Measurement Tools & Verification of Savings Calculations

E. Savings calculation methods

E. Savings Calculation Methods

- What are the main M&V savings calculation methods?
  - Load and schedule method
  - Regression methods
  - Simulations
- How are they applied?
- What software and tools are available?

Load and Schedule Method

- Based on simple equations:

$$kWh_{saved} = kWh_{base} - kWh_{post}$$

- Variations
  - Constant load, constant schedule (hours of use)
    - EEM changes hours of use: $kWh_{saved} = kW(HRS_{base} - HRS_{post})$
    - EEM changes load: $kWh_{saved} = (kW_{base} - kW_{post})HRS$
  - Other equations exist for variable load
- Note how 'adjustments' are included in calculations:
  - EEM changes hours of use – kW same in base and post
  - EEM changes load – HRS same in base and post

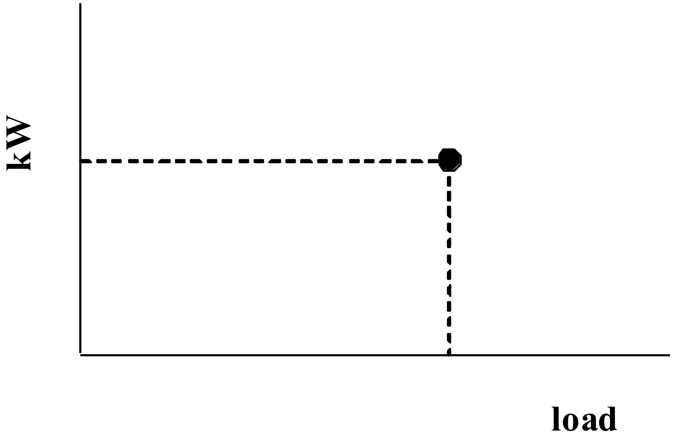
Load and Schedule Method

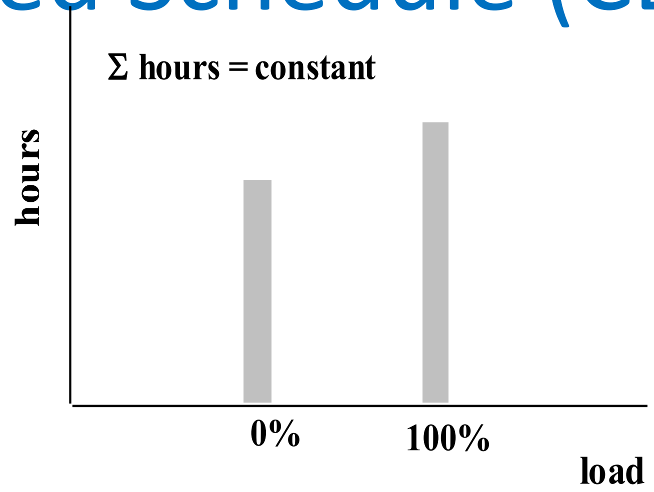
- Procedure
  - Characterize baseline equipment load and schedule operation
    - Constant or Variable
  - Determine impact of EEM on load & schedule
    - Changes load or changes schedule or both
  - Characterize post-install operation
  - Define analysis algorithms (pick equation)
  - From equation, identify data required
  - Develop data collection plan
    - Data points (i.e. kW, HRS, etc.)
    - Spot measurement
    - Monitoring required

Load and Schedule

- Operation Categories
  - Four categories are used to characterize the operation characteristics of the end-uses:
    - Constant Load, Timed Schedule
    - Variable Load, Timed Schedule
    - Constant Load, Variable Schedule
    - Variable Load, Variable Schedule

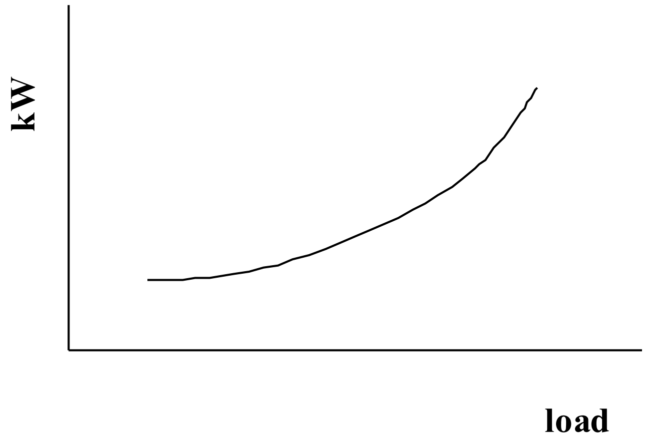
Constant Load, Timed Schedule (CLTS)

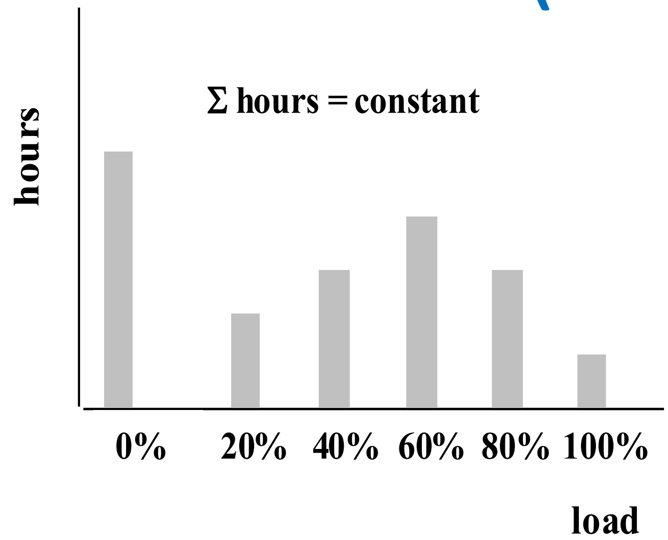




- Degree of "constant" defined by user
  - Variation less than 5% may be OK
- Examples
  - Lighting under time clock control
  - CRAH unit fan 24/7 operation

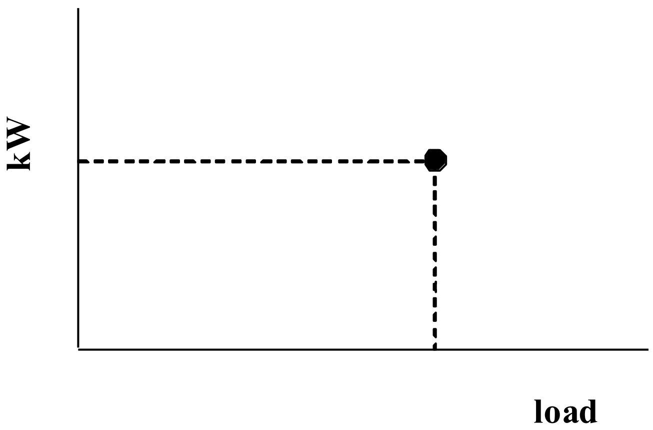
Variable Load, Timed Schedule (VLTS)

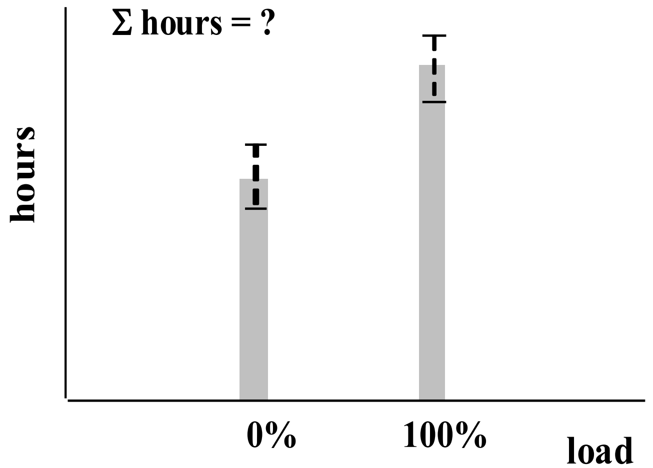




- kW varies with load
  - kW varies based on cfm, ton, speed, etc.
- Total hours constant, distributed over several load bins
- Examples
  - WW treatment blowers maintaining constant DO levels (24/7)
  - CRAC unit operation (split system, condenser on roof)

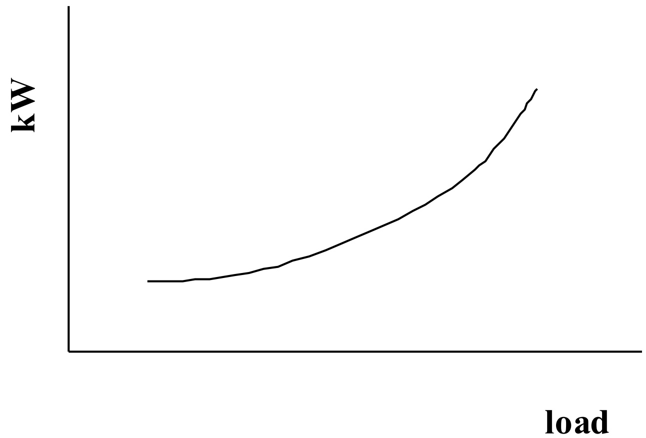
Constant Load, Variable Schedule

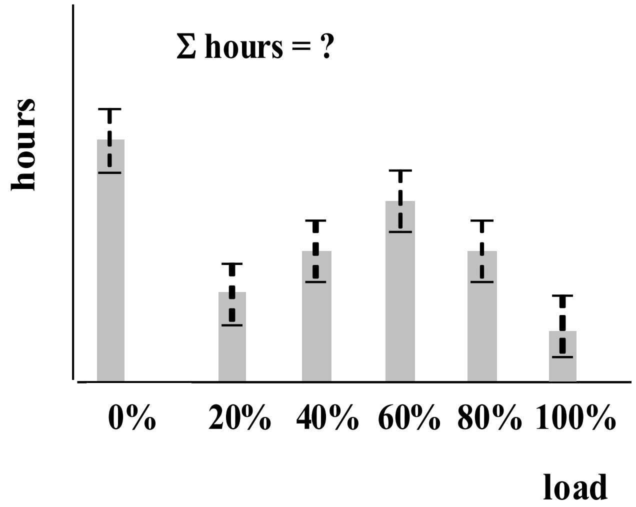




- Load is constant, but unknown hours-of-use
- Examples:
  - Lighting controlled with occupancy sensors
  - Constant speed cooling tower fans – hours vary with ambient temperature

Variable Load, Variable Schedule





- Hours-of-use in each bin and total are unknown
- Examples
  - Chilled water system maintaining CHWST reset schedule
  - Industrial VFD compressed air system

Load and Schedule: Algorithm

1. Identify baseline operation category
2. Determine impact of EEM
   a. Changes load, changes schedule
   b. Changes load or schedule from constant to variable
3. Based on EEM impact, identify post-installation operation category
4. Select equation, define analysis procedure
5. Determine relationships between load & hours-of-use, and other parameters
   - e.g. T, cfm, gpm, speed, tons, etc.
6. Collect baseline and post-install data
7. Calculate savings

Load and Schedule - Applicability

- Loads that may be isolated and measured
  - Air or water flow, heating Btu/h, cooling tons, etc.
  - Relationship to kW known or may be developed
- Energy flows: there should be few and straightforward to measure
- There are negligible or ignorable interactive effects with other equipment

Equations

- Savings equation selected based on
  - Characteristics of equipment operation
  - Impact of ECM
- Select equation to minimize data requirements
  - e.g. lighting fixture replacement, constant hours-of-use
    - Measure kW in baseline period (not hours-of-use)
    - Measure kW and hours-of-use in post-install period

$$kWh_{saved} = \left(kW_{base} - kW_{post}\right)HRS_{post}$$

Equations – Examples

- CLTS
  - Changes load

$$kWh_{saved} = \left(Eff_{base} - Eff_{post}\right) \cdot Q_{post} \cdot HRS_{post}$$

  - Changes hours-of-use

$$kWh_{saved} = kW_{base} \cdot \left(HRS_{base} - HRS_{post}\right)$$

  - Changes load from constant to variable

$$kWh_{saved} = kW_{base} \cdot HRS - \sum_{i}\left[kW_{post,i} \cdot HRS_{i}\right]$$

  - Changes hours-of-use from constant to variable

$$kWh_{saved} = kW_{base} \cdot HRS_{base} - kW_{base} \sum_{i} HRS_{post,i}$$

$$HRS_{base} \neq HRS_{post} \quad HRS_{post} = \sum_{i} HRS_{post,i}$$

Equations – Examples, cont.

- VLTS
  - Changes load

$$kWh_{saved} = \sum_i \left[kW_{base,i} \cdot HRS_{base,i} - kW_{post,i} \cdot HRS_{post,i} \right]$$

$$\sum_i HRS_{base,i} = \sum_i HRS_{post,i}$$

  - Changes hours-of-use

$$kWh_{saved} = \sum_i kW_{base,i} HRS_{base,i} - \sum_i kW_{base,i} HRS_{post,i}$$

$$\sum_i HRS_{base,i} \neq \sum_i HRS_{post,i}$$

  - Changes hours-of-use from constant to variable

$$kWh_{saved} = \sum_i kW_{base,i} HRS_{base,i} - \sum_j kW_j HRS_{post,j}$$

$$\sum_i HRS_{base,i} \neq \sum_j HRS_{post,j}$$

Equations – Examples, cont.

- CLVS
  - Changes load
  - $kWh_{saved} = \left(kW_{base} - kW_{post}\right) \cdot HRS_{base}$ (or HRS_{post})
  - Changes hours-of-use

$$kWh_{saved} = Eff_{base} \cdot Q_{base} \cdot \left(HRS_{base} - HRS_{post}\right)$$

  - Changes load from constant to variable

$$kWh_{saved} = kW_{base} \cdot HRS_{base} - \sum_i \left[kW_{post,i} \cdot HRS_{post,i}\right]$$

$$HRS_{base} = \sum_i HRS_{post,i}$$

Equations – Examples, cont.

- VLVS
  - Changes load

$$kWh_{saved} = \sum_i \left[\left(kW_{base,i} - kW_{post,i} \right) \cdot HRS_{post,i} \right]$$

  - Changes hours-of-use

$$kWh_{saved} = \sum_i \left[kW_{base,i} \cdot \left(HRS_{base,i} - HRS_{post,i} \right) \right]$$

  - Changes load and hours-of-use

$$kWh_{saved} = \sum_i \left[kW_{base,i} \cdot HRS_{base,i} \right] - \sum_i \left[kW_{post,i} \cdot HRS_{post,i} \right]$$

Simple Example

- A storage building at an Army Base is undergoing a lighting retrofit. The existing exterior lighting of the building consists of (9) 70W Metal Halide Wall pack fixtures.

- The following procedure complies with load and schedule approach and is used to determine project energy savings

Step1. – The existing fixtures produce a constant wattage and were observed to operate continuously day or night. Therefore the Constant Load Timed Schedule (CLTS) category best represents this existing equipment's load and hours-of-use characteristics.

Step2. – The ECM includes retrofitting the (9) 70W Metal Halide Wall pack fixtures with (9) 36W LED Wall pack fixtures and installing Daylight controls as shown in Table 1 and Table 2

Example, cont.

Table 1

Fixture	kW/Fixture	Qty	Hours of operation	Total kW
70W Metal Halide Wall pack	0.095	9	8,760	0.855

Table 2

Fixture	kW/Fixture	Qty	Hours of operation (estimated)	Total kW
36W LED Wall Pack	0.036	9	4,380	0.324

Example, conclusion

- Step 3. This ECM will reduce the equipment's load and hours of operation. The anticipated post-installation equipment's load and hours of use characteristics best fit into the CLVS category. Therefore, the appropriate equation to use in determining savings is:

$$kWh_{saved} = kW_{existing} \times HRS_{existing} - kW_{proposed} \times \sum HRS_{proposed}$$

- In review, the key parameters estimated were load and hours of use. Data sources for those parameters included nameplate information (in this case, the lamp label or model number), A Table of Standard Wattages, interviews with the facilities staff and a light logger.
- Total savings for this project were 6,071 kWh.

Advantages of L&S Method

- M&V is extension of methods used to calculate ex-ante savings
- Allows use of technical (not measured) info.
- Many required measurements may be cost-effectively obtained
- Can apply to more complicated systems, if operation characteristics same
- Can quantify savings uncertainty, if required

Disadvantages

- Not practical for multiple EEMs throughout a facility
- Does not account for savings interactions
  - e.g. cooling savings from a lighting retrofit
- Not well applied to end-uses with highly random load and schedule characteristics

Regression Method

- Empirical relationships between energy use and factors that influence energy use
  - Ambient temperature
  - Time (of year, of week, etc.)
  - Occupancy
  - Etc.
- Influencing parameters must be <u>measureable</u>

Regression Method

- General procedure
  - Develop a regression relationship between energy use and one or more independent variables using data from the baseline period
  - Check model quality – fit statistics, error
  - Using post-install data, determine 'adjusted baseline' in post-install period
  - Subtract actual energy use to determine savings (avoided energy use)

Monthly Bill Regression - Heating

- Based on monthly energy bills
- Calculate heating degree-days to determine the weather-induced load on the heating system
  - Requires a balance-point temperature, which is the temperature above which the building requires heating, and varies from building to building, typically 60 or 65F.

$$\boxed{HDD = \sum_{day=1}^{month} \left(T_{bal} - \overline{T}_{ambient} \right)_{day_i}}$$

(toss out negative values)

Monthly Bill Regression - Cooling

- Calculate cooling-degree-days to determine the base load and weather-induced load on the cooling system
  - Also requires a balance point temperature above which cooling is required. Can be different than heating balance point temperature.
  - Due to internal heat gains, the Tbal may be much lower than ambient

$$\boxed{CDD = \sum_{day=1}^{month} \left(\overline{T}_{ambient} - T_{bal} \right)_{day_i}}$$

(toss out negative values)

Weather Data

- The NOAA website and other websites such as weather underground provide weather data including ambient dry-bulb temperature for many airports and other weather stations throughout the country.
  - www.noaa.gov
  - www.wunderground.com
- Values provided are generally on an hourly basis.
- Data must be checked, often there are gaps and erroneous values in the data
- Some site provide heating degree days directly
  - www.degreedays.net

Monthly Bill Regressions

- Most spreadsheet tools have a regression tool.
- Tabulate the monthly bills and HDD for each month in a spreadsheet.
- Also record the number of days each month.
- Use the regression tool to determine the linear regression's model coefficients and coefficient of determination (R^2)
- Also calculate the CV(RMSE) – coefficient of variation of the root mean squared error

$$CV(RMSE) = 100 * \frac{\left[\sum_i (E_i - \hat{E}_i)^2 \Big/ (n-p)\right]^{1/2}}{\overline{E}}$$

Monthly Bill Regression: Brief Example

- Monthly Gas Bill Data (cu.ft.)

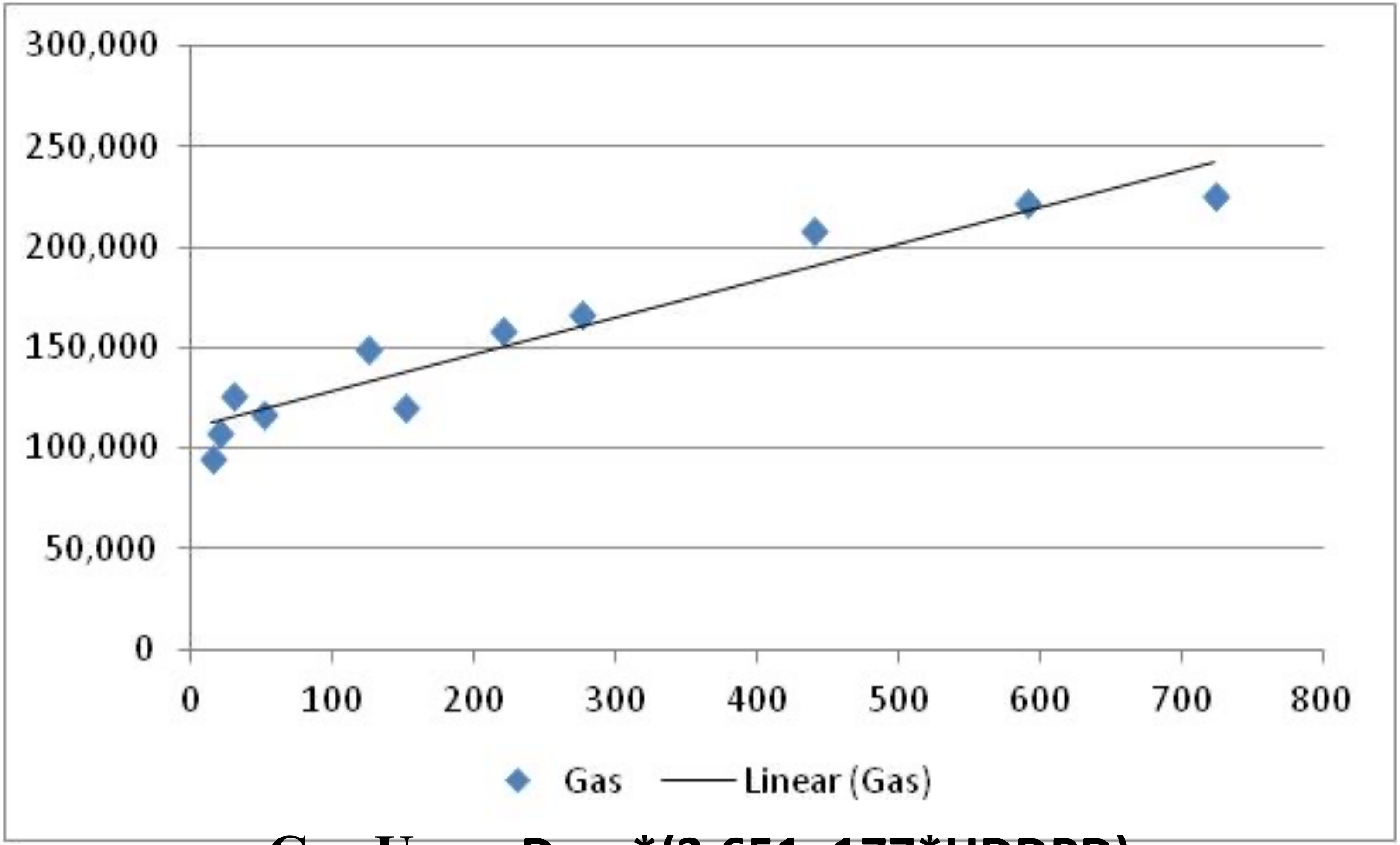
Date	Days	Natural Gas Consumption	Heating Degree-Days	Predicted Gas Consumption
4/7/2004	33	208,664	440	187,595
5/6/2004	29	157,866	220	149,476
6/5/2004	30	120,793	150	137,347
7/7/2004	32	116,508	50	120,020
8/7/2004	31	107,272	20	114,822
9/5/2004	29	95,411	14	113,782
10/6/2004	31	126,423	29	116,381
11/6/2004	31	149,253	125	133,015
12/4/2004	28	166,202	275	159,006
1/6/2005	33	221,600	590	213,586
2/5/2005	30	224,958	723	236,631
Total		1,694,950		1,681,661

Baseline Model Improvement

- Improve example linear model by:
  - Normalizing the data (divide Gas and HDD by no. days)
  - This “weights” the points by the number of days
- Perform regression on weighted values
  - Result: Gas = Days*(3,651+177*HDDPD)
  - NBE = -0.044% (was 0.8%)

Date	Days	Natural Gas Consumption	Heating Degree-Days	Nat Gas Use per Day	HDD per Day	Predicted Gas Use per Day	Predicted Gas Consumption
4/7/2004	33	208,664	440	6,323.2	13.33	6,004.8	198,160
5/6/2004	29	157,866	220	5,443.7	7.59	4,990.1	144,714
6/5/2004	30	120,793	150	4,026.4	5.00	4,533.5	136,005
7/7/2004	32	116,508	50	3,640.9	1.56	3,926.6	125,650
8/7/2004	31	107,272	20	3,460.4	0.65	3,764.6	116,703
9/5/2004	29	95,411	14	3,290.0	0.48	3,735.9	108,342
10/6/2004	31	126,423	29	4,078.2	0.94	3,815.9	118,292
11/6/2004	31	149,253	125	4,814.6	4.03	4,362.6	135,242
12/4/2004	28	166,202	275	5,935.8	9.82	5,384.8	150,774
1/6/2005	33	221,600	590	6,715.2	17.88	6,807.4	224,644
2/5/2005	30	224,958	723	7,498.6	24.10	7,905.8	237,174
Total		1,694,950					1,695,698

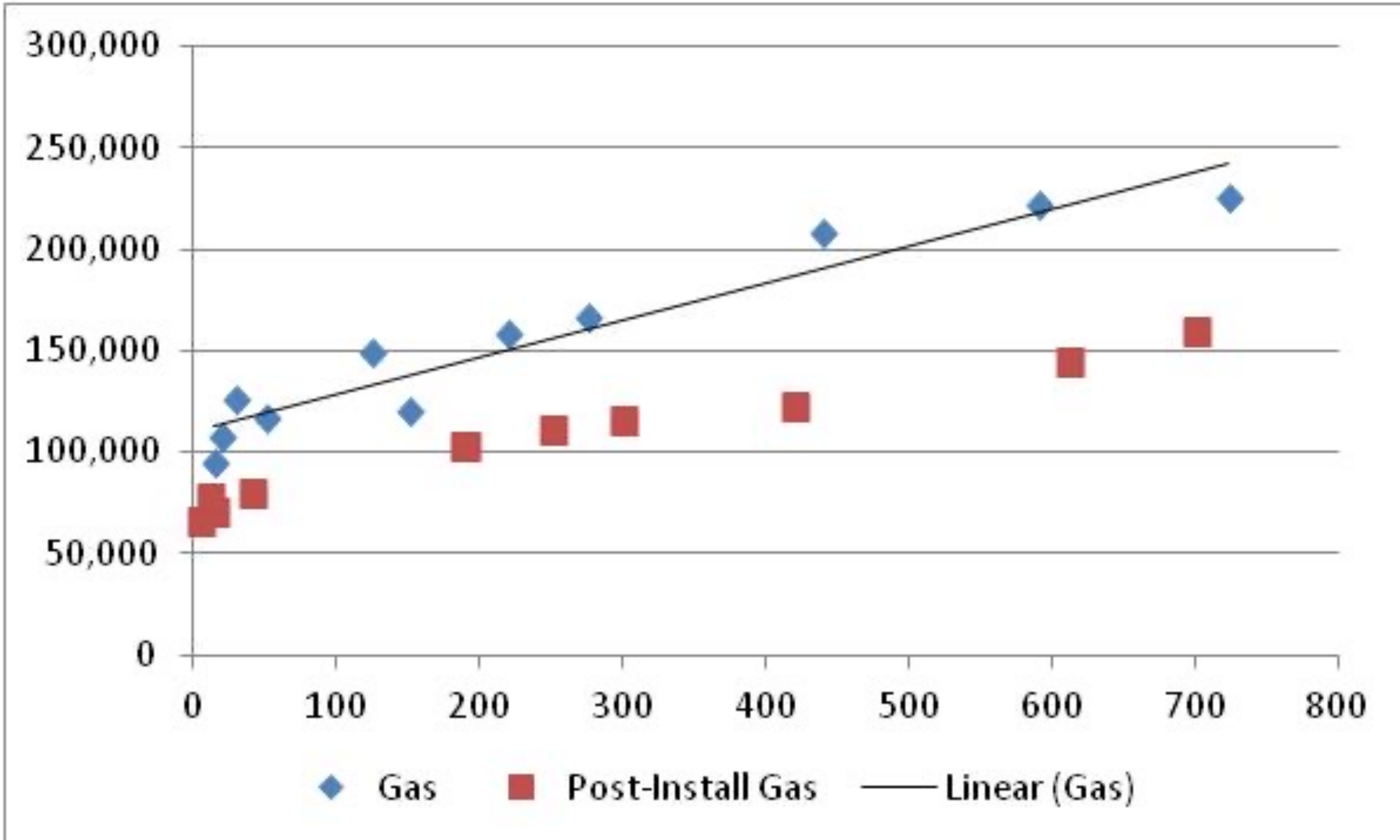
Baseline Model: Actual v. Predicted



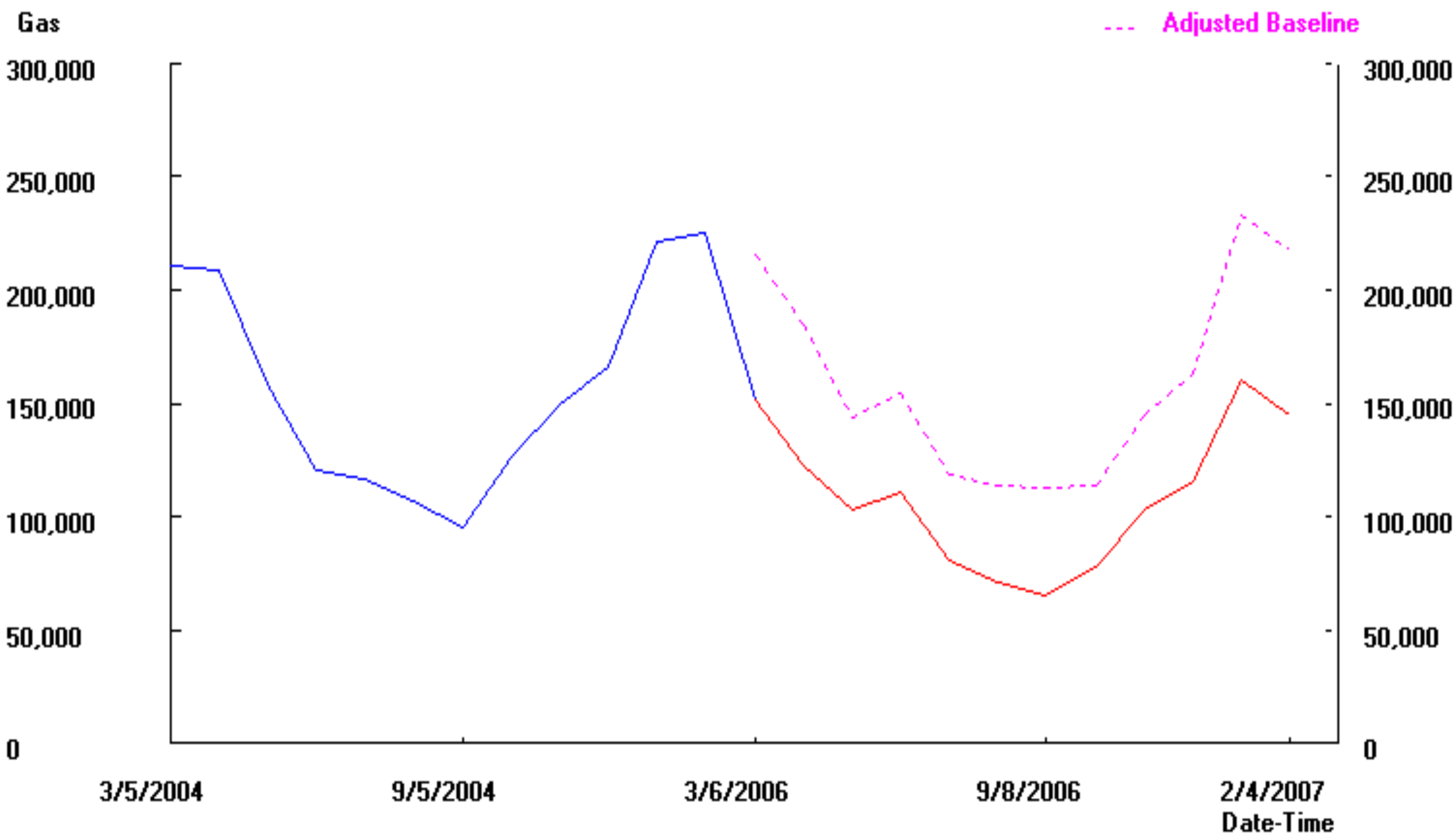
Gas Use = Days*(3,651+177*HDDPD)

R^2 = 0.92, CV(RMSE) = 8.9%

Adding Post-Installation Data



Baseline Projection & Savings



- **Post-Installation Period Savings: 609,567 cu.ft. ± 17%**
- **Savings percentage: 32%**

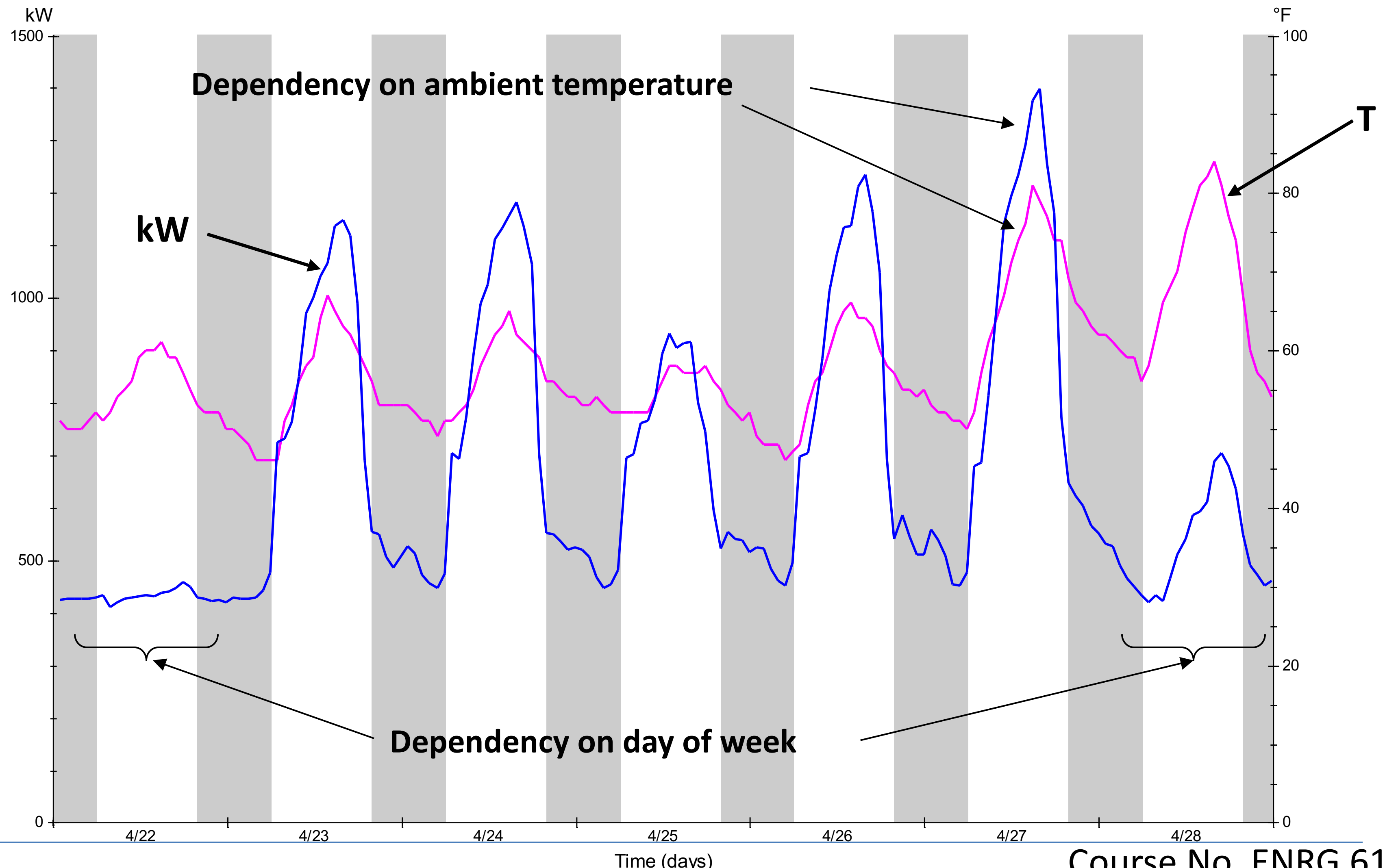
Best Applications with Monthly Data

- Significant energy savings
  - Rule of thumb: 10-15% or more of consumption measured by the utility meter
- All parameters which significantly affect energy usage can be clearly identified (during baseline and after implementation)
- Adjustment factors are simple
- Individual ECM measurement is not required
- Multiple ECMs
- Complex ECMs

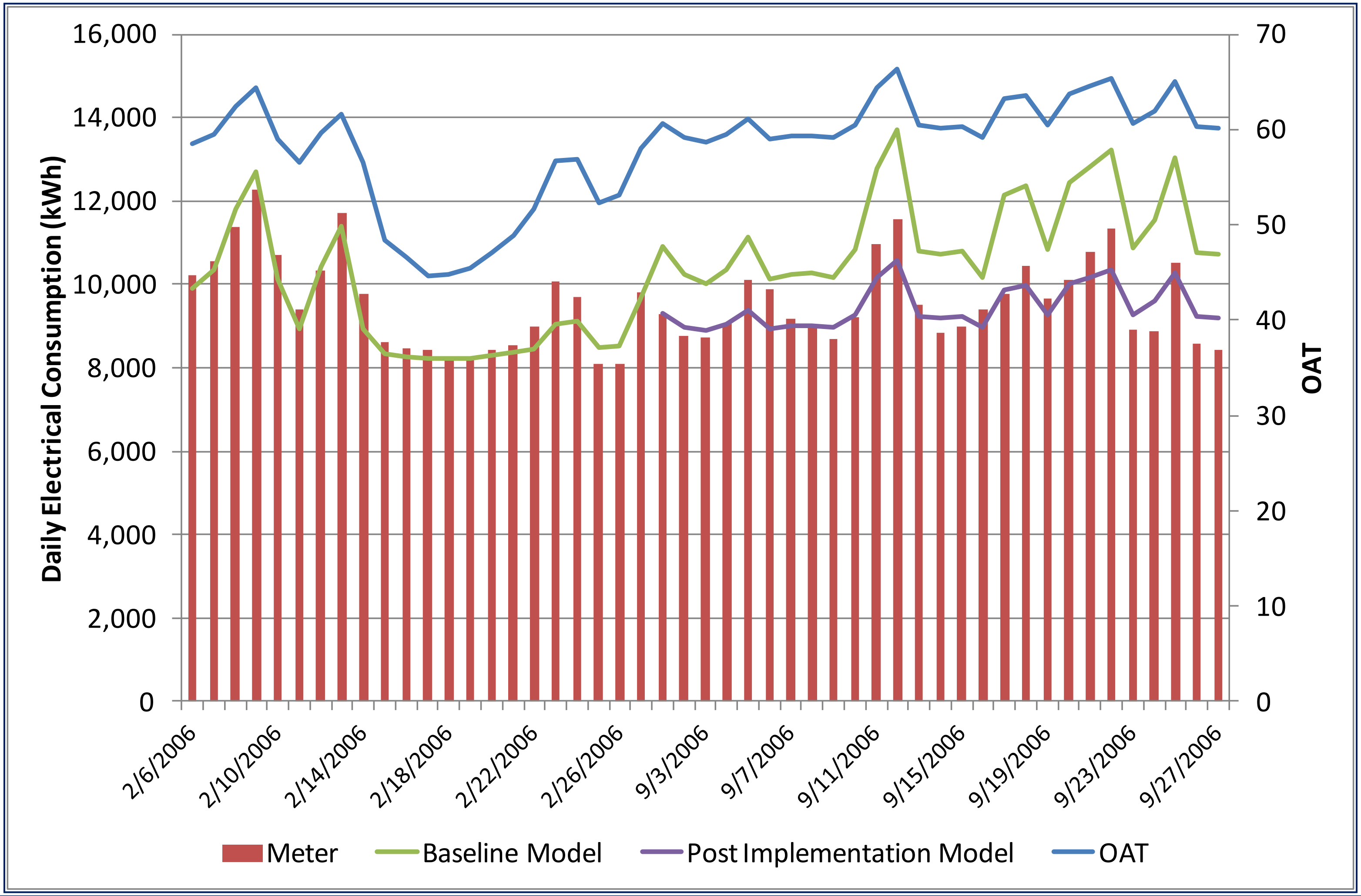
Energy Models based on Interval Data

- “Interval data” = data from Time-of-Use Meters, typically in very large commercial and industrial buildings.
- Smart Meters in smaller buildings and houses are now providing interval data.
- Interval data is energy use data from short time interval measurements, typically 15-minutes for electricity.

Short Time Interval Methods



M&V with Interval Data



Useful Software

- ASHRAE Inverse Modeling Toolkit (RP1050)
  – Purchase with Research Project 1050
- Energy Explorer
  – "Change-point" models
  – Source: Prof. Kelly Kissock, University of Dayton
- Energy Charting and Metrics Tool
  – www.northwrite.com
- PG&E Universal Translator M&V Analysis Module
  – www.utonline.org (coming soon)

Calibrated Simulation

- A simulation of a building or system is made using a recognized software
  - eQUEST
  - EnergyPlus
  - EnergyPRO
- The building or system is ‘modeled’ within the software, and ‘calibrated’ with measured data from the building to make sure the model accurately predicts baseline energy use
- After EEMs are installed, the simulation is run with post-installation data (temperature, occupancy, etc.) to determine the adjusted baseline.
- Savings are determined by subtraction of the measured post-installation use from the adjusted baseline.

Calibrated Simulation

- Advantages
  - Can quantify individual EEM savings as well as whole building
  - Useful to have a simulation for other purposes
- Disadvantages
  - Can be most difficult and expensive method
  - Requires a lot of building data to calibrate
  - Simulation programs may model the building well

BEST Center Curricula, Resources & Recordings

Academic Programs
Georgia Piedmont Technical College - Building Automation Systems
Milwaukee Area Technical College - Sustainable Facilities Operations
Laney College - Commercial HVAC Systems
City College San Francisco - Commercial Building Energy Analysis & Audits

Professional Development Materials, Presentations & Videos
National Institutes
Building Automation Systems Instructor Workshops
Webinars (e.g., BEST Talks)

Faculty Profile Videos
Reports & Case Studies
Marketing Resources

BEST
Building Efficiency for a Sustainable Tomorrow

National Science Foundation