The Solutions Network

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Further Methods for Setting the Bar: Modeling Facility Energy Use

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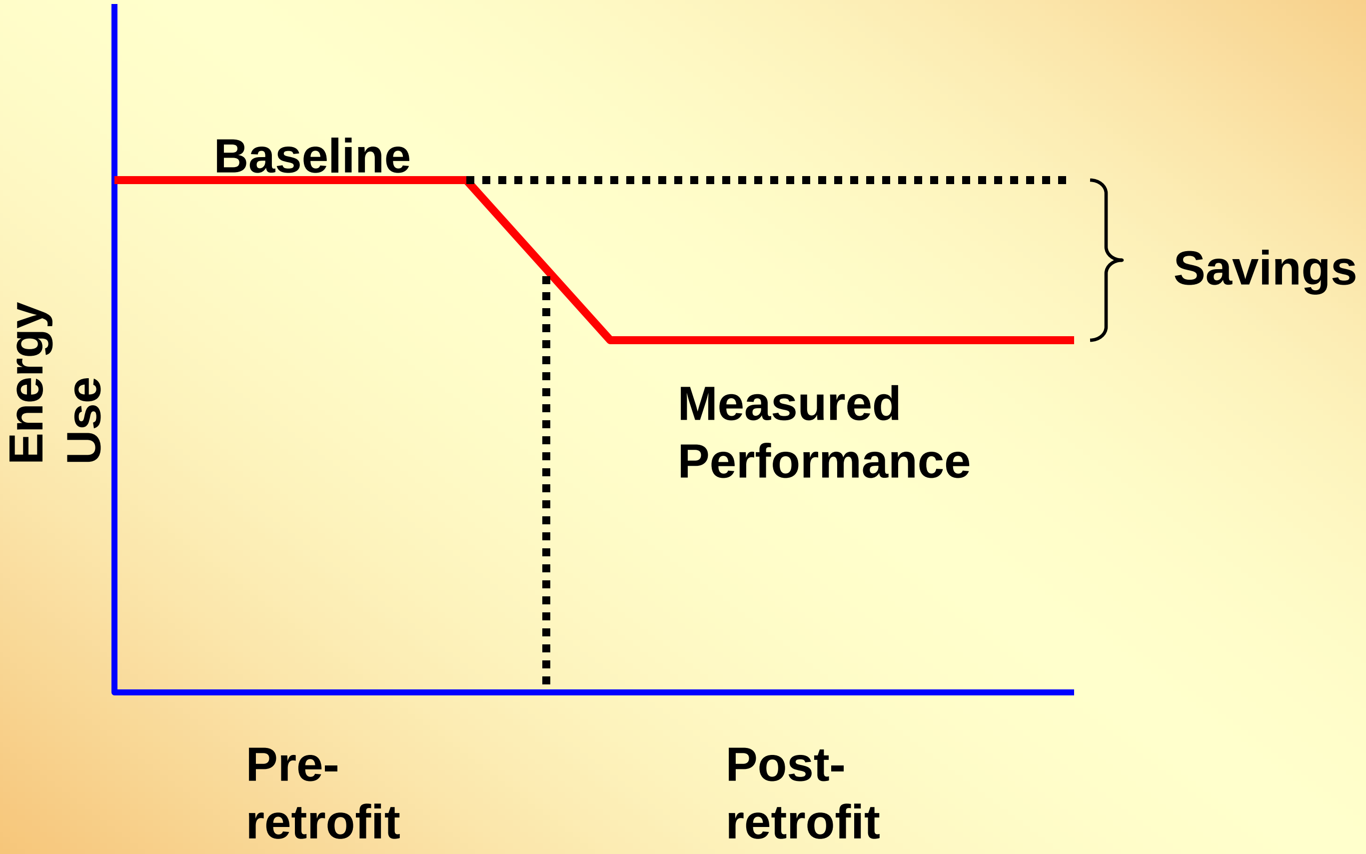
What is the baseline and why is it important?

- The baseline energy use is the amount of energy the facility uses prior to retrofits
- Documenting the baseline is imperative in ESPC, because once retrofits are installed, the baseline no longer exists
- Baseline is the starting point for determining energy savings, and the foundation of the M&V plan

Determining savings from energy conservation retrofit projects



Building energy use is not constant; depends on many variables

- Weather
- Level of occupancy
- Type and quantity of equipment in use
- Operating hours
- Production rate (industrial facilities)
- … etc.

To determine savings, we need a *model* of energy use as a function of these variables

There are two basic types of baseline models

- Statistical models: Based on multivariate regression, they model energy use as a function of a set of independent variables
- Engineering models: Based on engineering principles, these models simulate the performance of the building and its equipment in response to the independent variables

These correspond to specific M&V options prescribed by FEMP

- Option C: Whole-facility or main-meter verification (regression analysis)
- Option D: Whole-building computer simulation

Regression Analysis: FEMP M&V Guideline Option C

- Pre-retrofit utility bills form the baseline
- Normally requires 12 months (preferably 24 or more) of data
  - Billing dates
  - Energy consumption
  - Daily average temperatures (if energy use is mostly weather-driven)
- Use data to develop a regression model of energy use as function of parameters

When Option C is appropriate

According to FEMP M&V Guidelines, Version 2.2:

- Savings are above the “noise level”
- High degree of interaction between multiple measures at a single site
- Measurement of individual component savings is not relevant
- Other approaches are too expensive

Potential problems with utility bill analysis

- Energy conservation projects usually focus on small areas, whereas utility bill applies to entire facility
  - Thus the savings may not show up in the utility bills
- Some facilities submeter individual areas, but who maintains these meters?
  - If it's not the utility, beware
  - Also beware of allocation formulas

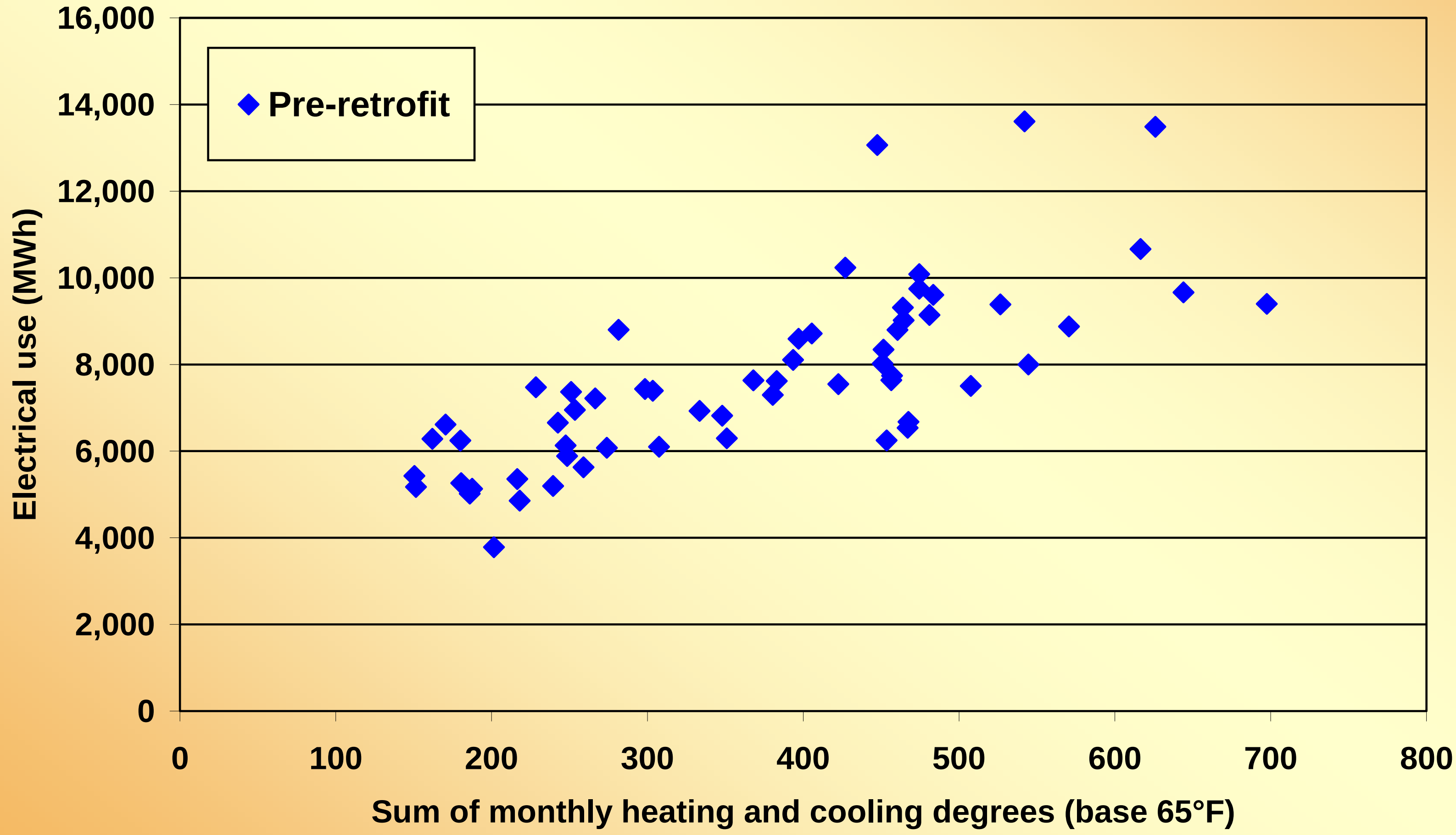
FEMP's M&V Guidelines discourage this method, but:

- The approach has been used successfully to perform M&V
  - Used in the Fort Polk residential retrofit of 4,003 residences to GHPs
- It is very straightforward, easy to understand, and easy to present
  - Think about auditors
- Utility bills are (or should be) the ultimate arbiter of whether energy is saved or not

Example: Another GHP retrofit for military family housing

- 4,000 residences
- Average housing unit size 1100 square feet
- Space conditioning provided by air source heat pumps
- Electric water heating
- Energy conservation measures cover half the residences only: install geothermal heat pumps with desuperheaters

Five years of monthly utility bills were available



Developing the baseline model

- In a residential setting we expect monthly electrical use to be a function of heating degree days, cooling degree days, and the number of days in the billing period:

$$E = a \times n + b \times HDD_{65} + c \times CDD_{65} \quad (1)$$

- Here we use base 65°F degree days, but if desired we could estimate the balance temperatures from the data

But there are problems with a model like this

- Note that the equation has no intercept:
  $E = a \times n + b \times HDD + c \times CDD$
- This will introduce a *bias* in the correlation
- There are ways to eliminate this bias (see ASHRAE Guideline 14)
- Since *n* varies only between 28 and 31, our estimate of parameter *a* is not very accurate
  - Technically it would be better to use something like
    $E = a + b \times HDD + c \times CDD$
- Nevertheless, for conceptual reasons, model (1) is preferred

Output from regression analysis

	Estimated	StdErr	t value	Pr(>|t|)
A (n)	120,654	15,288	7.885	1.69E-11
b (HDD)	11,288	1,105	9.31	3.04E-14
c (CDD)	10,165	1,479	6.523	6.54E-09

Multiple R-Squared: 0.5731, Adjusted R-squared: 0.5581

Standard error of model prediction: 1,356,562 kWh

Baseline model for monthly electrical use is:

$$E = 120{,}654 \times n + 11{,}288 \times HDD + 10{,}165 \times CDD$$

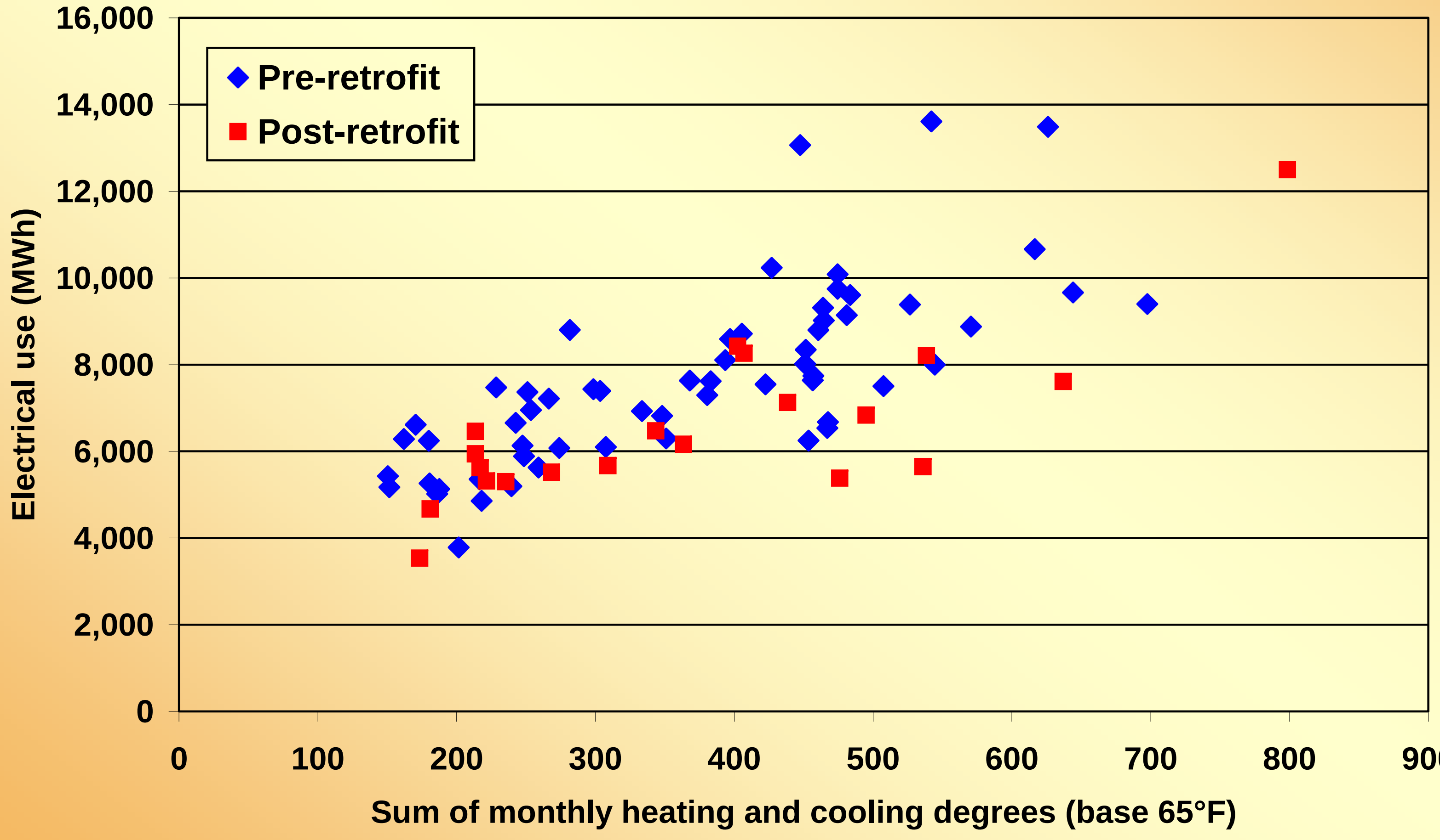
What this model says about pre-retrofit electrical use

- There is a base electrical use of about 121,000 kWh/day in family housing unaffected by weather
- A heating degree day uses 11% more electrical energy than a cooling degree day (possibly because of supplemental heating)
- R-squared of 0.57 means the model accounts for only about 57% of the variation in the data
  - The rest is "noise," i.e., things we can't explain
- The noise level — on the order of ±1,345 MWh per month — is quite high, but this is to be expected

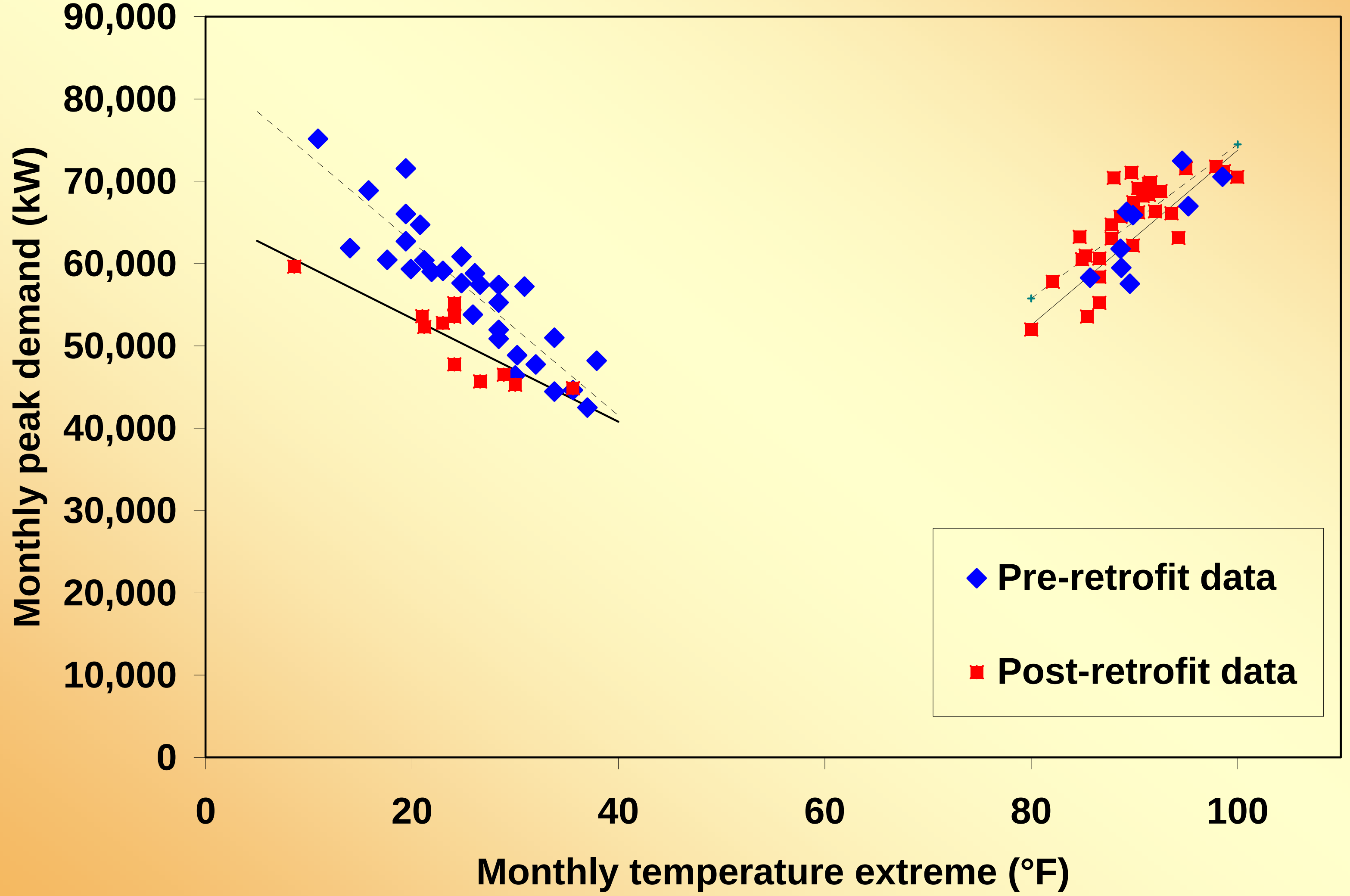
Using the model to determine savings

- ESCO guarantees an annual level of savings — say, 12%
- Annually, the measured heating and cooling degree days are substituted into the baseline model to determine pre-retrofit electrical use
- Actual energy use for the year is subtracted from the baseline to determine savings
- If savings is greater than or equal to 12%, the guarantee is considered to be met

Pre- and post-retrofit energy use



Pre- and post-retrofit peak electrical demand



Calculating annual savings

Year 1 post-retrofit energy use:

Month	days	HDD	CDD	kWh
Oct	31	156	61	5,623,200
Nov	30	194	28	5,317,044
Dec	31	394	9	8,426,324
Jan	31	530	9	8,207,990
Feb	28	476	1	5,382,435
Mar	31	290	20	5,671,275
Apr	30	106	130	5,300,235
May	31	42	172	6,459,853
Jun	30	0	364	6,161,765
Jul	31	0	495	6,835,666
Aug	31	0	439	7,124,929
Sep	30	0	344	6,471,776
Total	365	2,186	2,068	76,982,492

Pre-retrofit energy use:
$(120{,}654 \times 365) + (11{,}288 \times 2{,}168) + (10{,}165 \times 2{,}068) = 89{,}532{,}314$ kWh

Year one savings: 12,549,822 kWh

12.5/89.5 = 14%

But normalizing to a typical year is a better approach

Correlate monthly post-retrofit electrical use to HDD and CDD:
$E(post) = 113{,}156 \times n + 8{,}384 \times HDD + 8{,}075 \times CDD$

$E(pre) = 120{,}654 \times n + 11{,}288 \times HDD + 10{,}165 \times CDD$
$E(saved) = 7{,}498 \times n + 2{,}904 \times HDD + 2{,}090 \times CDD$

Typical year (TMY) has 2,581 HDD, 1,686 CDD

TMY electrical use:
$(120{,}654 \times 365) + (11{,}288 \times 2{,}581) + (10{,}165 \times 1{,}686)$
$= 90{,}311{,}228$ kWh

TMY electrical savings:
$(7{,}498 \times 365) + (2{,}904 \times 2{,}581) + (2{,}090 \times 1{,}686)$
$= 13{,}755{,}743$ kWh = 15.2% of pre-retrofit

Potential problems with this approach

- Plug load creep causes electrical use to increase over time
- Changes in occupancy change energy use
- Demographics can affect energy use as well
  - Residential energy use highly dependent on number and age of occupants
- All of these factors can potentially invalidate the baseline, making the savings calculation suspect

Significant changes may require baseline adjustments

- Given enough information, some of these issues could be addressed in a statistical model
  - For example, the pre-retrofit model could include percent occupancy p:
    $E = p^*(a \times n + b \times HDD + c \times CDD)$
  - Could also determine rate of load growth from pre-retrofit data:
    $E = p^*[(a + k \times t) \times n + b \times HDD + c \times CDD]$
- But as these models get more complicated, they become less useful and more suspect

We need something more sophisticated than a statistical model

- The ESCO needed something more sophisticated too
  - Statistical model of pre-retrofit cannot provide accurate estimates of post-retrofit energy use
  - The ESCO probably used a sophisticated hourly building energy analysis program:
    - Developed simulation models of representative housing units
    - Calibrated models to pre-retrofit energy use data
    - Implemented ECMs in software
    - Calculated post-retrofit energy use

Option D : Whole-Building Computer Simulation

- Process begins with an hourly simulation model of the buildings
- Model parameters correspond as closely as possible to actual building
- Model is calibrated to conform to monitored data, and model output becomes the energy use baseline
- ECMs are implemented in software and model is run again to determine savings
- Objective of M&V is then to ensure that performance of ECMs conforms to the performance assumed in the model

When Option D is Appropriate

According to FEMP M&V Guidelines, Version 2.2:

- ECM savings cannot be readily determined using baseline and post-installation measurements
- ECM improves or replaces the building energy management or control system
- There is more than one ECM and the degree of interaction between them is unknown or too difficult or costly to measure
- Energy use of ECM is dependent on variables that are difficult to measure/monitor

Example: Another military base in the Southeastern U.S.

- Project involved three groups of buildings
  - Admin/training area (6 buildings)
  - BEQ (bachelor enlisted quarters) area (15 buildings)
  - Maintenance/warehouse area (19 buildings)
- Objectives: Reduce energy, maintenance and water costs associated with:
  - Aging, inefficient, air-cooled chillers (admin/training)
  - HTHW plant, distribution system (admin/training,BEQ)
  - Inefficient chillers/chiller operation (BEQ)
  - Inefficient lighting (maintenance/warehouse)
  - Swimming pool

Admin/Training Area: Pre-retrofit HVAC Equipment

- 2-pipe/4-pipe fan coil systems, both VAV and constant volume AHUs
- Heating coils supplied by aging, inefficient HTHW distribution system with high maintenance requirements
- Cooling coils supplied by a variety of aging water chillers
- Also a number of split DX systems, heat pumps, electric resistance heaters, and window air conditioners serving some zones
- Occupied temperature setpoints and ventilation rates maintained 24 hours/day

Proposed ECMs in the Admin/ Training area

- Replace chillers/unitary equipment with geothermal heat pumps
  - Water to air for zone heating and cooling
  - Water to water for ventilation air
  - Each building with its own vertical borefield
- Disconnect buildings from HTHW line
- Install building automation system to provide night temperature setback/setup
- Install demand-controlled ventilation system including CO_2 sensors and variable frequency drives for fans

Option D M&V was chosen for ECMs in the admin/training area

Why Option D M&V is necessary for the ECMs in these buildings

- No building-level metering of electrical use or HTHW use
  – With no baseline energy use data, there is no way to determine savings
- Savings from the GHP/controls ECM is substantial (about 47% of current energy costs for these buildings)
- There will be interaction between the GHPs and the controls
  – Post-retrofit measurements alone could not isolate the savings from each measure

What does an hourly simulation model do?

- Models the complex, dynamic interactions between the conditioned spaces of a building, the occupants, lighting and other appliances, construction materials, and ambient conditions (air temperature, humidity, wind speed and direction, solar gain, etc.)
- Determines the hourly heating/cooling load in each conditioned space
- Given these loads, equipment models determine how often the HVAC equipment (chillers, boilers, air handlers, etc.) runs during each hour, and how much energy that equipment consumes
- Examples: DOE-2, Trace 700, Energy Plus

Model development is an involved process

- Begin with as-built plans
  - Dimensions of all spaces
  - Construction materials of walls, doors, roofs, flooring, windows, etc.
  - Overhangs (roof, mullions)
- Conduct on-site survey
  - Collect nameplate data for HVAC equipment
  - Count light fixtures and wattages
  - Count other appliances
  - Determine occupancy and operating schedule
- Enter the data into the computer program

Once the data is entered, there is more work to do

- Many unknowns still remain
  - Actual vs. nameplate energy use
  - Operation of controls
  - Rate of outdoor air infiltration
- In general, uncalibrated simulation models can predict annual energy use to within about +/- 15%
- The uncalibrated model is not the baseline. It must be calibrated with actual building energy use data

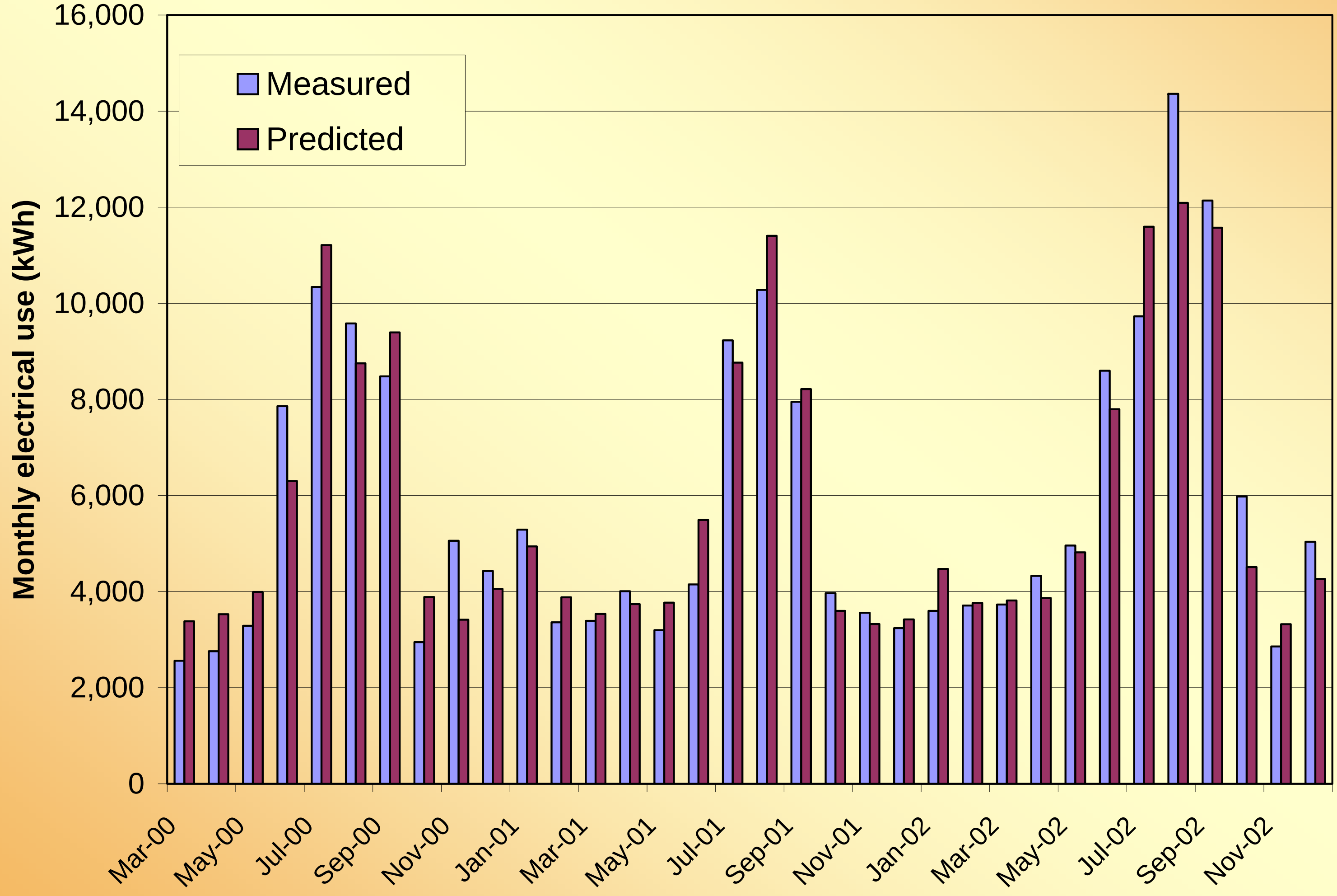
Objective of model calibration is to ensure that model matches actual performance

- Use utility bills if they exist
  - Monthly bills most common, 15 minute interval data available for larger commercial buildings
  - Need weather data (usually available on web)
- Install temporary data collection equipment
  - Ambient weather conditions
  - Electrical energy use
  - How long to collect data?
    - Obviously more is better
    - But this raises costs and causes delays
    - ESCO and site must agree on how much data will be collected

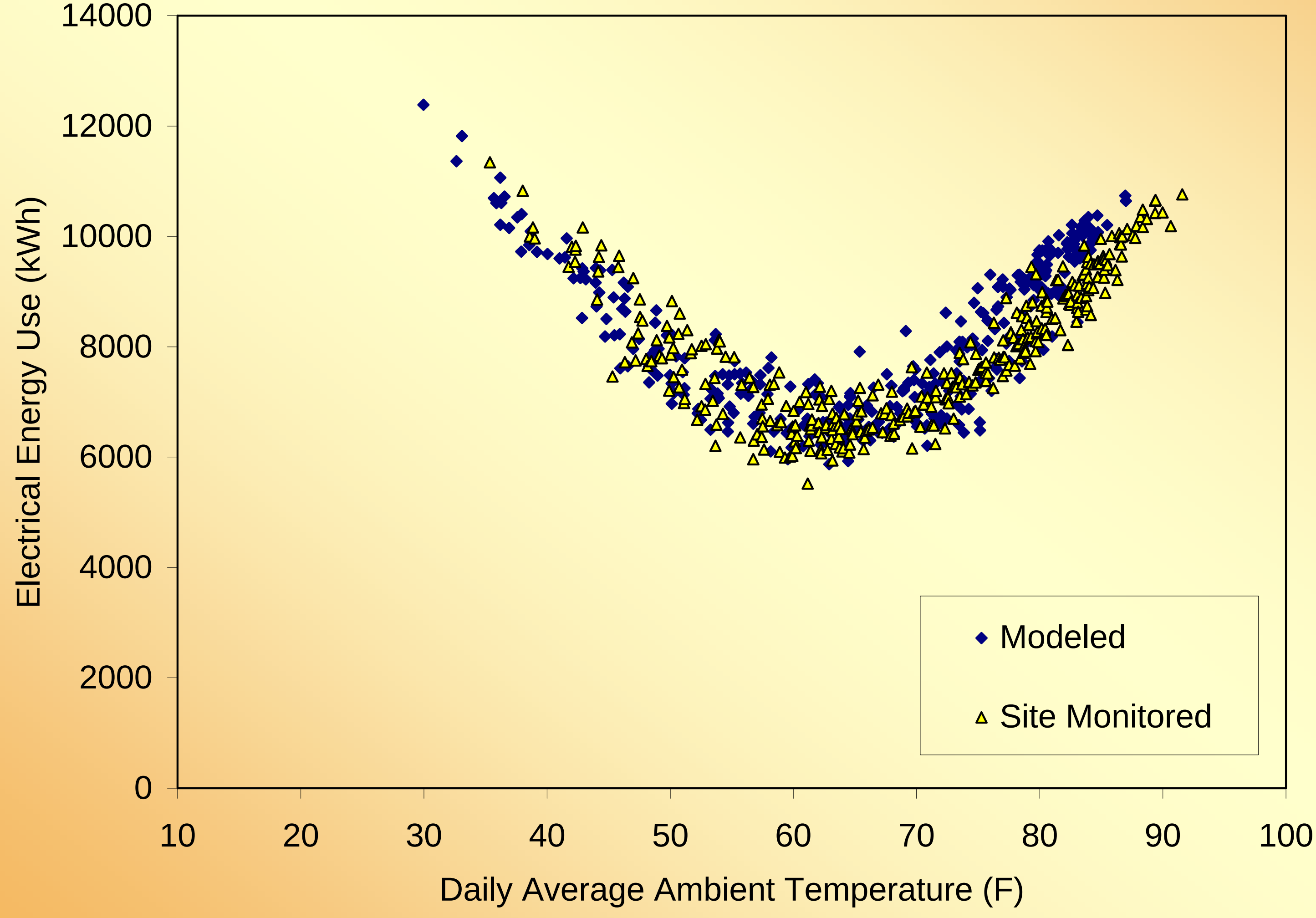
Model calibration is as much art as science, and requires experienced professionals

- Run the model and compare output with collected data
  - Visual checks
  - Statistical tests
- Refine the model as necessary by adjusting parameters such as infiltration, occupancy, equipment efficiencies, etc.
- Run the refined model, compare with output, and adjust again as necessary

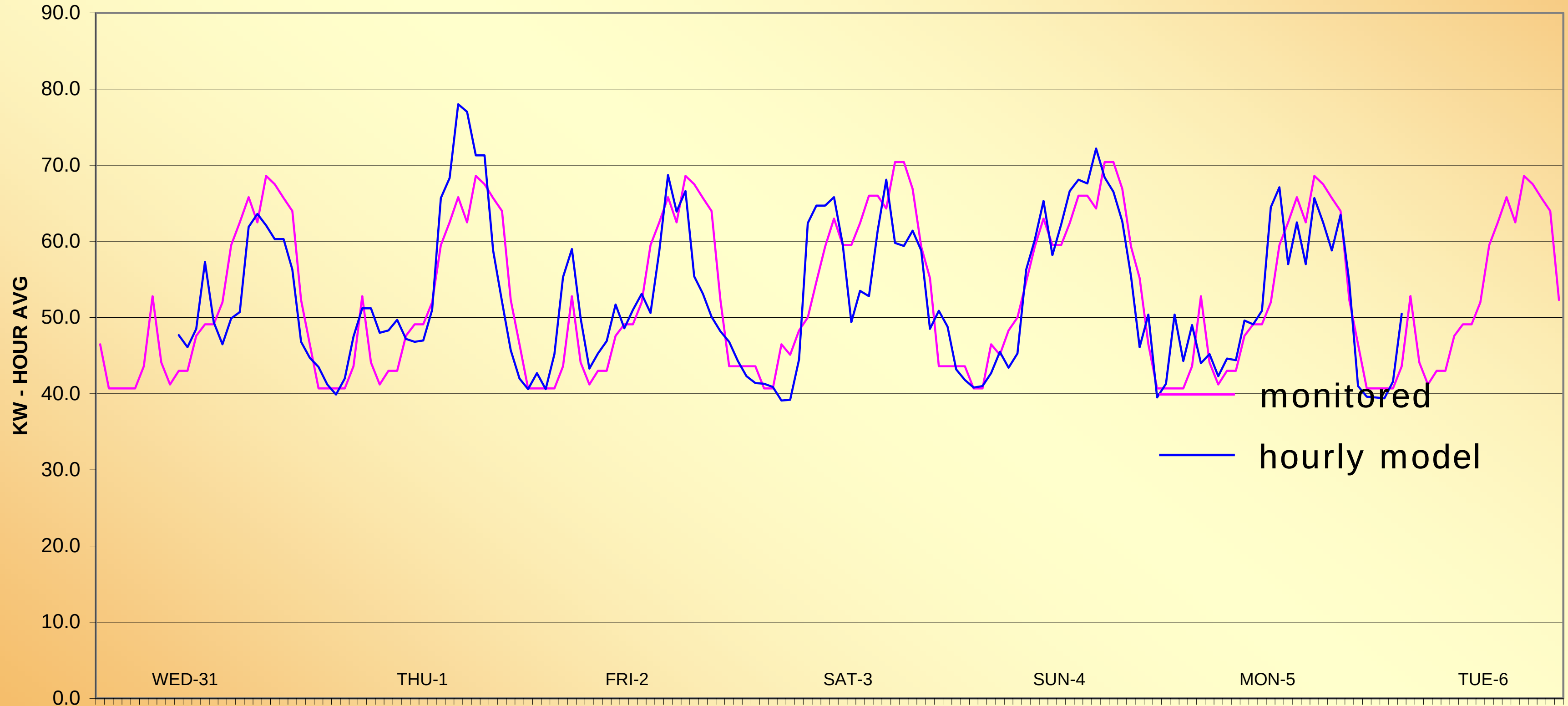
Example of calibration to monthly utility bills



Example of calibration to one year of daily data



Even one week of data is useful for calibrating model



FEMP M&V guidelines specify the degree of accuracy to which model must be calibrated

- For the modeling period:
  - Mean bias error must be within ±10%
  - Coefficient of variation must be within ±25%
  - Applies to models calibrated with hourly data; other criteria apply when calibrating to monthly utility bills
  - These are statistical measures that can be easily calculated on a spreadsheet, given measured and predicted data

Meeting the statistical criteria does not necessarily ensure that the model is correct

- Site and ESCO must agree on all model inputs, including:
  - Occupancy schedules
  - Temperature setpoints
  - Lighting loads
  - Miscellaneous equipment loads
  - Construction details (materials, R-values)
  - Infiltration rates
  - Ventilation rates
  - Equipment efficiencies

Who at the site will be responsible for verifying the baseline model?

- Savings (and annual payments) are based on the calibrated simulation model
- Therefore it is imperative that the site concur with every feature of the model
- Not all sites will have the expertise or resources required to assess whether model parameters are correct

Once consensus is reached on the model, savings can be calculated

- Model is run with typical-meteorological-year (TMY) weather input to determine baseline energy use
- ECMs are implemented in software using manufacturer's catalog data, and the building models are run with the same TMY weather data
- Energy rates (and escalation rates) are applied to determine annual savings
- ESCO decides how much of these savings they are willing to guarantee (in this case it was about 90%)
- Note that savings are based on TMY, while actual savings may fluctuate from year to year

Baseline model and all assumptions must be well documented

- The model represents the original performance of building
- The model output as driven by TMY weather defines the baseline
- Archive the model, the TMY data, and other important input parameters

Building simulation models then provide the basis for M&V

- Calibration to site-monitored data gives confidence that the model corresponds to actual building behavior
- Site is confident enough of the model that it agrees to pay the savings the model calculates
- All that is necessary then is to verify that ECMs perform “as advertised,” or as they were assumed to perform in the savings calculations

If required, baseline adjustments are easier to do with calibrated model

- Model can be used to determine the effect of changes in
  - Operating schedule
  - Occupancy
  - Production rate (industrial facilities)
  - Equipment
- All are simply parameters (or schedules) that drive the model

Summary: What baselining is all about

- The baseline is a model of the pre-retrofit energy use of the buildings that are to receive ECMs
- The model can be statistical or based on engineering principles (simulation)
- Baseline model has many purpose
  - Provides an understanding of how energy is presently used in the buildings
  - Provides a basis for savings calculations
  - Provides the foundation for measurement and verification of the savings

Baseline model using regression of utility bills

- Advantages
  - Easily understood
  - Relatively easy to implement
  - Utility bills are the ultimate arbiter of savings
- Disadvantages
  - Savings may not rise above the “noise” level
  - Savings may disappear due to load creep
  - Baseline adjustment is difficult

Baseline model using calibrated simulation model

- Advantages
  - Can be used where no utility bills available
  - Can be extremely accurate, if calibrated
  - Easy to adjust if necessary
  - The simulation model probably exists already
- Disadvantages
  - Development/calibration requires specialized expertise
  - Usually requires temporary on-site data collection