A refined baseline methodology for large scale lighting retrofit projects

Y Mvudi, SN Chan Wing, JHC Pretorius, MM Beya, SM Ndlovu

University of Johannesburg, Johannesburg, ZA

Abstract

The residential sector is one of the major consumers of energy produced in the world. According to International Energy Balances (IEA, 2013), the residential sector demand represents about a quarter of the primary energy used in the world. Therefore, most energy efficiency programmes targeting large savings on a national or regional level pay particular attention to the opportunities in the residential sector. Lighting retrofitting on a large number of sites constitutes one of the most used strategies of energy conservation in the residential sector. However, given the large number of sites involved in this type of project, conventional measurement and verification (M&V) techniques based on the audit of each site, are not cost effective. Often, a statistical assessment approach based on the audit of a limited number of sites is the methodology used to mitigate the cost and the logistical challenges associated with the project. The major challenge in projects of this nature is to accurately estimate the energy consumption of a large number of sites using the measurement performed on a sample of sites selected from the overall population. In this research, baseline methodologies used in a selected number of light retrofitting projects have been analysed and, based on the observations made during this analysis, some improvements are suggested. The proposed methodology has been tested on a number of residences located on the premises of the University of Johannesburg. This paper describes the existing baseline methodologies and presents the improvements suggested to enhance the credibility of M&V results. The key results of the experimental phase of this project are also presented in this paper.

Introduction

The residential sector is a major consumer of the energy generated in the world (IEA, 2013) and lighting retrofit programmes constitute a powerful tool for tapping into the energy saving opportunities in the residential sector (Jackson & Vanderpuije, 2000; NREL, 2013). Therefore, energy conservation measures implemented in this area may result in significant savings. However, a particular measurement and verification (M&V) approach is required to determine the performance of this type of project. The conventional M&V techniques based on individual site surveys are not feasible in this context because of the large number of sites involved in such projects. In South Africa the approach used consists of auditing a sample of sites and extrapolating the result to the overall population. Richman recommends that 10% of the overall population should be audited once a year to assess the sustainability of the performance (Richman, 2012). The main purpose of this research is to propose a method for evaluating the accuracy of the results obtained by auditing a sample.

Baseline methodology for large scale lighting projects in South Africa

Description of the methodology

The assessment method used to establish the baseline consists of surveying a small number of sites deemed to be representative of the overall population and then generalizing the results obtained from the sample. The methodology used to determine the sample size is based on Cochran's Formula below:

$$\boldsymbol{n} = \frac{\boldsymbol{z}^2 \times \boldsymbol{cv}^2}{\boldsymbol{e}^2}$$

where **n** is the sample size, **z** is the desired confidence, **e** is the desired precision and **cv** represents the coefficient of the variation of the population (EVO, 2010; Cochran, 1977). During surveys auditors focus on the determination of the key parameters as recommended by the EVO and SANS standards (EVO, 2014; SANS 50010). In lighting retrofit projects, the operating hours, number of fixtures and power draw per fixture are considered as the key parameters (NREL, 2013). All these parameters are usually given by the project developer (ESCo). The site survey is therefore conducted on a small random sample to confirm the accuracy of the information provided by the project developer. Based on the survey results, the evaluator can either decide to use the information provided by the project developer or adjust these figures with a factor to reflect results observed during the survey. After collecting all these parameters, the baseline energy can be calculated using the following formula:

$$Daily\ baseline\ energy = Number\ of\ fixtures \times Daily\ operating\ hours \times Power\ draw\ per\ fixture \quad (1)$$

(DOE, 2008)

Using the operating hours collected from the survey, it is also possible to develop an average demand profile by determining the percentage of the load that is being used during each specific period of the day.

Table 1 illustrates how the daily profile will be determined.

Table 1: Daily profile based surveys

Time	*Total installed capacity (kW)*	*% of lights on*	*Power usage kW*
00:00	600	100	600
02:00	600	60	360
04:00	600	60	360
06:00	600	50	300
08:00	600	35	210
10:00	600	35	210
12:00	600	35	210
14:00	600	35	210
16:00	600	35	210
18:00	600	100	600
20:00	600	100	600
22:00	600	100	600

Errors associated with the baseline methodology

A baseline developed from extrapolated information will have inherent errors relating to the nature of the data collection process that was used. It is therefore the responsibility of the M&V practitioner to mitigate these errors and keep them at an acceptable level. These errors represent a risk for the project, especially if incentives are paid based on the reported performance. The following types of errors should be considered when using this approach: sampling errors, human errors and instrument errors.

Sampling errors are related to the size of the sample. The level of accuracy of the results from a sample survey depends on the ratio between the size of the overall population and the sample size. Although, the IPMVP (EVO, 2010) provides a clear method for determining the optimal sample size, budget constraints often force M&V practitioners to use a sample size that is suitable for the budget and provides valuable results (GSEP, 2014).

Human errors usually affect the equipment inventory during the site audit because it is easy for installers and auditors to lose the count when dealing with a very large number of lights. Operating hours also constitute a parameter that can be very sensitive to human error, especially when interviews are used as the data collection method. It can be difficult for people to accurately remember the operating hours of lights in certain areas (Theletsane, Coetzee & Grobler, 2007), and since operating hours are obtained through questionnaires, the accuracy of the answers should be assessed. Note that in all the lighting retrofit projects reviewed as part of this research, the operating hours are determined through questionnaires. In South Africa data loggers are often avoided in order to mitigate the M&V costs.

Instrument errors result from the built-in inaccuracies of instruments that are used for spot and/or laboratory measurements. Such errors are usually manageable because they are specified by the manufacturer and can be considered in the calculations.

Proposed improved methodology

The integration of a validation phase was suggested in order to evaluate the accuracy of the results obtained from the survey. This phase consists of monitoring the energy consumption of a few sites (number lower than sample size) and comparing the metered results with survey-based results. Based on the difference between the two, the evaluator can either choose to refine his approach or use the survey results as they are. In the next section of this paper, the implementation and results of such tests are presented for illustration purposes.

Case study: Sophiatown residence in Johannesburg

Description of the test phase

The methodology suggested was applied to the University of Johannesburg unisex student residence named Sophiatown. The residence consists of single dormitory rooms and common areas which include kitchens, communal bathrooms and passages (corridors). The methodology was implemented in two phases, the first phase being the metering phase and the second phase a survey phase.

For the metering phase, data loggers were installed in the distribution board of the student residence. The loggers were placed on the circuits that feeds a number of dormitory rooms and common areas (passages, kitchens and bathrooms).The monitored areas included 48 dormitory rooms, 5 passage ways, 3 communal toilets and 2 kitchens.

During the survey phase, the research team interviewed 18 students residing at Sophiatown. Using a questionnaire, the operating hours and number of lights in a dormitory were obtained. An on-site audit was conducted to determine the number of fixtures per area and the power drawn by each fixture.

Results of the test phase

Table 2 presents a summary of the data collected from the interviews with the residents.

Table 2: Sophiatown residence dormitory and common area lighting data

Areas	Number of areas	Number of lights	Power (W)	Average operating hours (h)
Passage	5	8	12	24
Toilet	3	6	12	24
Kitchen	2	2	36	24
Rooms	48	3	28	8.8

Table 2 illustrates that the average number of operating hours per room is 8.8. According the interviewed students, the lights located in the common areas are on at all hours (24 hours) whereas the operating hours of dormitory lights vary from one room to another. A load profile was developed based on the survey results. The latter information allowed the research team to develop the average daily profile of electricity consumed for lighting usage as presented in Figure 1. Based on the information collected from the respondents (operating hours, number of fixtures and wattages) total energy consumed per day was found to be 55.66 kWh. The average daily profile is presented in Figure 1.

Figure 1: Survey-based lighting consumption profile

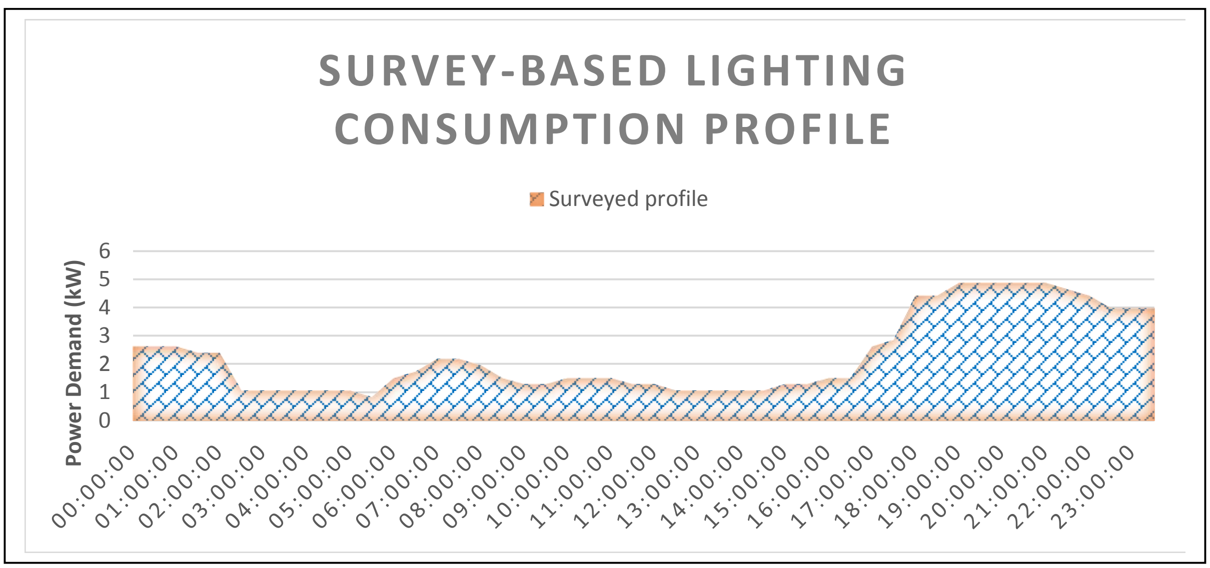

Figure 1 shows the peak consumption is around 4.8 kW and occurs between 18:00 and 21:00 whereas the lowest demand is around 0.8 kW and occurs between 05:00 and 06:00.

Data gathered through the loggers was recorded at five minute intervals for the duration of three days. The energy consumed for each hour of the three days was averaged to develop a 24 hour hourly profile. The daily average energy consumed was found to be 55.57 kW. The 24 hour hourly profile developed by averaging the hourly energy consumption of each day is presented in Figure 2.

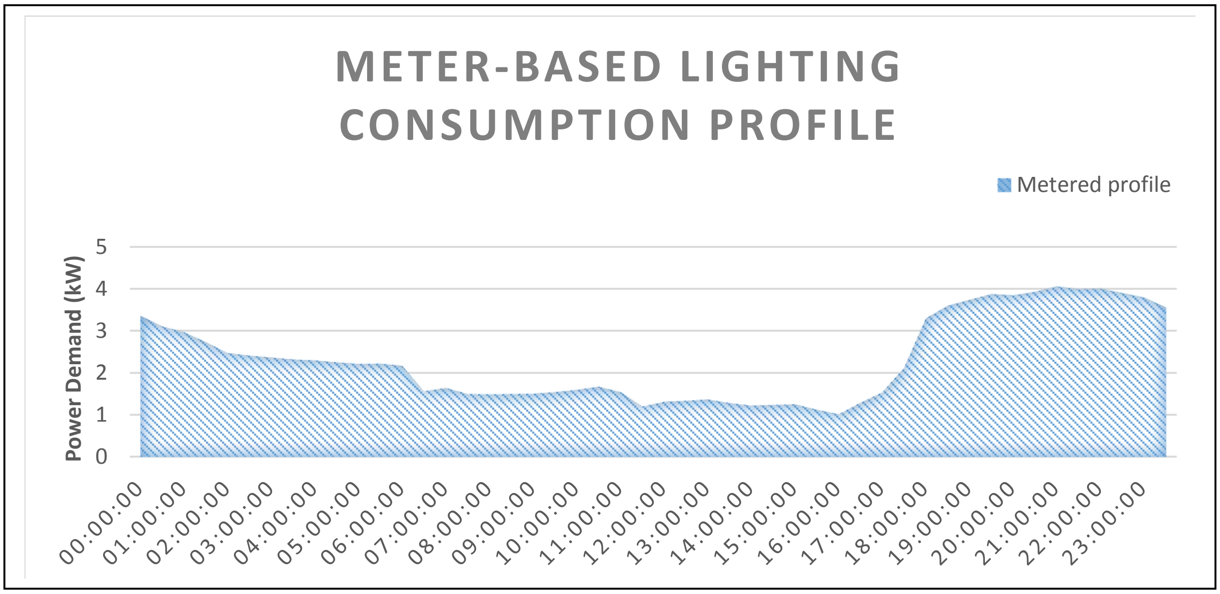

Figure 2: Meter-based lighting consumption profile

Figure 2 shows the peak consumption is around 4 kW and occurs between 20:00 and 22:00 whereas the lowest demand is around 1.2 kW and occurs between 15:00 and 16:00.

Meter results vs survey results

The purpose of conducting this test phase was to evaluate the quality of results obtained from the survey and to decide if these results should be used as they are or improved by conducting further investigations. From the results presented in the previous sections, the relative error on the daily energy consumption was found to be 0.16% and the errors on the peak power and lowest demand are respectively 20% and 33.3%. The difference between the two profiles can be observed in Figure 3 below.

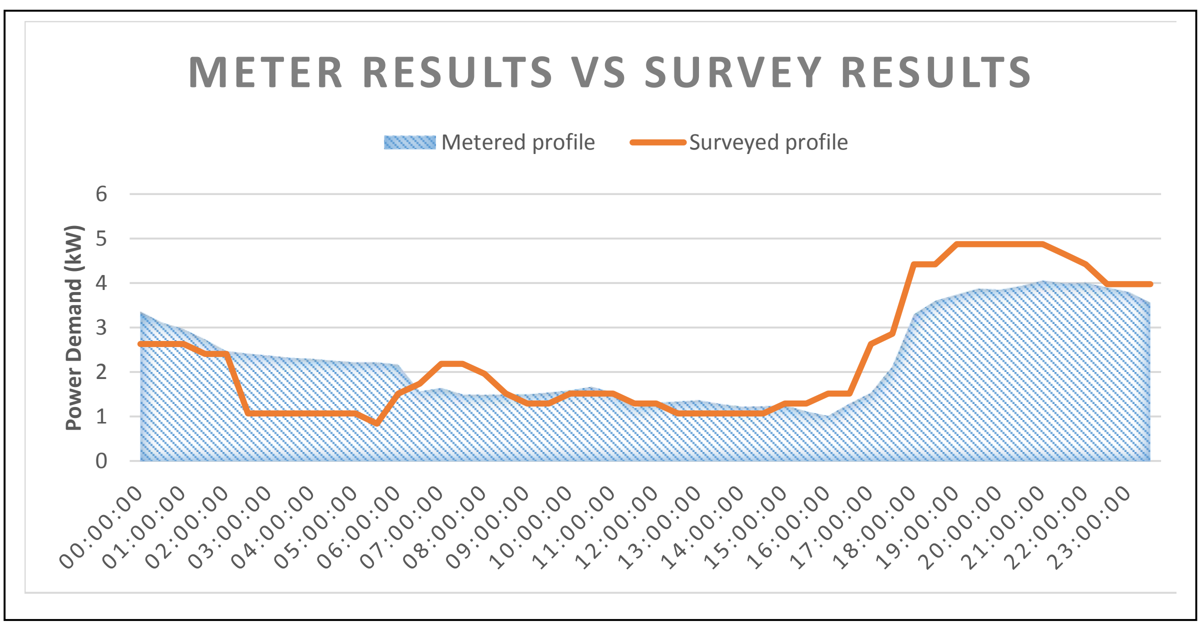

Figure 3. Profile comparison

Based on the project objectives, the budget available and accuracy required, the M&V practitioner can use these findings to decide if survey results are accurate enough for the project. For this particular project, the survey results may be suitable for calculating daily energy savings, but not very effective for computing peak demand reduction.

Conclusion

The purpose of this paper was to propose a practical method of assessing the accuracy of the data collected through interviews and site surveys for use in lighting retrofit projects. It was suggested that the results obtained from interviews and survey data can be compared to meter-based results. This comparison can assist M&V practitioners in evaluating the quality and accuracy of their results, especially in cases where human and sampling errors are difficult to assess. The case study illustrates how such a test phase can be designed and implemented in projects in the field. It would be interesting to see more similar case studies with a longer test phases and larger samples in order confirm the effectiveness of this approach.

References

[1] South African National Standard, Measurement and Verification of Energy Savings. SANS 50010:2011, ISBN 978-0-626-26352-2

[2] Efficiency Valuation Organization (EVO). International Performance Measurement and Verification Protocol, Core Concepts. June 2014

[3] US Department of Energy (DOE). M&V Guidelines: Measurement and verification guidelines for Federal Energy Projects. April 2008

[4] National Renewable Energy Laboratory (NREL). The Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures. April 2013

[5] Global Superior Energy Performance (GSEP). Energy Performance Measurement and Verification: Guide of data quality. August 2014

[6] Theletsane, M., Coetzee R. & Grobler L. Lessons learnt from CFL and lighting retrofit projects by measurement and verification. Domestic use of Energy 2007 conference, February 2007

[7] Jackson, E. & Vanderpuije, H. Impact of Residential CFL Retrofit Program in Ghana. 2000 ACEEE Summer Study on Energy Efficiency in Buildings - Proceedings. ISBN: 0-918249-44-9

[8] Richman E. Standard Measurement and Verification Plan for Lighting Retrofit Projects for Buildings and Building Sites. Pacific Northwest National Laboratory, October 2012

[9] International Energy Agency (IEA). World Energy Outlook 2013. http://www.iea.org/Textbase/npsum/WEO2013SUM.pdf, October 2013

[10] Efficiency Valuation Organization (EVO). International Performance Measurement and Verification Protocol, Concept and Options for Determining Energy and Water Savings. September 2010

[11] Uniform Method (EVO). International Performance Measurement and Verification Protocol, Concept and Options for Determining Energy and Water Savings. September 2010

[12] Cochran, W.G. Sampling Techniques. New York, NY: John Wiley & Sons: 1977