Predicting and Verifying Energy Savings for Energy Service Companies Using Short-Term Monitoring

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ABSTRACT

This paper describes a method using short-term monitoring to estimate lighting retrofit savings. This method meets the requirements of Options A and B of the IPMVP (International Performance Measurement and Verification Protocol, U.S. DOE 1997) This protocol was previously known as the NEMVP (North American Energy Measurement and Verification Protocol, U.S.DOE 1996a). These protocols require that energy savings be calculated from the measured reduction in demand with run hours stipulated (Option A) or measured (Option B).

Using short-term monitoring, the pre- and post-retrofit demand and energy consumption are recorded to meet the Option A requirements of measuring the demand reduction, including demand diversity, and through monitoring, the actual run hours are quantified. The short-term measured run hours are used to determine the stipulated annual run hours. After the retrofit has been performed, short-term monitoring is again performed to measure the reduced demand, and to verify that the post-retrofit run hours have not significantly changed. For Option B, both sets of run hours measurements are used for the energy savings estimates.

Two case studies are presented. The first case study used the whole-building approach to monitoring of the lighting systems. The second case study required a sampling approach, since multiple end uses were served by the circuit panels. In both cases the savings estimated from the monitored data was less than the estimates based on the more traditional spreadsheet approach.

Introduction

Lighting retrofits in commercial, institutional, and industrial buildings have taken place for twenty years and are the bread and butter of the performance contracting industry, primarily due to recent advancements in electric lighting technologies. They also are a significant piece of many utilities' past and present DSM programs.

The standard calculation procedures for estimating the savings have been fairly simplistic as compared to methods used for HVAC analysis. The basic equation for calculating savings for efficient lighting equipment contains factors for the connected load before and after the retrofit, the number of full load hours (or run hours), and a demand diversity factor (ASHRAE 1989 and EPRI 1993). The pre- and post-retrofit connected loads can be determined with a high level of precision, but the demand diversity factors and run hours are often inaccurate resulting in over-prediction of savings. A large utility DSM evaluation project in the Northwest was one of the first studies to address this issue (Taylor and Pratt 1990, Stoops and Pratt 1990).

This paper presents an innovative method using modern data gathering tools and analysis software. This method meets the requirements of Options A and B of the IPMVP. Option A requires that energy savings be calculated from the measured reduction in demand and stipulated annual run hours agreed to by both parties (typically an ESCo and a building owner). Using short-term monitoring, the pre- and post-retrofit demand and energy consumption are measured to meet the Option A requirements of measuring the demand reduction, including demand diversity; and through monitoring, the actual run hours are quantified. The short-term measured run hours are used to determine the stipulated run hours. Option B is similar to Option A except that savings estimates use measured, rather than stipulated, annual run hours before and after the retrofit.

Typical Lighting Retrofit

In a typical lighting retrofit only lamps and ballasts are replaced. Efforts are made to prevent replacing entire fixtures, which drives up payback periods to a point where the project may be uneconomical. Lighting quality is improved with new high frequency electronic ballasts, new lamps with improved color rendering indices, and replacement of yellowed and cracked lenses. In spaces where aggressive de-lamping has decreased light levels below current standards, extra lamps may be installed.

Since the fixtures and wiring are not usually modified, pre- and post-retrofit measurements at the circuit level can be employed. This allows the collection of data for many fixtures as compared to monitoring at the fixture or room level. To monitor at the circuit level, the circuit panel covers must be removed. A wide range of circuit panel types are encountered. Some covers have not been removed since the building was constructed and take extra effort to open. Others are very large and require two people to remove their covers.

Two Approaches to Lighting Evaluation Using Short-Term Metered Data

Whole Building Approach

In newer buildings, dedicated lighting panels will often be present. In smaller, single-story buildings, one panel will power all the lighting circuits. In larger, multistory buildings there is often one lighting panel per floor. If these panels are 277/480 volt, they will rarely serve additional non-lighting loads. In these cases, the entire panel can be monitored using one current transformer (CT) on each of the three main panel feeders.

Sampling Approach

In older buildings, panels are usually 120/208 volt and serve receptacles, fans, and other non-lighting loads. This requires that monitoring be done at the circuit level, rather than at the whole panel level. To avoid using too much monitoring equipment, a sampling approach can be employed. To maintain statistical validity a minimum number of circuits must be monitored. Table 1 presents the number of required circuits (or control points) to be monitored for a given population This table is for a confidence level of 80% and a precision level of 20%.

Table 1. Sample Sizes for Various Populations (DOE 1996b)

Population	Sample Size
4	3
8	4
12	6
16	7
20	7
25	8
30	8
35	8
40	9
45	9
50	9
60	9
70	9
80	10
90	10
100	10
125	10
150	10

To further refine savings estimates, the lighting circuits are disaggregated by space type with the sampling strategy applied to each type. For K-12 schools the space types have been classroom, administration, kitchen/cafeteria, gymnasium, and common (this includes hallways, restrooms and stairwells).

Both evaluation methods typically have a monitoring period of two weeks and a sampling interval of three minutes.

Current monitoring is used to measure the demand and energy usage of the lighting equipment for both methods. When a building is wired with the lighting systems on dedicated circuit panels, the entire panel is easily monitored so that all of the lighting in the building or area is monitored. When buildings or areas have a mixture of end uses served by the circuit panels, then a sampling strategy is employed to monitor a sample of the lighting for each major usage group. Monitoring current is much cheaper and easier than monitoring true power. Spot checks of power factor are made on typical circuits. A factor using voltage and power factor is derived to convert the current measurements to power.

Traditional and New Methods of Monitoring and Verification for Lighting Retrofits

Traditional Method - Long-Term Whole Building Data

The traditional method of measuring and verifying energy savings has been the whole building or meter approach (similar to Option C meter approach of the IPMVP). In this approach, energy accounting programs or spreadsheets use monthly utility meter data as the basis for the energy saving calculations, and account for some macroscopic, external factors effecting energy consumption (billing days, weather (degree-days), building square footage and production units). The accuracy of this method is dependent on the ESCo's ability to measure and account for all external factors affecting energy consumption over the term of the contract (typically 10 years). Due to the inherent difficulty and cost associated with the long-term accounting of these factors, the end use methods (Options A & B) provide a more accurate and less costly way to demonstrate energy savings.

New Method - Short-Term End Use Monitoring

This method utilizes end use data derived from pre-and post metering of lighting circuits. It eliminates the need to track utility bills on a long-term basis and significantly reduces error by concentrating on the end use.

A six step process has been developed to fully implement this method. The steps are as follows:

- preliminary assessment
- detailed assessment
- pre-retrofit monitoring
- data analysis
- post-retrofit monitoring
- post-retrofit data analysis

Preliminary Assessment. A preliminary site assessment is typically conducted by an engineer from the ESCo. The purpose of the assessment is to gather enough field information to make decisions regarding the economic viability of a project. A proposal to the building owner is made. If the proposal is accepted, a letter of intent is signed by both parties. During the site visit the engineer can inspect the lighting systems and gather information to develop a preliminary monitoring plan and budget for all M&V activities. This information includes the number, size, voltage, and condition of panels. Conditions include how "clean" the panels are, usage groups served, and potential access problems.

From this site information, a preliminary monitoring plan can be developed (ASHRAE 1997, EPRI 1992) At this point the M&V engineer identifies the proposed sampling period, sampling frequency, and desired data products. The monitoring equipment is then chosen to fit the needs of the monitoring plan. At this point, a preliminary M&V budget is established. The IPMVP guidelines suggest a range of 1-10% of construction costs.

Detailed Assessment. Once the letter of intent is signed, the detailed or engineering assessment is conducted. With this information, a final proposal is made to the owner. As part of the detailed assessment, the ESCo collects additional information for the M&V engineer so that the monitoring plan and budget can be finalized. This information includes location of each lighting panel (marked on small scale floor plans), identification of circuits for monitoring, and type and number of fixtures on each monitored circuit. This last item entails switching circuit breakers on and off to properly identify the connected load for each circuit. The circuits are selected by usage group if a sampling approach is used.

During the detailed assessment, the lighting installation contractor performs a detailed room-by-room audit of the fixtures that are to be retrofit. The contractor is instructed to categorize all fixtures by usage group to aid in the data analysis.

Pre-retrofit monitoring. Based on the information from the detailed assessment, the monitoring plan and budget is finalized. Depending on project schedules, some or all of the pre-retrofit monitoring may take place prior to the signature of the performance contract.

The monitoring equipment is installed with two-person teams, preferably an engineer and an electrician. Electricians are comfortable working with energized panels. The panels cannot be turned off unless the monitoring equipment is being installed during unoccupied hours. The data loggers are programmed on-site using a laptop computer. The panel cover is removed, the CTs and loggers are installed, and the cover is replaced. While the cover is open, spot measurements of current, power, and power factor are taken. These values are used in the data analysis to convert the short-term current readings to units of power (kW). At the end of the monitoring period the loggers are retrieved and downloaded (Frey et al 1996).

Data analysis. The goal of the data analysis is to establish a solid baseline and to estimate energy savings. The estimated savings values are used in the final contract with the owner. Accurate estimates are especially important in guaranteed savings contracts. The baseline is presented in the form of 15-minute load shapes for occupied, unoccupied, and partially occupied days for each building (or groups of buildings). The diversity factors and run hours are calculated using the data from the load shapes.

The three-minute time-series data is converted to 15-minute load shapes using spreadsheets or other commercially available software tools. Load shapes for each site are developed for occupied, unoccupied, and partially occupied days. The number of day types per month are agreed to by the owner and ESCo. The use of day types easily accounts for summer and winter vacations, spring break, and conference days. School districts typically publish annual calendars making it easy to fix the number of days each of each type for every month. For other building types with varying schedules, longer monitoring periods may be necessary to establish valid samples.

The pre- and post-retrofit connected loads are obtained from the contractor surveys. The surveys have the number of fixtures and estimated watts per fixture. The connected loads are summed by usage group. If sampling has occurred, the monitored load shapes reflect the performance of only a portion of the lighting in each usage group. The monitored load shapes are "rolled-up" to the entire site using a ratio of the monitored connected load to the connected load for each usage group in the building. Using the number of days per month for each day type and the current rate schedules, the baseline demand, energy usage, and costs are calculated. Performing the calculations on a monthly basis allows for the application of variable rate structures. Similarly, the use of daily load shapes allows for the application of time-of use rates. The process and statistical validity of extrapolating short-term data to annual values has been verified. (Amalfi et al 1996).

If desired by the owner or ESCo, the additional savings from reduced cooling is also calculated. The ASHRAE method of HVAC interaction is used (Rundquist and Johnson 1993).

The baseline report is submitted to the ESCo and becomes part of the contract documents with the owner. The ESCo assesses the project and signs the final contract with the owner based on preliminary monitoring results.

Post-retrofit monitoring. After the retrofit work is complete, the post-retrofit monitoring is conducted. Usually, the same circuits that were monitored during pre-retrofit monitoring are re-monitored.

Post retrofit analysis. The data from the pre- and post-retrofit monitoring is analyzed to establish actual savings and a final report is submitted to the ESCo. Savings from the pre-and post-retrofit data are compared to the original estimated savings. Any large discrepancies are discussed with the owner and the savings guarantee is adjusted if necessary.

Case Histories

Florida School District

An energy service contract with a school district in northern Florida included lighting and HVAC measures in six schools. The sites included one high school, one middle school, three elementary schools, and one school for developmentally disabled students. The number of buildings per school campus ranged from seven to ten. The panels at four sites were very clean and therefore the whole building approach to monitoring was utilized. The sampling approach was used at the other two sites.

Figure 1 shows the pre- and post-retrofit load shapes for one of the elementary schools. Figure 2 shows the estimated savings for the same school. This second load shape was not actually constructed as part of the original estimate, but is presented here to graphically demonstrate the differences between the two calculation methods.

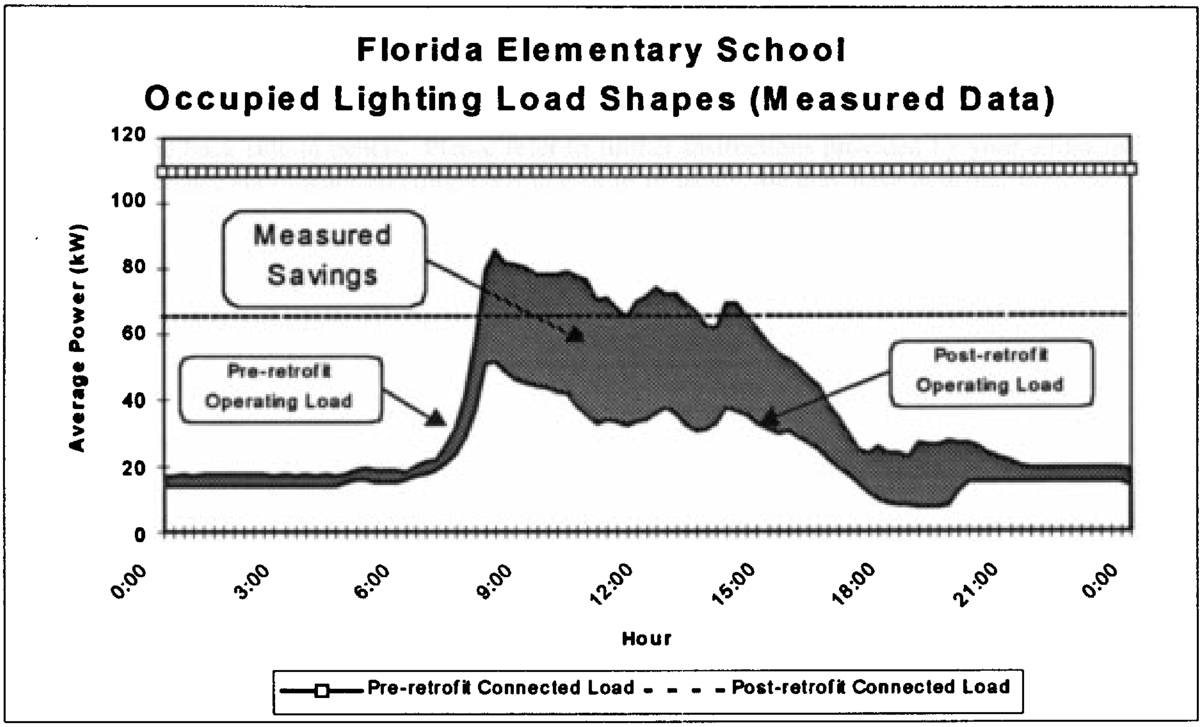

Figure 1. Occupied Lighting Load Shapes for a Florida Elementary School (using monitored data)

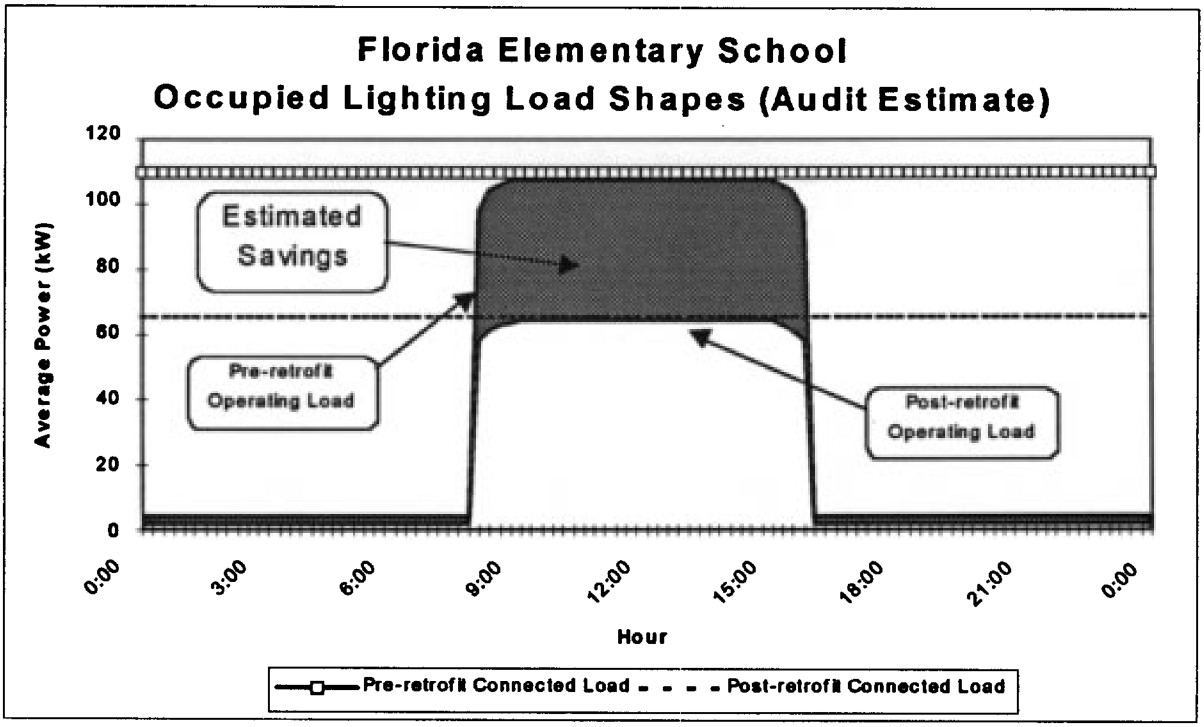

Figure 2. Occupied Lighting Load Shapes for a Florida Elementary School (using audit data)

Table 2 summaries the results of three savings calculations, one using the standard spreadsheet method, one using the pre-retrofit monitored data and one using the pre- and post-retrofit monitored data. The estimates of savings fall as the level of monitoring increases. In this case the original "guess" of operating hours used in the spreadsheet method was less than that determined through monitoring. In addition, the measured demand diversity factors were much lower than those assumed in the spreadsheet method. The spreadsheet method resulted in savings estimates 18% higher than the monitored pre-retrofit estimate and 19% higher than the monitored post-retrofit estimates. At other sites the annual run hours **and** the diversity factors obtained from monitoring were lower than the spreadsheet estimate, creating even larger differences in the savings estimates.

Table 2. Summary of Calculation Parameters and Savings Estimates for Different Estimating Methods

Parameter	**Spreadsheet Method**	**Short-Term Monitoring (estimated from pre-retrofit data)**	**Short-Term Monitoring (using pre- and post-retrofit data)**
Connected Load (pre)	109.88	109.88	109.88
Connected Load (post)	65.65	65.65	65.65
Operating Hours (pre)	2,500	2,814	2,927
Operating Hours (post)	2,500	2,814	2,927
Demand Diversity (pre)	1.00	0.81	0.78
Demand Diversity (post)	1.00	0.81	0.78
Annual Savings	$9,527	$8,062	$7,995

Georgia School District

A total of forty-eight schools were covered in this project. The number of buildings per school campus ranged from two to eight. All buildings were more than ten years old, and most had 120 volt panels, requiring use of the sampling approach. Eighteen schools were included in an initial phase; the contract was eventually extended to all forty eight schools in the district.

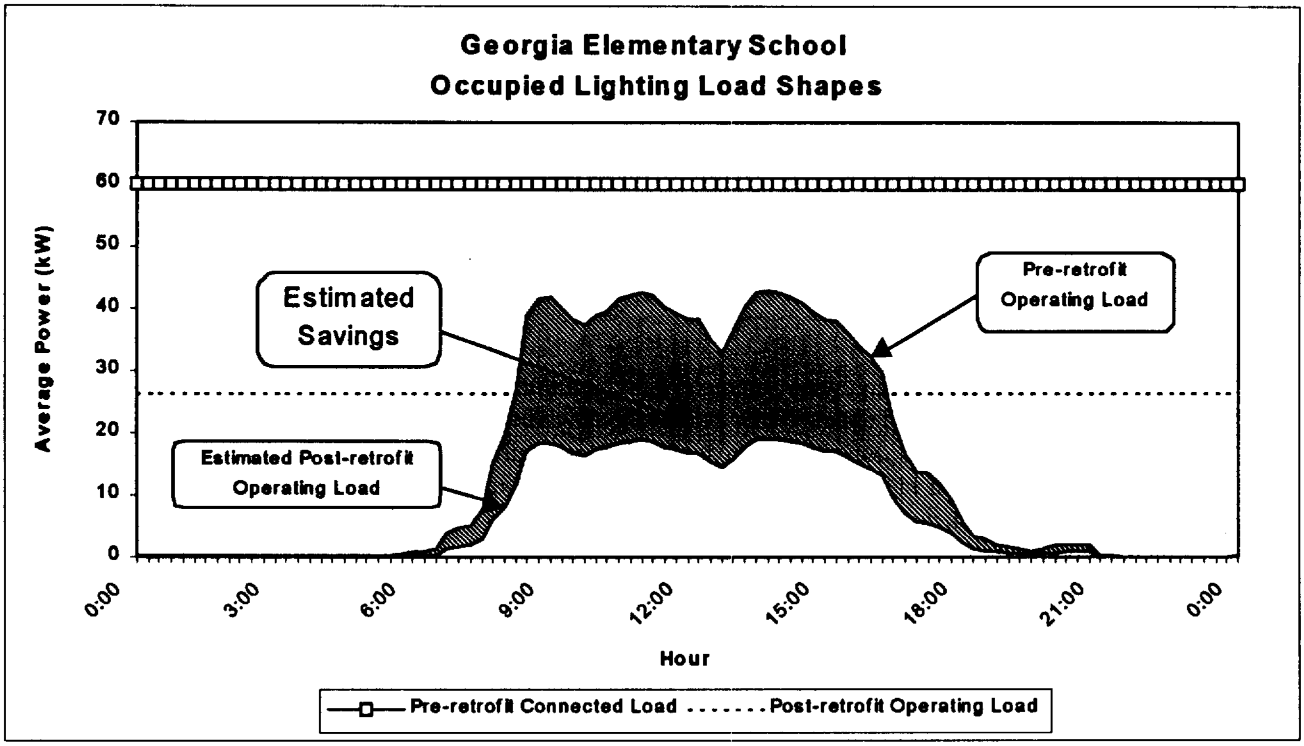

Figure 3. Occupied Lighting Load Shapes for a Georgia Elementary School (using monitored data) show pre and post load shapes with connected loads

Table 3. Summary of Calculation Parameters and Savings Estimates for Different Estimating Methods

Parameter	Spreadsheet Method	Short-term Monitoring (estimated from pre-retrofit data)
Connected Load (pre)	60.1	60.1
Connected Load (post)	26.5	26.5
Operating Hours (pre)	1,823	1,905
Operating Hours (post)	1,823	1,905
Demand Diversity (pre)	1.00	0.71
Demand Diversity (post)	1.00	0.71
Annual Savings	$5,008	$4,747

M&V Costs

The IPMVP gives guidelines for how much the M&V process should cost for each project. One guideline suggests that costs for Option B range from three to ten percent (3-10%) of the installed retrofit cost. Another guideline is that M&V costs be less than twenty percent (20%) of the anticipated net savings benefit to the owner. Table 4 summarizes the costs for the two case histories. As shown, the M&V costs for these projects are well within both guidelines. The savings values are accrued savings over the 10-year contract periods assuming present utility rates. The M&V costs include data acquisition equipment leases, equipment installation, engineering analysis, project management, and mark-up to the customer.

Table 4. Summary of Sample Project Costs

Project	10% Construction	20% Savings	M&V Costs
Florida Schools	$70,000	$114,000	$50,000
Georgia Schools	$320,000	$786,000	$180,000

Conclusions

This method is a cost-effective way to estimate the energy savings in large scale lighting retrofits. Short-term monitoring is effectively used to estimate annual run hours and diversity factors, thereby reducing risk for the ESCO, and adding accountability for the owner. Similar methods can be applied to HVAC retrofits, especially with equipment replacement projects such as chillers, boilers, and motors.

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