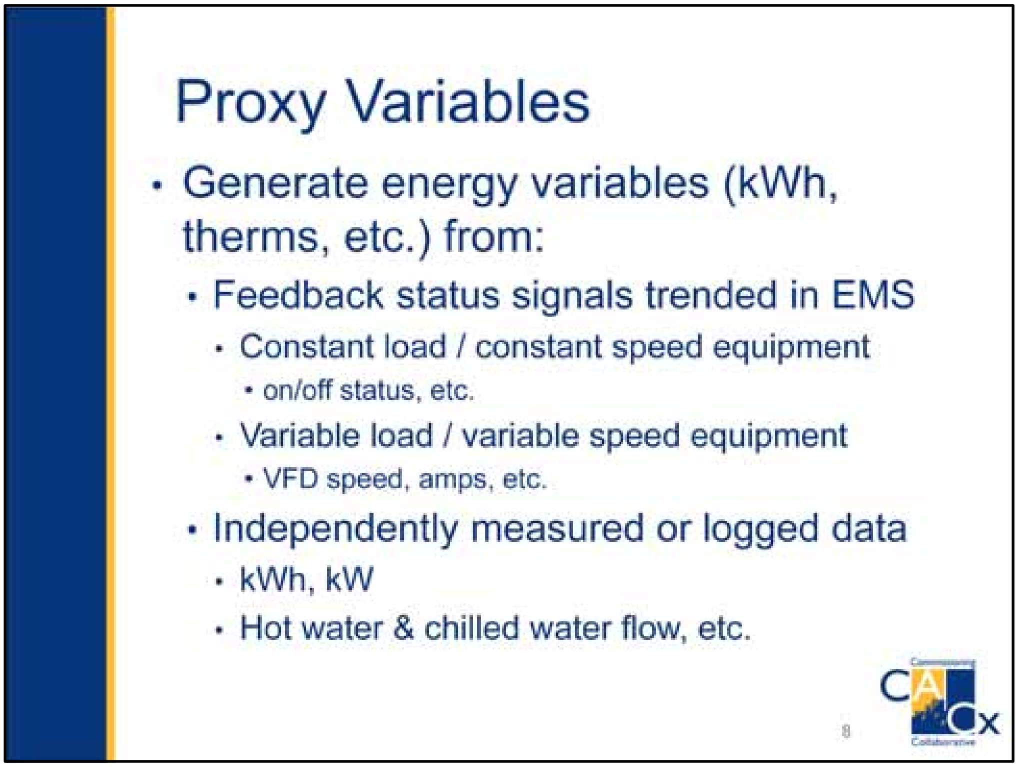
Short-time interval natural gas meters are not yet common.

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.



Proxy Variables

- Generate energy variables (kWh, therms, etc.) from:
  - Feedback status signals trended in EMS
    - Constant load / constant speed equipment
      - on/off status, etc.
    - Variable load / variable speed equipment
      - VFD speed, amps, etc.
  - Independently measured or logged data
    - kWh, kW
    - Hot water & chilled water flow, etc.

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.

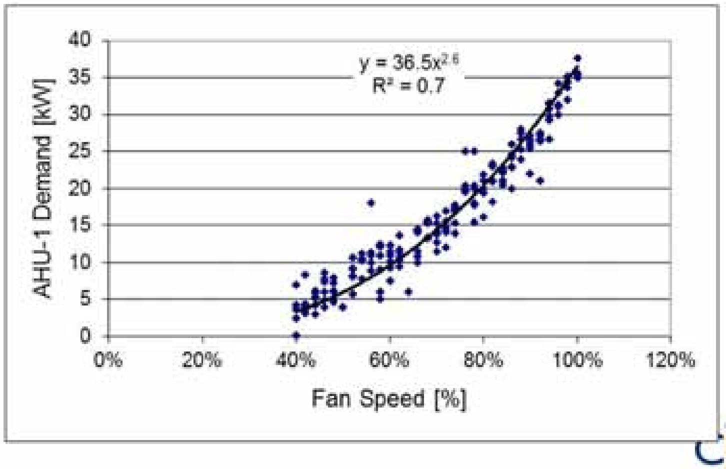
These signals may be translated to energy variables.

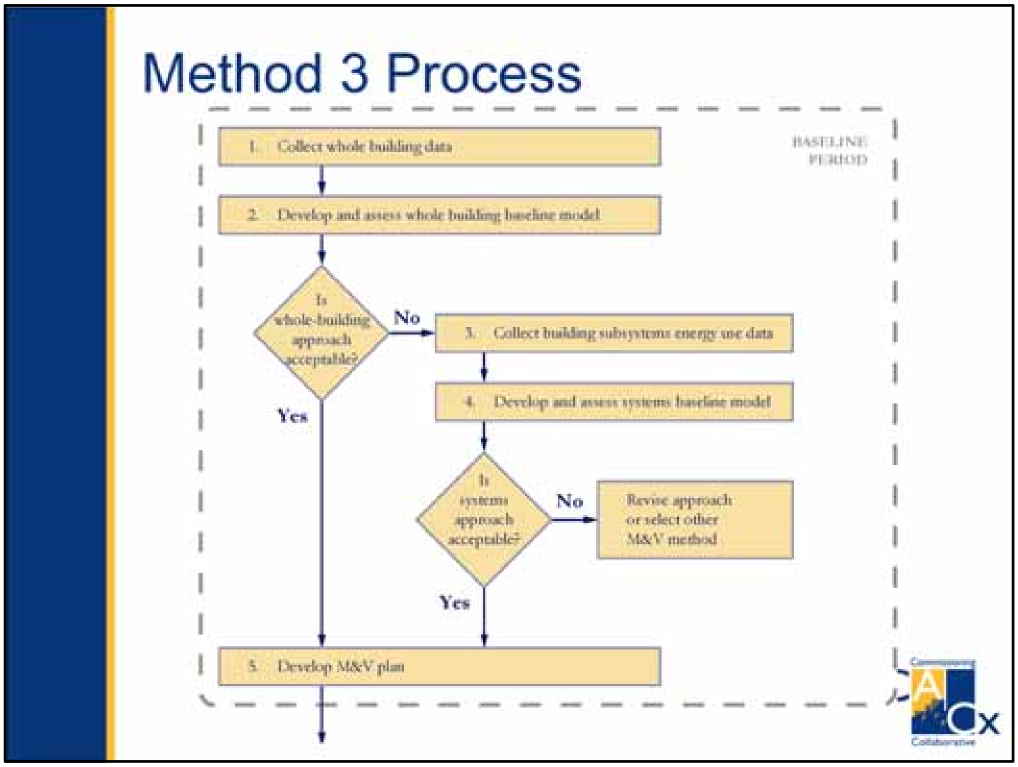
Constant load status signals may indicate on or off status. Spot measurements of power may be used to convert the status signal into an energy monitoring variable.

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





Method 3 Process

BASELINE PERIOD

1. Collect whole building data
2. Develop and assess whole building baseline model

Is whole-building approach acceptable?

No

3. Collect building subsystems energy use data
4. Develop and assess systems baseline model

Is systems approach acceptable?

No

Revise approach or select other M&V method

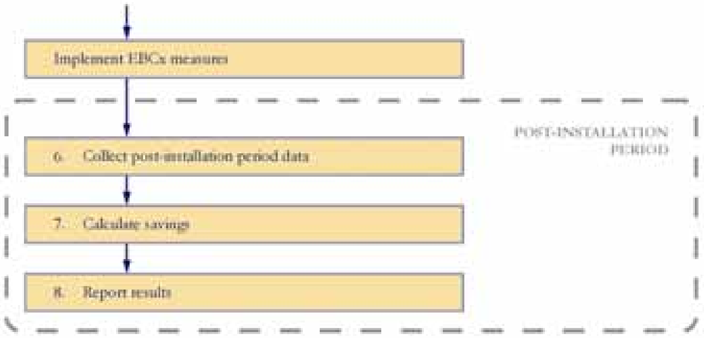
Yes

Yes

5. Develop M&V plan

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.

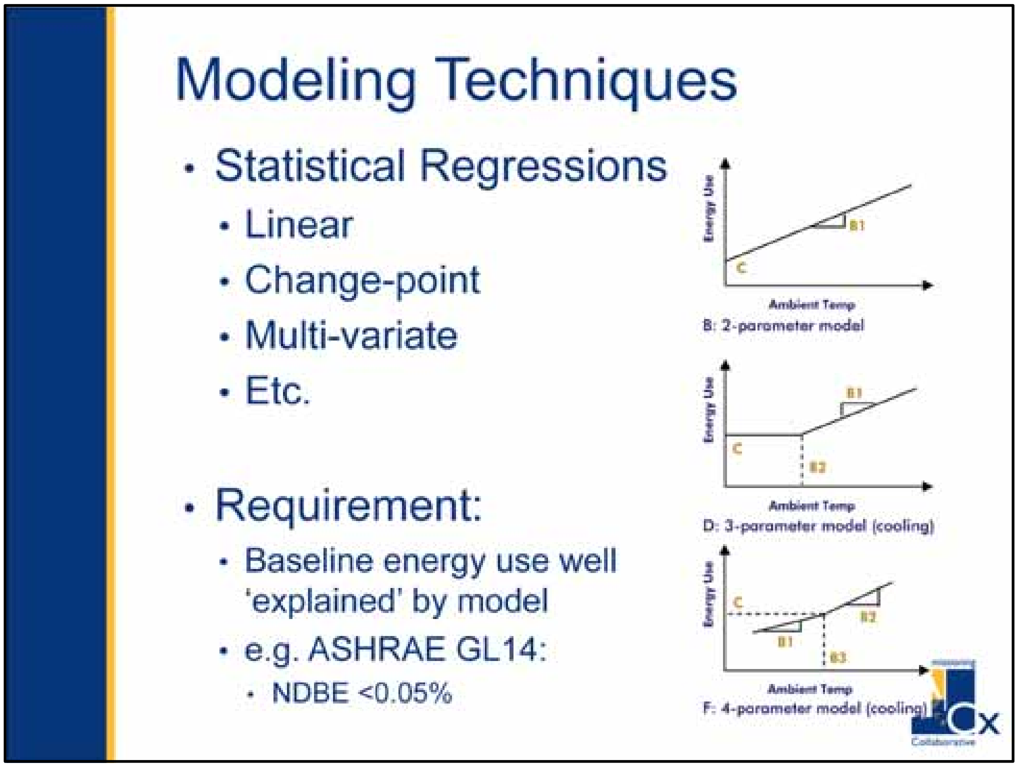
Method 3 Process



Implement EBCx measures

POST-INSTALLATION PERIOD

6. Collect post-installation period data
7. Calculate savings
8. Report results

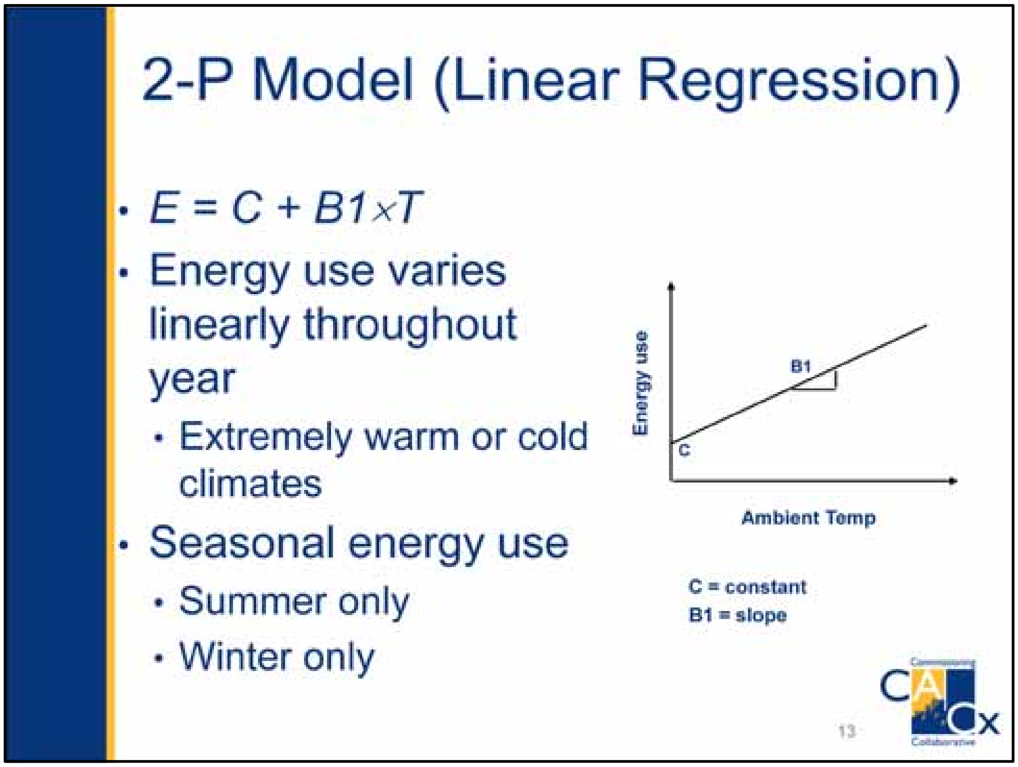


Modeling Techniques

- Statistical Regressions
  - Linear
  - Change-point
  - Multi-variate
  - Etc.

- Requirement:
  - Baseline energy use well 'explained' by model
  - e.g. ASHRAE GL14:
    - NDBE <0.05%

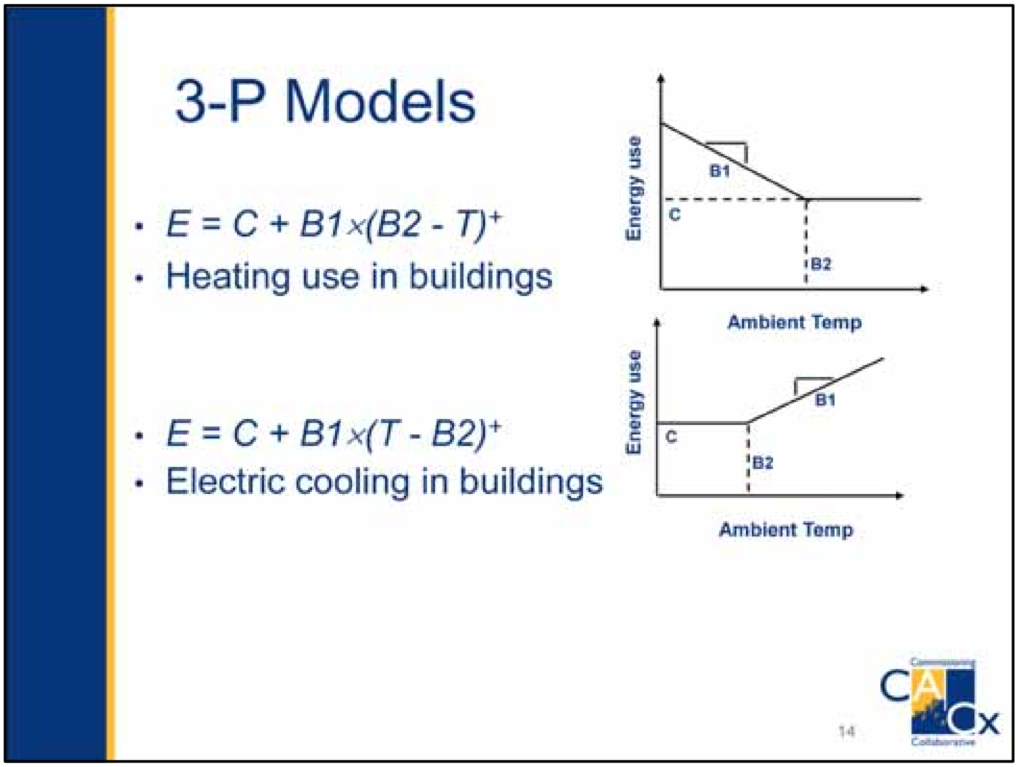
The Guideline discusses linear regressions and change-point models, however other types of regressions or empirical methods may be used, as long as it can be shown that the models accurately predict the data upon which they are built.



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

C = constant
B1 = slope



3-P Models

- $E = C + B1 \times (B2 - T)^+$
- Heating use in buildings

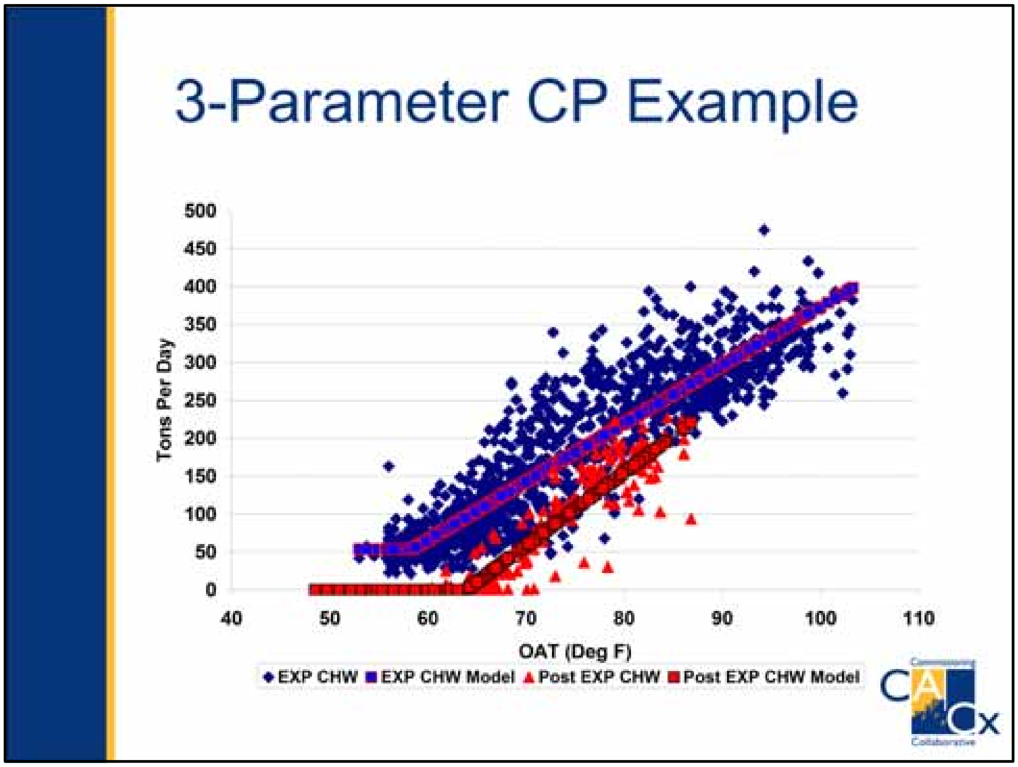
- $E = C + B1 \times (T - B2)^+$
- Electric cooling in buildings

Note that there are different models for heating than for cooling.

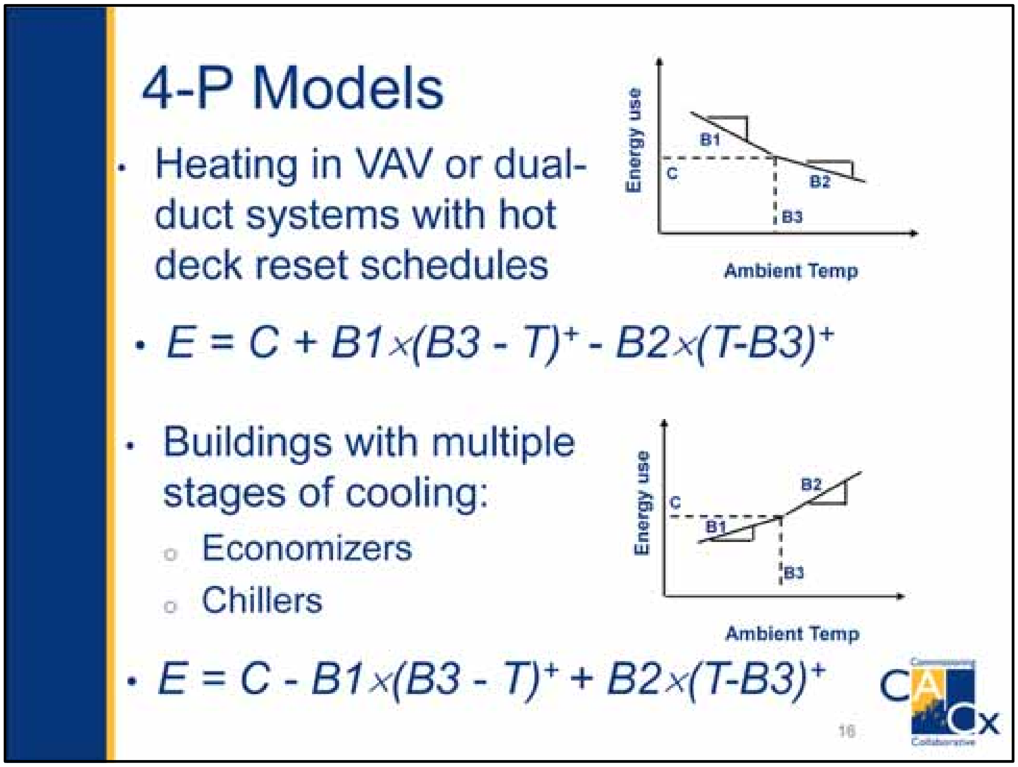
Heating models are based on heating fuels: natural gas and steam

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

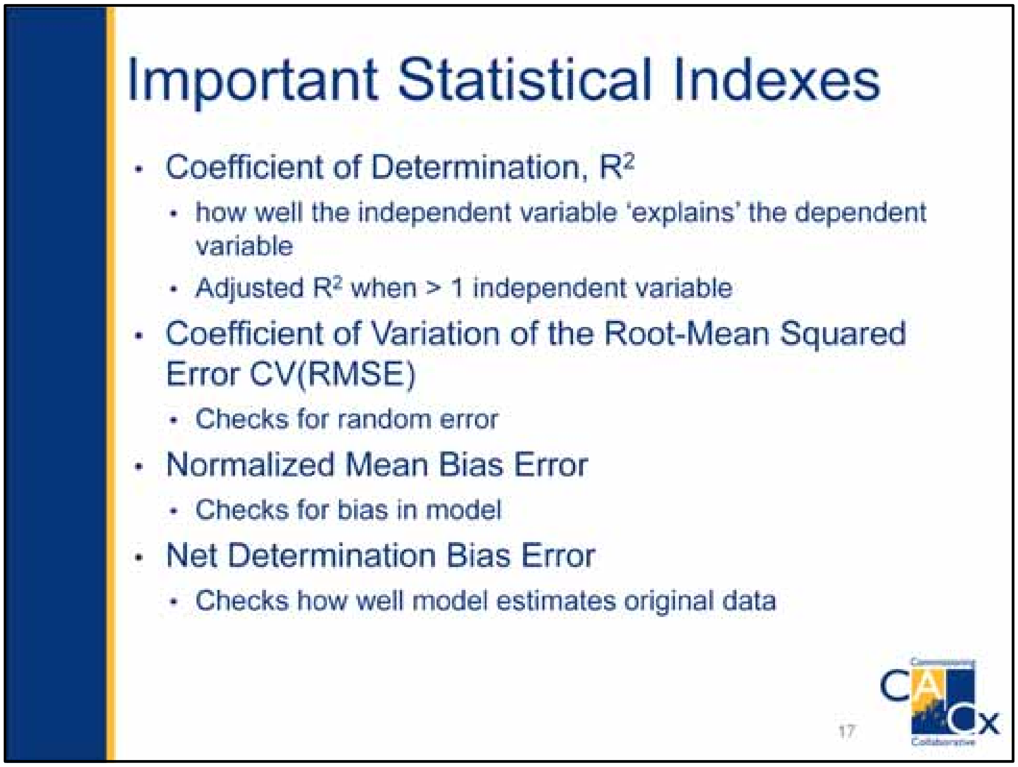
- Heating in VAV or dual-duct systems with hot deck reset schedules

- $E = C + B1 \times (B3 - T)^{+} - B2 \times (T-B3)^{+}$

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

- $E = C - B1 \times (B3 - T)^{+} + B2 \times (T-B3)^{+}$

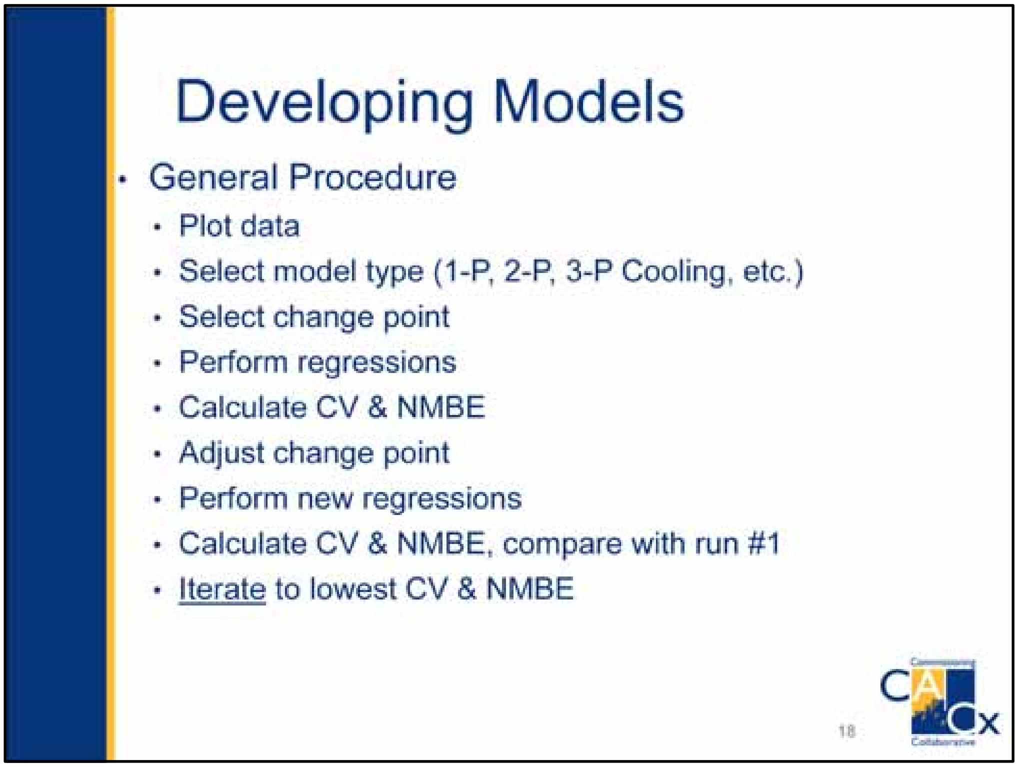
4-p cooling models are typical for buildings in California



Important Statistical Indexes

- Coefficient of Determination, R^2
  - how well the independent variable 'explains' the dependent variable
  - Adjusted R^2 when > 1 independent variable
- Coefficient of Variation of the Root-Mean Squared Error CV(RMSE)
  - Checks for random error
- Normalized Mean Bias Error
  - Checks for bias in model
- Net Determination Bias Error
  - Checks how well model estimates original data

Model 'fit' (how well the model fits the data on which it is built) is assessed using these statistical indexes.



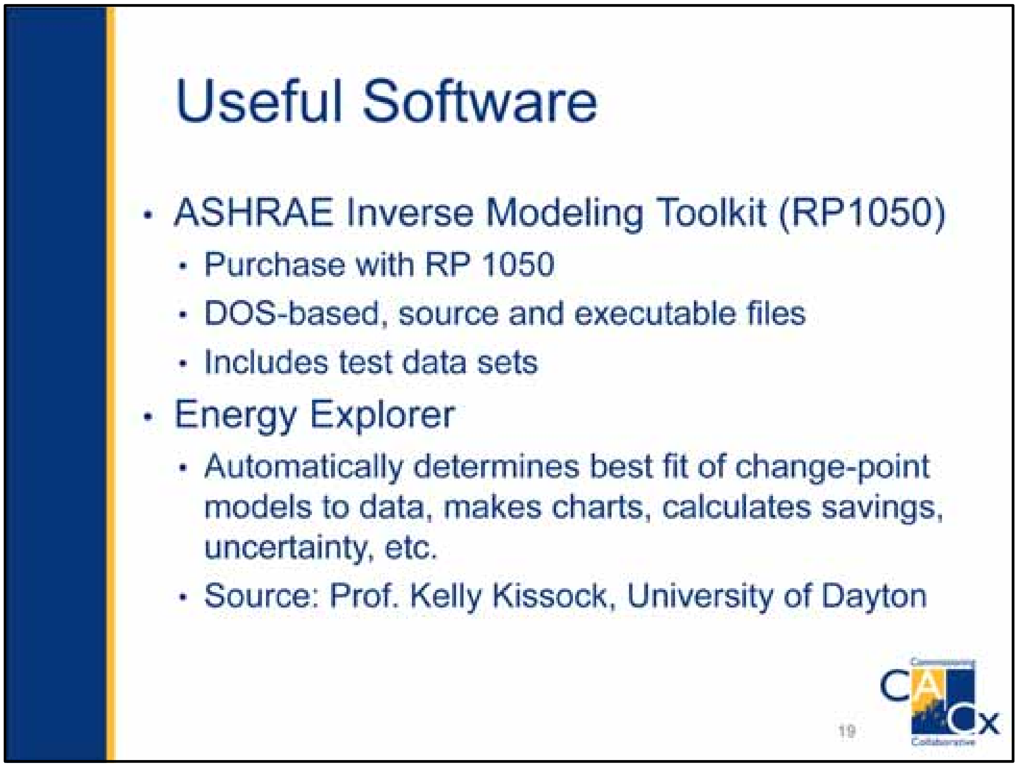
Developing Models

- General Procedure
  - Plot data
  - Select model type (1-P, 2-P, 3-P Cooling, etc.)
  - Select change point
  - Perform regressions
  - Calculate CV & NMBE
  - Adjust change point
  - Perform new regressions
  - Calculate CV & NMBE, compare with run #1
  - Iterate to lowest CV & NMBE

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.

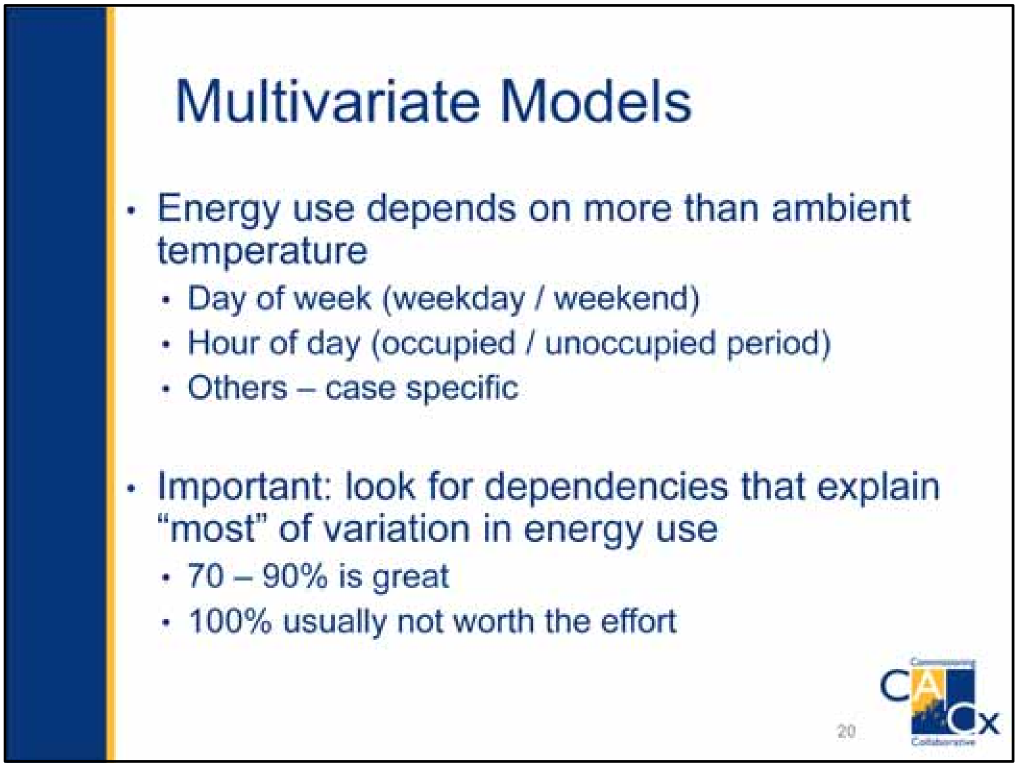


Useful Software

- ASHRAE Inverse Modeling Toolkit (RP1050)
  - Purchase with RP 1050
  - DOS-based, source and executable files
  - Includes test data sets
- Energy Explorer
  - Automatically determines best fit of change-point models to data, makes charts, calculates savings, uncertainty, etc.
  - Source: Prof. Kelly Kissock, University of Dayton

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.

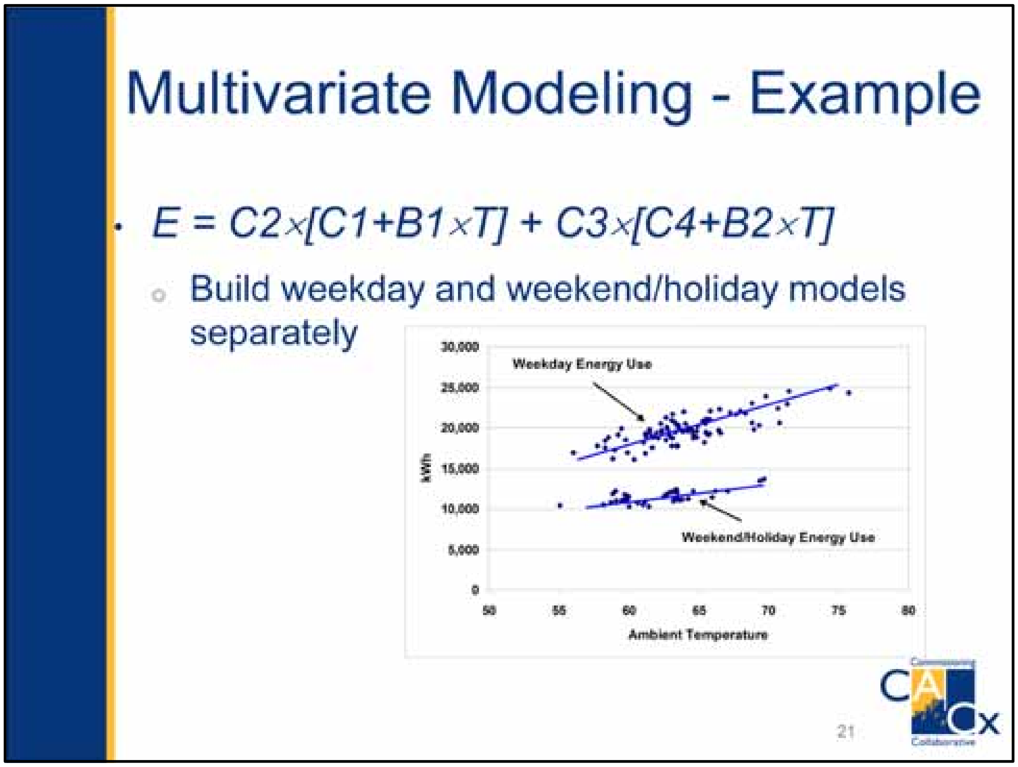


Multivariate Models

- Energy use depends on more than ambient temperature
  - Day of week (weekday / weekend)
  - Hour of day (occupied / unoccupied period)
  - Others – case specific
- Important: look for dependencies that explain “most” of variation in energy use
  - 70 – 90% is great
  - 100% usually not worth the effort

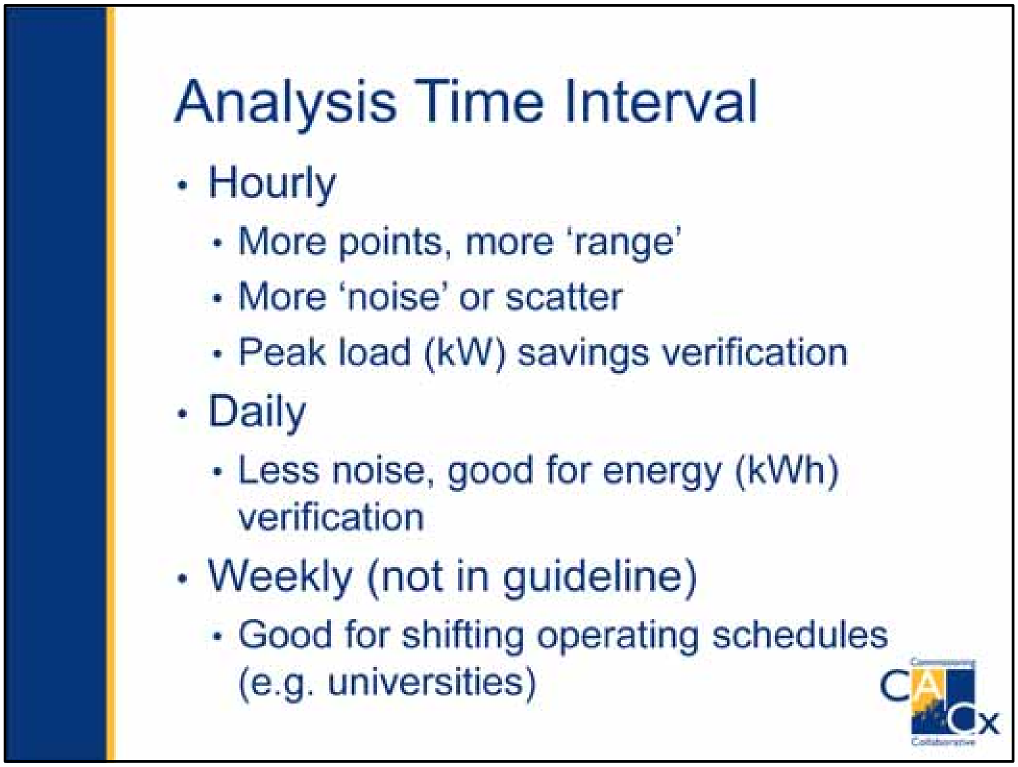
In seeking the best model fit, additional variables may be needed.

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



Multivariate Modeling - Example

- $E = C2 \times [C1 + B1 \times T] + C3 \times [C4 + B2 \times T]$
  - Build weekday and weekend/holiday models separately

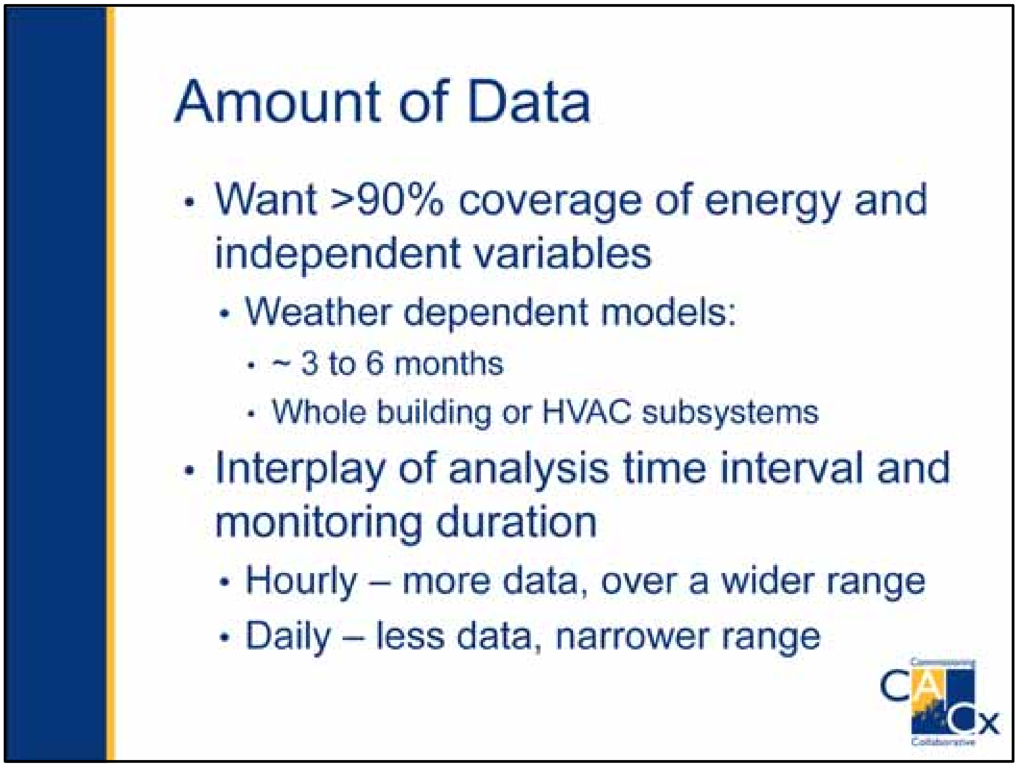


Analysis Time Interval

- Hourly
  - More points, more ‘range’
  - More ‘noise’ or scatter
  - Peak load (kW) savings verification
- Daily
  - Less noise, good for energy (kWh) verification
- Weekly (not in guideline)
  - Good for shifting operating schedules (e.g. universities)

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.



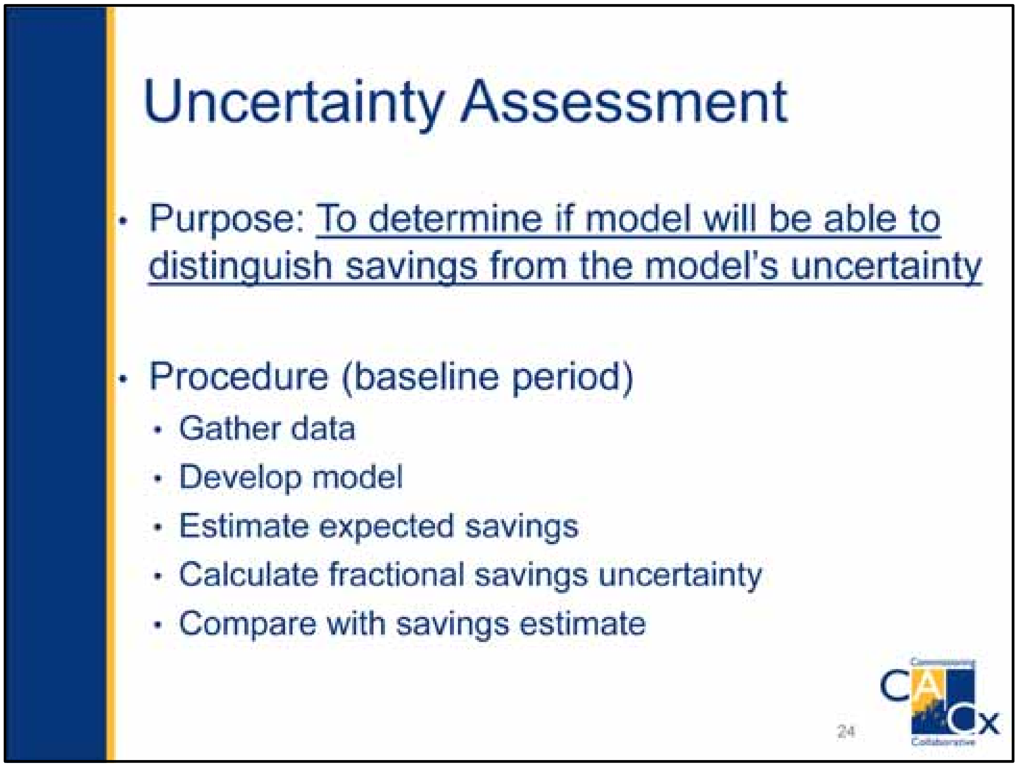
Amount of Data

- Want >90% coverage of energy and independent variables
  - Weather dependent models:
    - ~ 3 to 6 months
    - Whole building or HVAC subsystems
- Interplay of analysis time interval and monitoring duration
  - Hourly – more data, over a wider range
  - Daily – less data, narrower range

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.



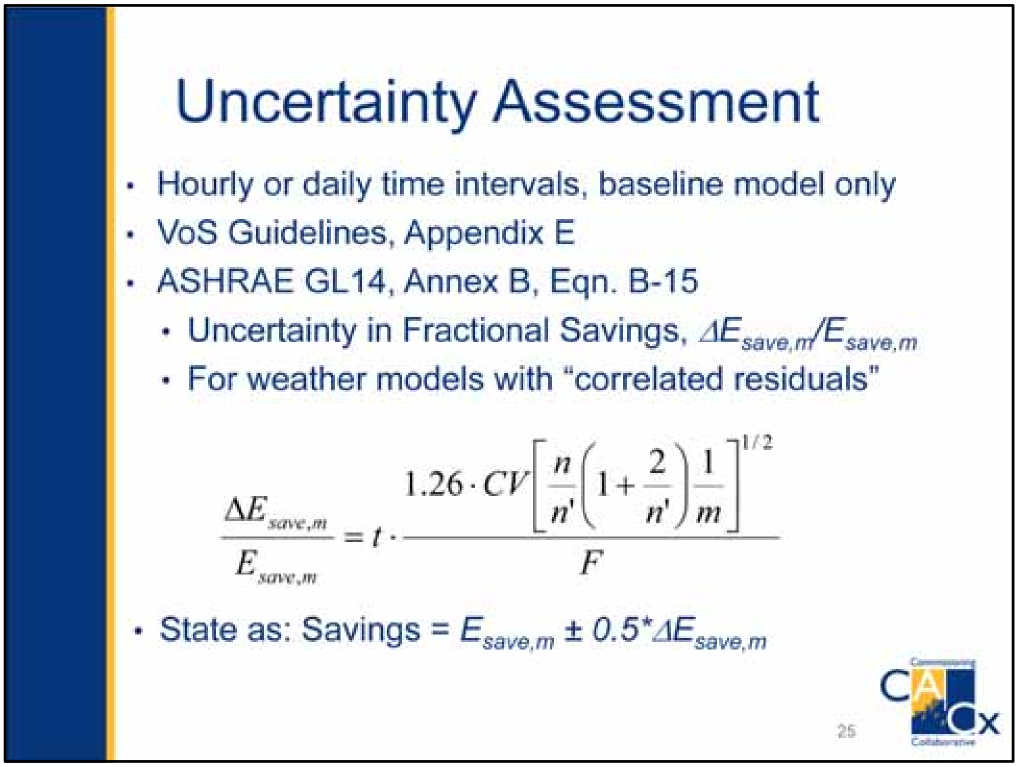
Uncertainty Assessment

- Purpose: To determine if model will be able to distinguish savings from the model's uncertainty
- Procedure (baseline period)
  - Gather data
  - Develop model
  - Estimate expected savings
  - Calculate fractional savings uncertainty
  - Compare with savings estimate

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.



Uncertainty Assessment

- Hourly or daily time intervals, baseline model only
- VoS Guidelines, Appendix E
- ASHRAE GL14, Annex B, Eqn. B-15
  - Uncertainty in Fractional Savings, $\Delta E_{save,m}/E_{save,m}$
  - For weather models with "correlated residuals"

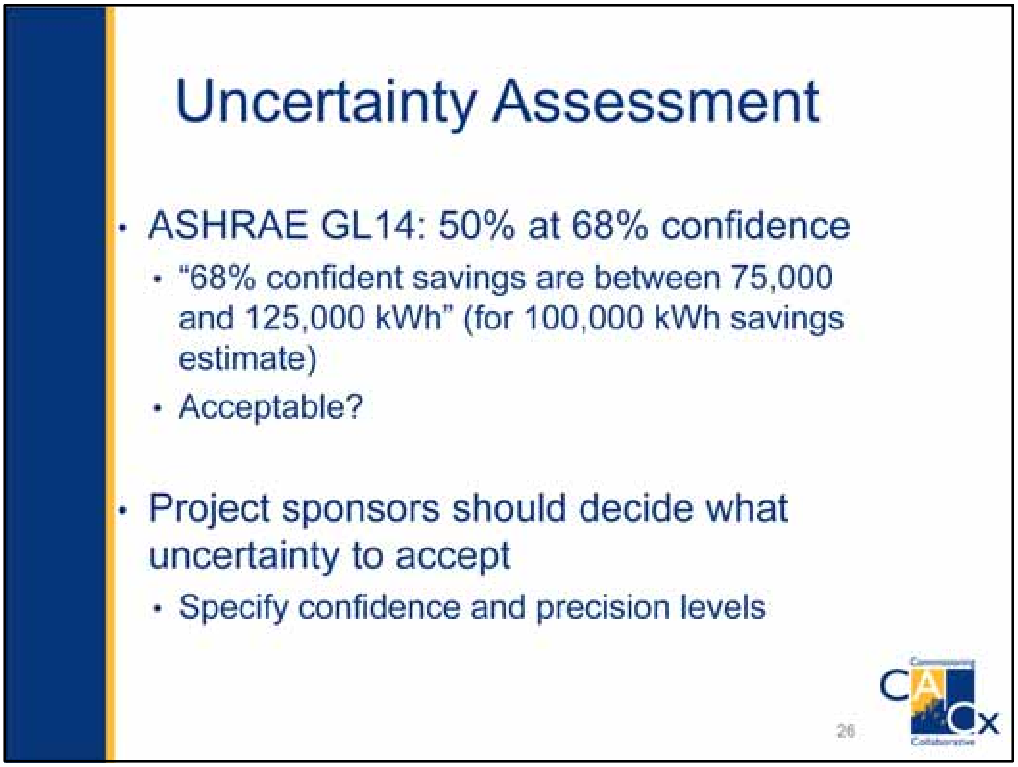
$$\frac{\Delta E_{save,m}}{E_{save,m}} = t \cdot \frac{1.26 \cdot CV\left[\frac{n}{n'}\left(1+\frac{2}{n'}\right)\frac{1}{m}\right]^{1/2}}{F}$$

- State as: Savings = $E_{save,m} \pm 0.5^{*}\Delta E_{save,m}$

Fractional savings uncertainty may be estimated once a baseline model is developed and an estimate of the expected savings have been made.

t is the t-statistic – selection of the confidence interval specifies the t-statistic.
CV is the CV(RMSE)
n is the number of points in the baseline period
n’ is an adjustment to n based on the degree of correlation among data points
m is the number of points to be monitored in the post-installation period
F is the fraction of savings (savings over annual energy use) expected from the project

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

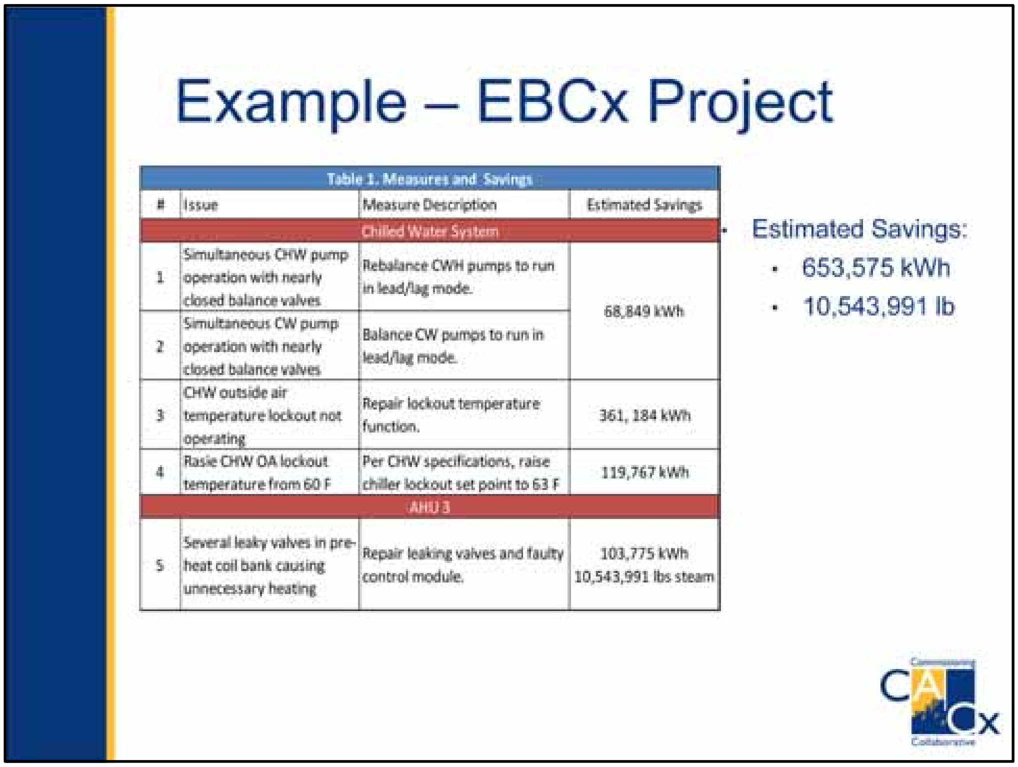


Uncertainty Assessment

- 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

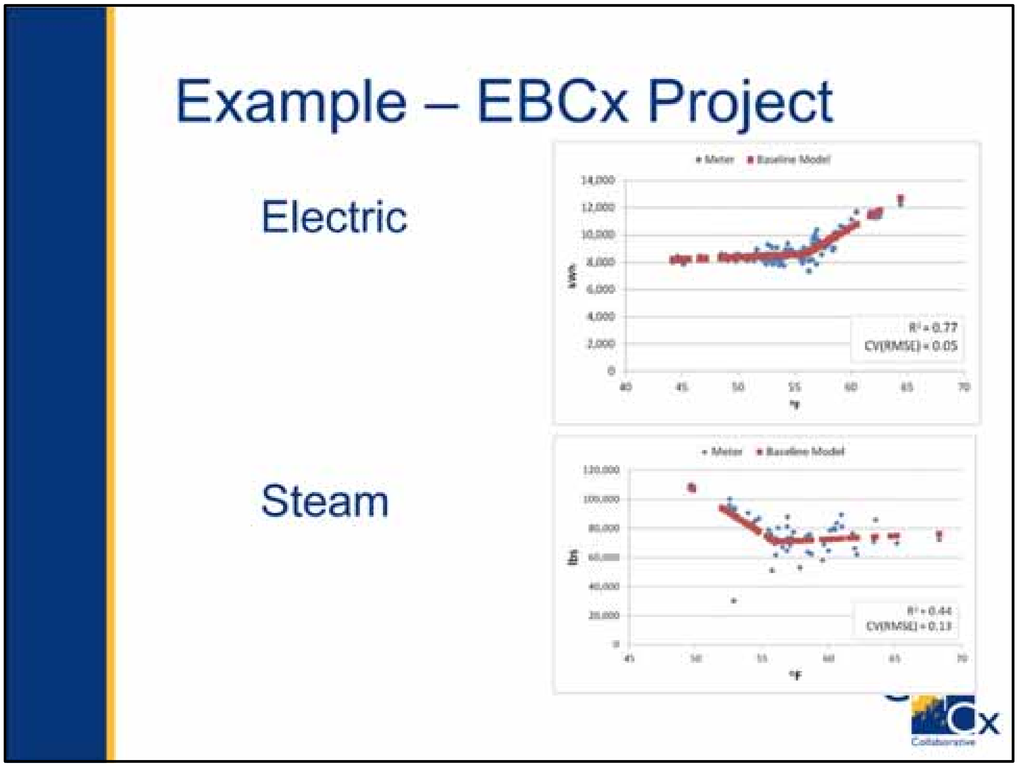


Example – EBCx Project

Table 1. Measures and Savings

#	Issue	Measure Description	Estimated Savings
		Chilled Water System	
1	Simultaneous CHW pump operation with nearly closed balance valves	Rebalance CWH pumps to run in lead/lag mode.	68,849 kWh
2	Simultaneous CW pump operation with nearly closed balance valves	Balance CW pumps to run in lead/lag mode.	
3	CHW outside air temperature lockout not operating	Repair lockout temperature function.	361, 184 kWh
4	Rasie CHW OA lockout temperature from 60 F	Per CHW specifications, raise chiller lockout set point to 63 F	119,767 kWh
		AHU 3	
5	Several leaky valves in pre-heat coil bank causing unnecessary heating	Repair leaking valves and faulty control module.	103,775 kWh 10,543,991 lbs steam

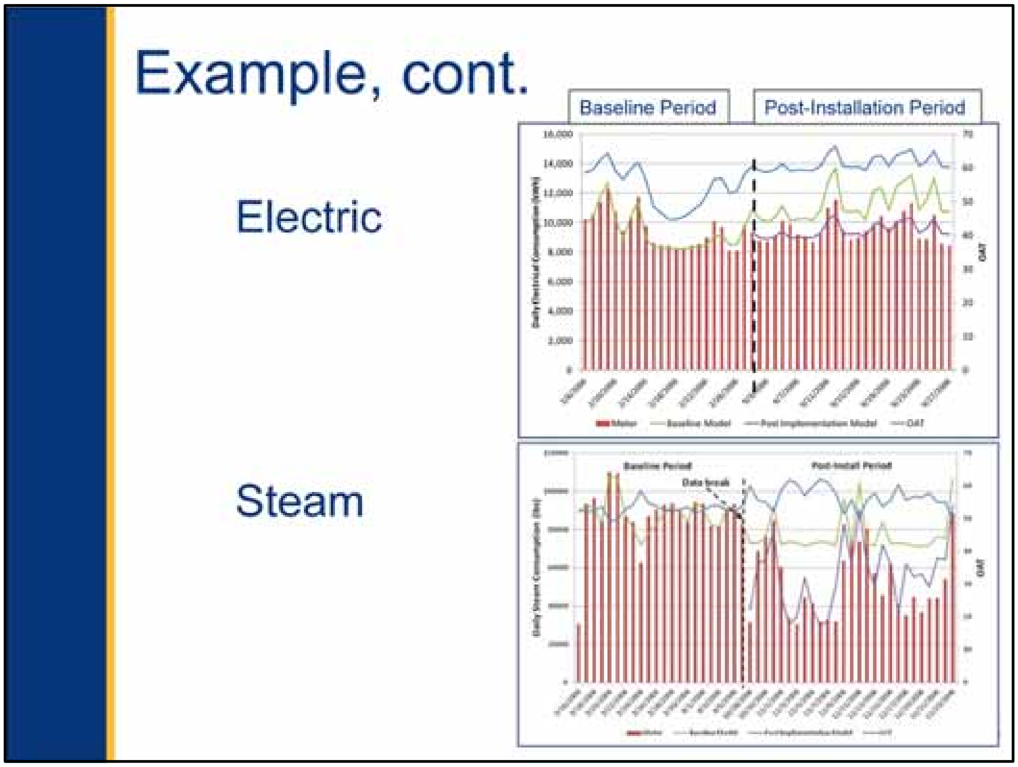
- Estimated Savings:
  - 653,575 kWh
  - 10,543,991 lb



Example – EBCx Project

Electric

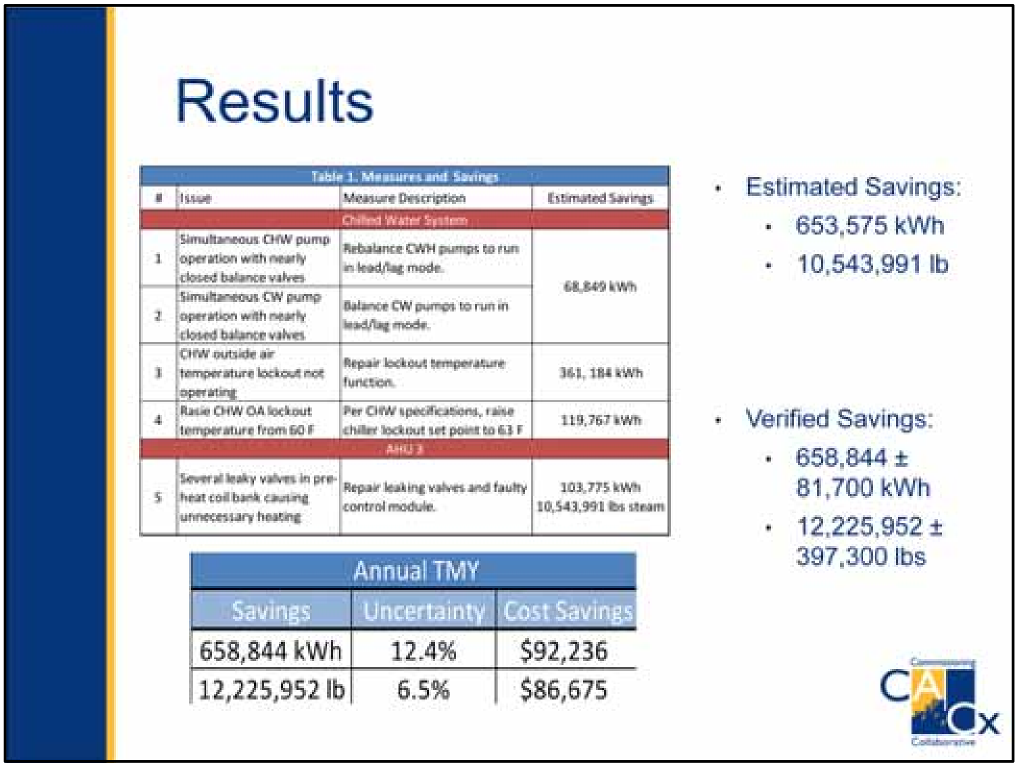
Steam



Example, cont.

Electric

Steam



Results

Table 1. Measures and Savings

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Annual TMY		
Savings	Uncertainty	Cost Savings
658,844 kWh	12.4%	$92,236
12,225,952 lb	6.5%	$86,675

- Estimated Savings:
  - 653,575 kWh
  - 10,543,991 lb
- Verified Savings:
  - 658,844 ± 81,700 kWh
  - 12,225,952 ± 397,300 lbs

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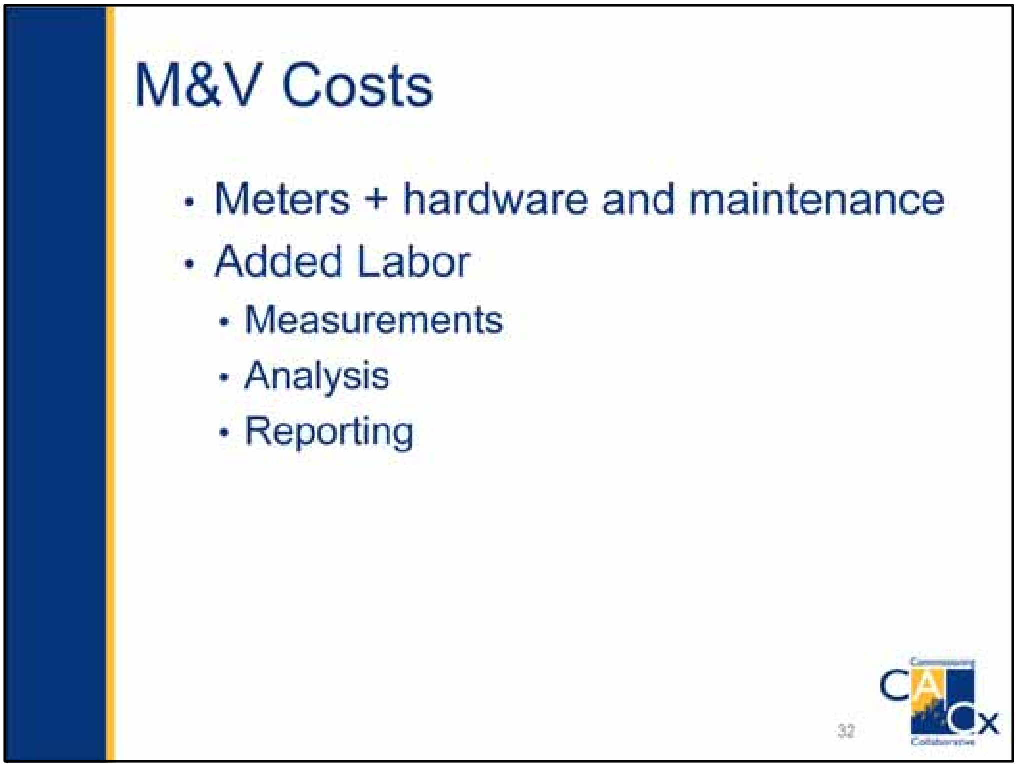
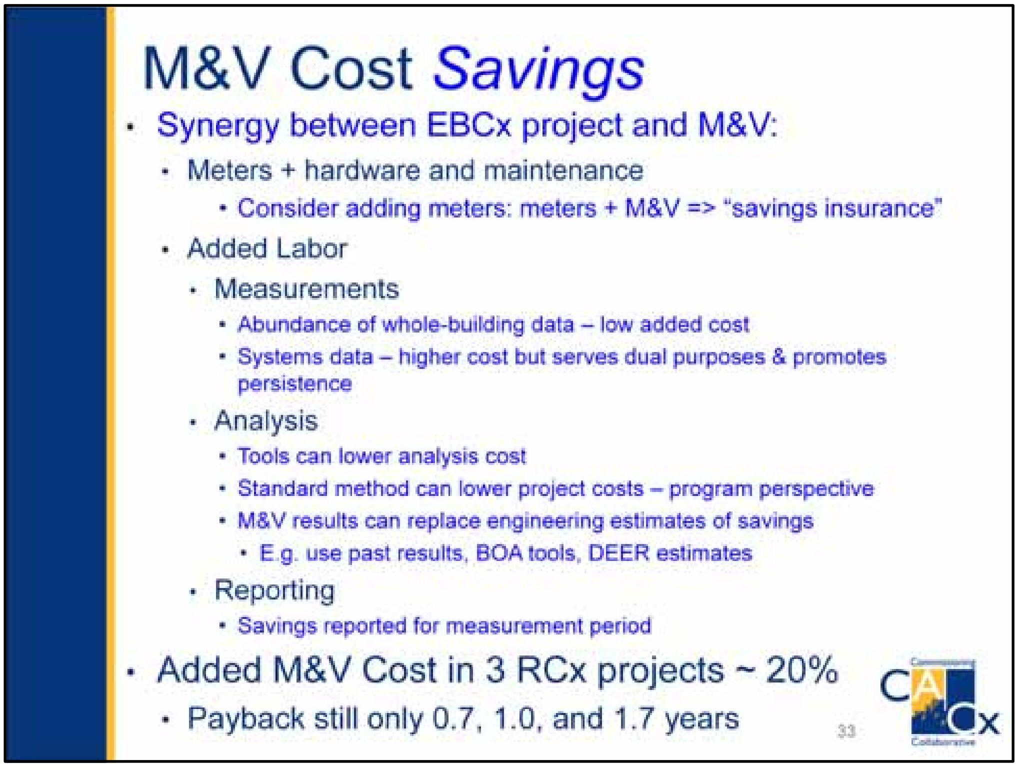
The example shows that the estimated electric savings are within the confidence intervals of the verified savings.

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

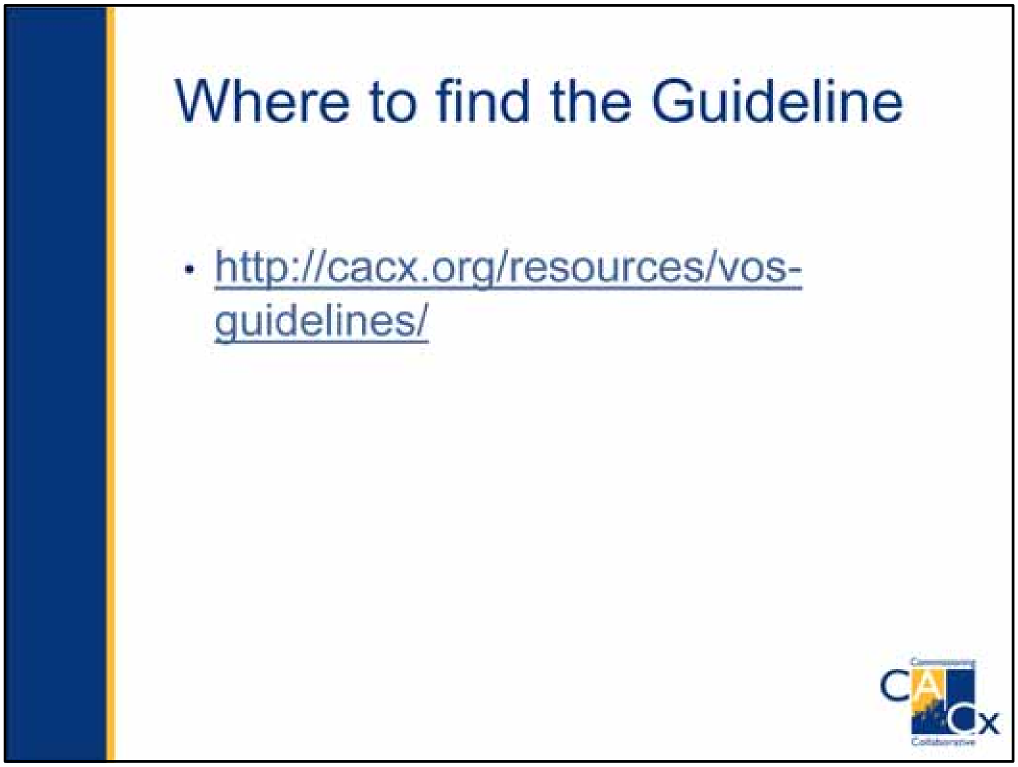
- Meters + hardware and maintenance
- Added Labor
  - Measurements
  - Analysis
  - Reporting



M&V Cost *Savings*

- Synergy between EBCx project and M&V:
  - Meters + hardware and maintenance
    - Consider adding meters: meters + M&V => "savings insurance"
  - Added Labor
    - Measurements
      - Abundance of whole-building data – low added cost
      - Systems data – higher cost but serves dual purposes & promotes persistence
    - Analysis
      - Tools can lower analysis cost
      - Standard method can lower project costs – program perspective
      - M&V results can replace engineering estimates of savings
        - E.g. use past results, BOA tools, DEER estimates
    - Reporting
      - Savings reported for measurement period
- Added M&V Cost in 3 RCx projects ~ 20%
  - Payback still only 0.7, 1.0, and 1.7 years

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/

Q&A

- Please submit questions via the Q&A box
  - Look for menu at the top center of your screen (it will expand down when you move your mouse over it) and select Chat box
  - Send questions to “Host”

2012 Meeting Dates

Date	Format
October 18, 2012	Webinar – Lighting Systems
December 6, 2012	In-person, host SoCal Gas in Downey, CA

Thank you for participating!

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Let us know what you thought of the meeting.

Please respond to the post-meeting survey. A link will be emailed to you.