Creating the Past: Verification of Savings in the Absence of Historical Consumption Data

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Verification of energy savings is traditionally thought of as comparing energy use before and after making improvements in energy use efficiency. The lack of meaningful, building level historical consumption data for many commercial buildings frustrates conventional methods for determining energy use prior to making efficiency improvements. Master metered facilities with multiple buildings, newly constructed buildings, and buildings that have undergone significant remodeling or renovation have no historical data that is useful for quantifying savings attributable to energy efficiency improvements.

In the absence of such data, establishing base usage and determining how much is saved represents a significant challenge. The most straightforward solution would be to attach watthour meters to each facility prior to treatment. Unfortunately, this approach would entail a delay of efficiency improvements until enough time had passed to establish a baseline usage, typically one year. In addition, the added expense of metering and then analyzing two years' billing data could drive the cost of some installations beyond the point of cost effectiveness. The proposed alternative to the traditional approach comparing pre-improvement consumption with post-improvement consumption employs the measured hours of operation after, along with measured power use before improvements in efficiency to construct historical energy use. The focus of the paper is on practical and cost effective solutions to an apparently intractable problem of verifying conservation savings for a retrofit project at a master metered facility with multiple buildings.

Introduction

The usual approach to determining how much is saved by improving the efficiency of a building's energy using equipment is to compare a building's consumption for a period prior to making the improvements to consumption for a like period after making the improvements. The difference between the prior period base usage and the post period efficient usage, as adjusted for the influence of weather, occupancy and other factors, is the estimated savings.

This approach will not work for many commercial buildings. Master metered facilities with multiple buildings such as military installations, educational facilities or medical institutions have no building level consumption data. Newly constructed or planned buildings have only engineering estimates of consumption. Buildings that have changed functions or been expanded, extensively remodeled or renovated have no consumption data that is representative of the building's current configuration. When there is no meaningful historical consumption data, accurate baseline use from which to measure improvement cannot be established in the usual manner using adjusted meter data.

The problem of determining how much is saved without these historical data was examined and an approach developed to allow accurate, economic savings estimates. This approach was developed specifically for a single master metered facility with multiple buildings but holds promise for application in other situations where consumption data is not available.

The Approach

The proposed approach to measuring savings examines the connected load (kW) represented by equipment and the time of use (h) of that equipment. Together, these two elements are used to determine energy use (kWh).

Critical to the proposed approach is the measurement of the time of use (h). First, a pattern of use of the equipment will be estimated by measuring hours of operation for a relatively short term, post efficiency improvement measurement period, which will vary for different equipment and for different applications. This pattern of use will then be used for both the historical pattern of use of the equipment that was replaced and the pattern of use throughout the new equipment's useful life. This single time (h) for both past and future use will allow for a simplified estimation of savings resulting from improvements to efficiency.

In situ power measurements of a representative sample of each type of equipment are the second critical element to accurately determining the savings attributable to the efficiency improvements. For single building applications of this approach, measuring the power use of a large percentage of the equipment would be required. For multiple building applications, initial sampling will be intensive, with smaller samples allowed over time. Power use averages for each type of equipment will be based on cumulative measurement results.

The connected load (kW) represented by various types of equipment is accounted for by grouping equipment according to the variability of its load over time and customizing the measurement strategy to fully characterize those loads. If equipment essentially uses a constant amount of energy when in use, such as lights, then one-time, instantaneous power measurements can be used to determine its load (kW). If equipment uses a variable amount of energy depending on output or operation, then multiple measurements or measurements tied to cycles of use or output may be called for. Lights, motors, and transformers each might be examined differently.

It may not be practical or necessary or even physically possible to measure the performance of some efficiency improvements. In instances where this is true, such as low flow shower heads or low cost envelope measures such as caulking, savings will be estimated to be a predetermined amount. The key to determining the appropriate measurement strategy for any type of equipment is the ease of measuring its performance and the dependability of that measurement.

Verification of efficiency improvement estimates for all measures and strategies will be addressed at a minimum through engineering calculations. Some may receive no further attention, while others may be examined through short term or long term power and use measurement. The matrix shown in Table 1. illustrates this principal. Please see endnote number 1 for details of efficiency codes.

A Retrofit Project

An estimated 5 average megawatts of efficiency improvements are being made at a multi-building, master metered facility. The major focus is replacing existing lights, motors and transformers in over 3,000 buildings with more efficient equipment. Payment by the utility for these improvements and reimbursement to the utility of their costs will be based upon how much they save, so an accurate determination is important.

The usual pre versus post approach to verifying savings can not be employed because the facility's electricity is metered at only three main delivery points, and meaningful building level consumption data is not available. Without these data it is impossible to establish historical building level base usage from which to calculate improvement. Likewise, watthour meters will not be installed during the project, so determining individual building consumption after the new efficient equipment is installed will not be possible.

The proposed approach was developed to determine how much is saved as a result of energy efficiency improvements at the facility.

Examples

In simple one-to-one changeouts of lighting fixtures, estimated to comprise over 75% of the project, instantaneous, onetime power measurements will be made, on site, of a sample of like fixtures before changeout (kW_1). These measurements will be replicated, on site, for a like sample of efficient fixtures after changeout (kW_2). The hours of use (h) will be determined, either through occupant surveys, simple runtime loggers for a representative sample of the fixtures or a combination of the two. The savings will be

$$(kW_1 - kW_2) \cdot (h) \cdot (n)$$

where n equals the total number of like fixtures involved.

For the replacement of motors with higher efficiency motors the approach calls for power measurements to be made under representative loading conditions. Thus if the motors are operated under a constant load, such as some ventilation fans, one time measurements (kW) along with time of use (h) will suffice. However, if the load on the motors varies, such as with many pumps, power measurements will be made under full load and various partial loads. These measurements will be used along with an agreed upon profile of pump loading and measured time of use (h) to establish savings.

Thus for pumps that were loaded (kW_1) part of the time (L_1) and partially loaded (kW_2) the rest of the time (L_2) before the changeout and fully loaded (kW_3) and partially loaded (kW_4) for equal times (L_1) and (L_2) after the changeout, the savings would be

Table 1. Equipment Efficiency Improvement and Verification Methodology Matrix

Efficiency Code	Engineering[1] Calculations	Run Time[2] Meters	Short Term[3] Measurement	Long Term[4] Measurement	Building[5] Meter
Lighting					
L-1, L-2, L-3	Yes	Yes	No	No	No[6]
L-4, L-7	Yes	Yes[7]	No	No	No[6]
L-5, L-8	Yes	No	No	No	No[6]
HVAC					
H-1, H-2	Yes	No	No	No	No[6]
H-3, H-6, H-7, H-9, H-10	Yes	Yes[7]	No	No	No[6]
H-12	Yes	No	Yes	No	No[6]
H-4, H-5, H-11, H-13, H-14	Yes	No	No	Yes	No[6]
Water Heating					
W-1, W-2	Yes	Yes[9]	No	No	No[6]
W-4, W-7, W-9	Yes	No	Yes	No	No[6]
W-3, W-6	Yes	Yes[7]	No	No	No[6]
W-8	Yes	No	No	No	No[6]
Refrigeration					
R-1, R-2	Yes	No	No	No	No[6]
R-3, R-4	Yes	No	Yes	No	No[6]
Management					
M-1	Yes	No	Yes[10]	Yes[10]	No[6]
Power					
P-1	Yes	Yes	Yes	No	No[6]
P-2	Yes	No	Yes	No	No[6]
P-3	Yes	No	Yes	Yes	No[6]
Envelope					
E-1, E-2, E-3, E-4, E-5	Yes	No	Yes[8]	Yes[8]	No[6]

1 All efficiency improvement savings will be estimated using engineering calculations.
2 Measurement of hours equipment is operated for a representative period.
3 Snapshot metering of pre and post efficiency improvement energy use.
4 Seasonal, cycle or annual metering before and after efficiency improvement.
5 Standard watthour meter.
6 No meter data available.
7 Measurement of operation of equipment that controls operate.
8 Envelope measures receive short and/or long term metering before/after improvement.
9 Single circuit power meters, short and/or long term measurement of water heating energy use before and after insulation improvement.
10 Data available from EMS and other computer control systems will be used for verification.
(See endnote 1 for details)

$$\{[(kW_1 - kW_3) \cdot L1] + [(kW_2 - kW_4) \cdot L_2]\} \cdot (h) \cdot (n)$$

where n equals the total number of like pumps involved. (see endnote 2.)

Matching

It is clear from this illustration that, with varying load conditions and operating schedules for multiple installations, calculations of savings could quickly become extremely complex. To avoid unnecessary measurement and complexity, extensive use of matching will be employed.

At the most basic level, matching refers to allowing one piece of equipment to stand for another in analysis. For instance, the average measured power use of a few light fixtures will be used to represent a larger group of like fixtures. On a broader scale this could be extended to allow the lights on one floor of a building to stand for those on other floors, or the equipment in one building to stand for that in other buildings.

Controls

One area of concern in applying this approach to measuring efficiency improvement is automated control systems and strategies. Whereas measuring the difference in connected load and the time of use provides data for savings calculations when equipment is operated, it fails to identify savings generated through limiting use.

For lighting control systems such as occupancy sensors or timers, efforts will be concentrated on measuring actual post-installation operating hours and determining what the hours would have been absent the control system. Short term measurement of a sample of like facilities without controls, along with established operating schedules and occupant surveys, should permit accurate estimation of pre-installation operation of affected equipment. Savings attributable to the controls would be determined by analytically comparing time of use of lights in non-controlled facilities with that of the controlled facilities. Savings for periods that controls deactivate the lights would be the original equipment's load (kW_1) times the hours of controlled non-use (h).

The impact of controls dependent on daylight for either dimming or stepped operation varies based on available light, shading, compass orientation, and other environmental factors. Extensive measurement of savings attributable to these approaches will be performed for a limited number buildings and, once agreed upon by all parties involved in the project, applied to other buildings. In cases where equipment, such as exterior lighting, is controlled by daylight in a straight forward on/off manner, savings estimates may be further simplified by using measured power uses (kW_1) and (kW_2) and deemed hours of operation (h).

To evaluate some control systems and strategies it may be necessary to perform detailed time series monitoring of equipment energy use. This could include monitoring of the existing equipment before and after making control changes. In some instances existing equipment energy use might be established through the power measurement (kW) and time of use (h) method outlined above and the performance with new controls established through more detailed time series monitoring.

Other Applications

This approach of using limited power measurements and relatively short term measurement of the time of use and analytically deriving equipment performance over a longer period holds promise for use in other settings.

The performance of new facilities, for which there are only engineering calculations and computer simulation, and therefore only theoretical historical usage, can be measured using a variation of this approach. Likewise, for facilities that undergo remodels or renovations so extensive that they essentially are different facilities, this approach will allow for measurement of performance and comparison to how the "new" building would have behaved with the "old" equipment and control strategies. Master metered, multi-building facilities, such as hospitals or schools, and unmetered facilities such as utility buildings or self powered industries can also be assessed using a variation of this approach.

Another application of this approach is for buildings in which only a portion of the energy using systems is treated, which is often the case in commercial retrofit installations. A variation of this approach will allow for a truer assessment of the performance of the treated equipment than that afforded by the whole building meter data alone. Limited use of this approach, along with a classic pre versus post approach, offers not only the promise of greater accuracy but also the possibility of refining classic comparison group evaluation methodology.

Summary

At the basis of the measurement of improved efficiency and reduced consumption is a comparison between what would have occurred and what did occur. Usually the best estimate of what would have occurred is a building's energy use prior to improving the efficiency adjusted in some manner to account for variables such as weather.

What did occur is usually estimated from the utility meter data for the entire building. For those buildings which have no historical use, computer simulations, engineering calculations or rules of thumb are used to establish what would have occurred.

Large samples of like buildings are usually sought to provide programmatic adjustments for other variables such as the economy, operating schedules, new technology, or changes in power rates. While large comparison groups of like technologies at like facilities account for some influences, accounting for all influences is not possible, nor is a large, representative comparison group always available.

The approach presented above, using the actual hours of operation after efficiency improvement, paired with equipment specific power use, provides a truer picture of what would have occurred. It provides a better measurement of the energy use of specific equipment for the period prior to and following improvement than whole building utility meter data. It also can be applied to buildings which are new or so changed as to be substantially new.

The segregation of equipment performance from whole facility meter data also offers the possibility of assessing the accuracy of savings estimates based on comparison group analysis of performance. The savings for all participant buildings can be estimated by choosing a sample of the buildings and comparing their energy consumption after participation with either their actual or engineering estimates of energy consumption before participation. Adjusting the difference to reflect any changes in the energy consumption of a comparison sample of non-participant buildings will provide an estimate of energy savings. At the same time, using the above approach, savings can be estimated for improvements in the efficiency of equipment for the sample of participant buildings. If the results of the two approaches substantially agree, the lower cost comparison group approach can be used with renewed confidence. If there is substantial difference, the results of the equipment specific assessment can be used as the basis for additional adjustments to savings estimates.

Endnotes

1. The table on the following page indicates which equipment is represented by each efficiency improvement code:

2. For variable load equipment the formula required to estimate savings would be:

$$\left(\sum_{i=1}^{n} (kW_{O,i} - kW_{N,i}) \cdot (h_i) \right) \cdot (E)$$

where:

E = the number of like pieces of equipment
n = the number of different partial loading conditions
h_i = hours of operation at load condition i
$kW_{O,i}$ = load on old motor at condition i
$kW_{N,i}$ = load on new motor at condition i.

Table 2. Equipment Efficiency Improvement Codes

Code	Description
Lighting:	
L-1	Efficient Interior Lighting Fixtures
L-2	Energy Efficient Lamps
L-3	Energy Efficient Ballast
L-4	Automatic Lighting Controls
L-5	Exterior Lighting
L-6	Daylighting Controls
L-7	Efficient Exit Signs
HVAC:	
H-1	HVAC Piping Insulation
H-2	HVAC Duct Insulation
H-3	Automatic Setback Controls
H-4	Economizer
H-5	Heat Pump Systems
H-6	Outside Air Controls
H-7	Reheat Primary Air Controls
H-8	Heat Recovery
H-9	Deadband Thermostat
H-10	Pump Clocks
H-11	Make-Up Air
H-12	Radiant Heat
H-13	Variable Air Volume
H-14	Air Destratification
Power:	
P-1	Motors/Controls
P-2	Transformers
P-3	Voltage Regulation
Water Heating:	
W-1	Tank Insulation
W-2	Pipe Insulation
W-3	Timers
W-4	Heat Pump Water Heater
W-5	Pump Controls
W-6	On Demand Heaters
W-7	Heat Recovery
Refrigeration:	
R-1	Containment
R-2	Defrost Controls
R-3	Pressure Controls
R-4	High Efficiency Compressors
Management	
M-1	Computer Controls
Envelope:	
E-1	Ceiling/Roof Insulation
E-2	Floor/Slab Insulation
E-3	Wall Insulation
E-4	Multiple Glazing
E-5	Insulated Doors