# Measurement & Verification of a Utility Sponsored Residential Demand Side Management Programme Involving Multiple Technologies

D. de Canha , J.H.C. Pretorius
Faculty of Engineering & the Built Environment
University of Johannesburg
South Africa
danieldc@uj.ac.za

***Abstract*— Due to the low reserve margin on the electrical grid in South Africa many energy initiatives were introduces by the utility over the last decade. One such initiative was to roll out identified energy efficiency technologies at residential homes. The utility aimed to achieve a 90MW evening peak (18h00 to 20h00) demand reduction by distributing free CFLs, LEDs, geyser timers, pool timers and low flow shower roses to residential electricity customers throughout the country. This paper presents an overview of the process and methodology used to measure and verify (M&V) the energy and demand impact of the programme. The verified saving achieved was 87.2MW. This includes both an energy efficiency and a load shifting component. The project was M&V'd using the International Performance Measurement & Verification Protocol (IPMVP) and SANS 50010 standard for determining energy savings.**

***Index Terms*—Measurement and Verification, Residential Energy Efficiency, Residential Load Management.**

## I. INTRODUCTION *(HEADING 1)*

A South African electricity utility has implemented a large residential mass roll-out programme where numerous energy or demand saving devices were distributed to residential consumers in the major cities of the country. The devices were distributed free of charge. The aim of the campaign was to reduce demand during the evening peak (18h00 to 20h00) by 90MW.

Three portions of household consumption were targeted:

- Sanitary hot water,
- Lighting and
- Pool pumps.

For the hot water consumption both demand and energy reductions were sought. The demand reductions were achieved though the installation of timers on the elements of the hot water geysers which block operation during the peak periods. The energy reduction on hot water usage was achieved by installing low flow (9l/min) shower roses and flow restrictors in showers.

For the lighting reductions, CFLs (9-20W) replaced incandescent lamps (100W, 75W, 60W, 40W) and halogen downlighters (50W) were retrofitted with LEDs (4-10W).

Swimming pool pump demand was controlled with timers that block operation during peak periods.

The utility hired an Energy Services Company (ESCo) to install the various devices in participating homes. Participation was by online application where the homeowner could pre-register and provide details on exchange options i.e. number of lamps and shower roses required, etc. The lamp and shower rose exchanges were done on a one-to-one basis with a limit on the number per household. The timer installations did not require an old timer to be exchanged.

The University of Johannesburg was contracted to determine the energy savings from the programme.

The number of installations and targeted evening peak demand reduction per technology is summarized in Table I.

TABLE I. NUMBERS OF DEVICES DISTRIBUTED & DEMAND TARGETS

| **Technology** | **Number installed (approx.)** | **Evening peak demand target** | **Total demand target** |
|---|---|---|---|
| LEDs | 625 000 | 20W/lamp | 12.5MW |
| CFLs | 254 000 | 15-40W/lamp | 7MW |
| Shower roses | 46 400 | 89W/unit | 4MW |
| Geyser timers | 126 000 | 410-600W/timer | 61MW |
| Pool pump timers | 2 400 | 140W/timer | 0.3MW |

The challenge was to develop an M&V methodology that would allow us to determine the energy savings from the campaign with a limited budget and short time schedule. Adhering to the International Performance Measurement & Verification Protocol (IPMVP) and SANS 50010 standard for determining energy savings is a requirement in order to ensure transparent and credible M&V is very important [1,2,3]. Excellent guidelines also exists that was helpful in determining the best method and approach for this project [4].

Fortunately, numerous lighting and hot water load control projects had been M&V'd in South Africa and data on hot water and lighting usage had been gathered from recent M&V projects. Usage profiles from previous projects had to be used while avoiding a deemed savings approach as far as possible since the timeline and budget did not allow for any metering other than spot measurements.

To ensure the integrity of the programme and the credibility of the savings the claimed number of installations (lamps, timers and shower roses) was rigorously audited and monitored by the utility, ESCo, an independent auditing firm and our M&V team.

Early failures and removals had to be determined for all the technologies and deducted from the claimed numbers of exchanges and installations.

## II. LIGHTING

The consumption of the new and old lighting systems depend on:

- the number and type of old and new lamps,
- the operating hours of the lamps, and
- the power consumption of the old and new lamps.

The power consumption of the old lighting systems is given by (1):

$$P_{LBi} = M_{Li} \sum_{1}^{K} N_{OTk} \times P_{OTk} \quad (1)$$

Where
$P_{LBi}$ is the lighting baseline demand at the $i$'th ½ hour interval and must be computed for LEDs and CFLs separately
$M_{Li}$ is the lighting model % of installed capacity which is switched on for the $i$'th ½ hour interval
$P_{OTk}$ is the 'Old Technology Type $k$' power requirement of a single lamp
$N_{OTk}$ is the number of 'Old Technology Type $k$' lamps retrofitted (as determined by M&V)
$k$ is the number of 'Old Technology' lamp types

The power consumption of the new lighting systems is given by (2):

$$P_{LAi} = M_{Li} \sum_{1}^{K} N_{NTk} \times P_{NTk} \quad (2)$$

Where
$P_{LAi}$ is Lighting Actual Demand for the $i$'th ½ hour interval and must be computed for LEDs and CFLs separately
$M_{Li}$ is the lighting model % of installed capacity which is switched on for the $i$'th ½ hour interval
$P_{NTk}$ is the 'New Technology Type $k$' power requirement of a single lamp
$N_{NTk}$ is the number of 'New Technology Type 1' lamps retrofitted ($N_{NTk}= N_{OTk}$)
$k$ is the number of an 'Old Technology' lamp types

$M_{Li}$ is the lighting usage profile which gives the percentage of lamps switched on for each half hour of the day after the lamp retrofit. This was determined from measurements in households done on previous projects. For this project, not being able to conduct new measurements of lighting usage, a survey was conducted where households were queried on how many lamps were burning for various periods of the day. The results of this survey indicated that the previously developed lighting usage profiles ($M_{Li}$) were still applicable and could be used to M&V the project.

The power savings is the difference between (1) and (2). The energy savings are then the integral of the power savings.

The number and type of lamps exchanged were verified by having our students visit and telephone the various homes in the ESCo database. Where a discrepancy was found, the lower of either the claimed number or the M&V number of lamps was used in the calculations. Additional credibility to the claimed number of exchanges was obtained by having the ESCo group the old lamps by wattage and then having them counted and crushed.

The power consumption of samples of the old and new lamps were measured in the laboratory under a range of voltages. Based on a number of spot voltage measurements in the sampled households the lamp power was taken as that at 220V.

Figs. 1-2 show the baseline and actual lighting demand (MW) profiles for LEDs and CFLs respectively for weekdays (separate profiles were developed for Saturdays and Sundays – not shown).

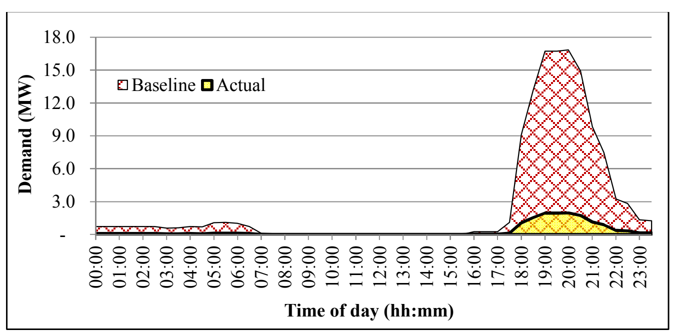


Figure 1. Downlighters and LED demand (MW) profiles

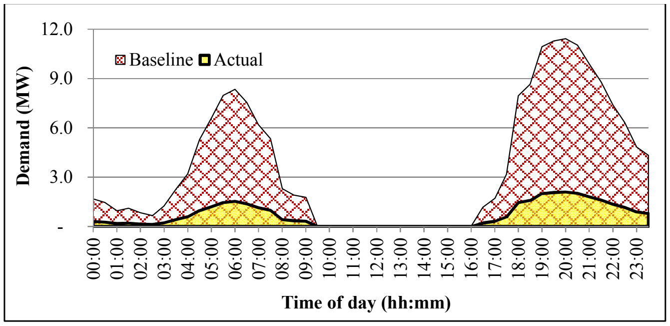


Figure 2. Incandescent and CFL demand (MW) profiles

## III. Hot Water Load Control & Shower Roses

Participating homes could obtain either shower roses or geyser timers or both. The following cases are handled separately:

- Houses with only shower roses and flow restrictors;
- Houses with only geyser timers;
- Houses with both timers and shower roses/flow restrictors.

A shower rose cannot create any energy saving during the evening peak if a timer is installed since the geyser element is switched off. However, an energy saving from other periods is possible due to the reduction in hot water consumption.

### *A. Geyser Timers*

Hot water demand profiles have been measured in South Africa at substation level during the M&V of Residential Load Management (RLM) projects. In these projects ripple injection equipment is installed in substations and ripple controlled relays are installed on the geyser element of homes. The municipality or utility can then control the residential hot water load. These projects are monitored continuously by M&V teams around the country. Therefore recent hot water demand profiles were available for coastal and inland towns or cities.

A simulation application was developed in [5] to simulate the behaviour of many geysers on a substation level. This application is capable of accurately modelling the drop off and comeback loads associated with large numbers of geysers being switched on and off at different times of the day.

The inputs to the application are:

- load control hours (determined by reading new timer settings on site),
- average geyser capacity (assumed to be 150l),
- average inlet water temperature (assumed to be 15$^{o}$C),
- average geyser set point (assumed to be 55$^{o}$C),
- standing losses (2.4kWh/day – mandated by SABS) and
- average element size (2.5kW – calculated from measurements on site)

Fig. 3 shows the uncontrolled geyser demand profile and the timer controlled geyser demand profile. As can be seen large comeback loads are created in time periods where the elements are allowed to operate and a reduction in load is achieved during the periods of control.

The timer control is energy neutral on a daily basis since any water not heated during the peak periods must be heated at other times of the day.

The majority of homes chose to either operate the element between the hours of 2 to 6 am and 2 to 6 pm or to simply allow the timer to block operation during peak periods (i.e. the element can operate from 8 pm to 6 am and from 8 am to 6 pm).

The timers distributed in the programme had real time clocks with battery backup and random switch on delays of 1-30 min. This helps to avoid timers losing time (e.g. due to black outs) and also distributes the comeback loads over the half hour after switch on more evenly. Rather than being totally programmable, the timers have 4 set programmes from which the homeowner can choose. However, the homeowners can obviously remove or bypass the timers. The number of operating timers is monitored from time to time by conducting telephonic and site surveys.

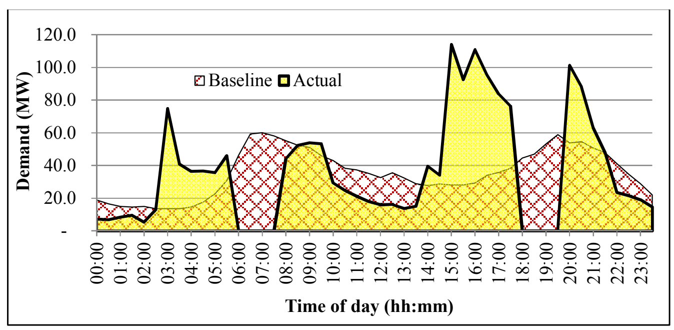


Figure 3. Reduction in hot water demand due to installation of shower roses and flow restrictors (no geyser timer present)

### *B. Shower Roses*

The energy savings from shower roses depend on:

- the reduction in flow rate achieved by the new shower roses,
- the average length of time that people shower,
- the probability that people will shower rather than bath on any given day,
- the number of showers per shower rose per day,
- the water temperature at which people shower,
- the geyser set point temperature,
- the incoming cold water temperature and
- the time of day that people shower.

The reduction in flow rate was measured by measuring the flow rate of 180 sample "old shower roses" in lab conditions at a static pressure of 3.5 bar (the average of that measured at the shower rose during the site visits) and doing the same for the new low flow shower rose. The average flow rate of the old shower roses was 20.2l/min (14% of the sample tested had a flow rate of <12l/min). The energy efficient shower rose has a flow rate of 10.0l/min [6]

The average length of time that people shower and the percentage of time that they prefer to shower rather than bath was determined by asking the homeowners various questions during the site visit (a field worker form was developed for the project).

The blended water temperature, incoming cold water temperature and geyser set point are assumed to be as follows based on experience from other sanitary hot water projects:

- Geyser set point: 55°C
- Inlet water temperature: 15°C
- Blended water temperature: 40°C

It is also assumed that the shower usage profiles have the same percentage distribution as the RLM profiles. The energy saved by saving a mass of blended water $m$ is:

$$Q = mc_p\Delta T \quad (3)$$

Where
$Q$ is the heat saved in Joules (1kWh = 3.6MJ)
$c_p$ = 4 180J/kg per Kelvin difference
$\Delta T$ is the temperature rise through which the mass $m$ was heated

The volume of blended water is calculated using:

$$m = \frac{(T_B - T_C)}{(T_H - T_C)} \cdot F_B \cdot t_s \quad (4)$$

Where
$T_B$ is the blended water temperature (40°C)
$T_c$ is the cold water temperature (15°C)
$T_H$ is the hot water temperature (55°C)
$F_B$ is the reduction in blended water flow rate (l/min)
$t_s$ is the avergage shower length taking into account the number of showers per shower rose per day and the percentage of time that people prefer to shower rather than bath.

On average there are 1.21 showers per shower rose per day, people who participated in the roll-out shower 68.4% of the time for 7.33min. The impacts are calculated only considering the first 2 shower roses or flow restrictors, although some homes did receive more than 2 shower roses.

The saving per shower rose is therefore 2.626kWh/day with zero saving during the evening peak (and other periods of load control) where a geyser timer is installed or 154W and 159W for inland and coastal regions respectively where no geyser timer is present.

Fig. 4 presents the demand profiles for houses which received shower heads without geyser timers.

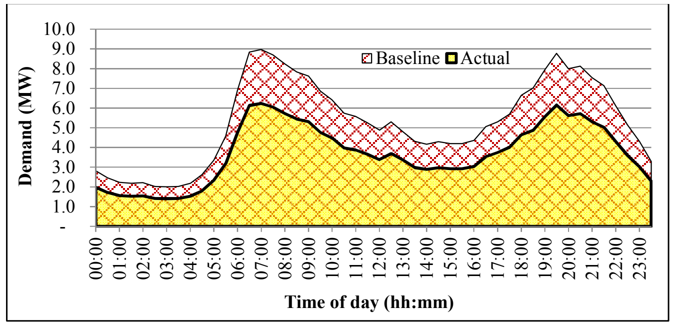


Figure 4. Reduction in hot water demand due to installation of shower roses and flow restrictors (no geyser timer present)

### C. *Geyser Timers and Shower Roses*

For sites with both shower roses and geyser timers the load shift created by the timer is calculated first. Then the energy reduction created by the shower roses is calculated based on the controlled geyser's profile. For example the controlled geyser's profile becomes the baseline for the shower roses. This is illustrated best by Figs. 5-6. The nett impact is the difference between the uncontrolled geyser profile and the controlled reduced usage profile.

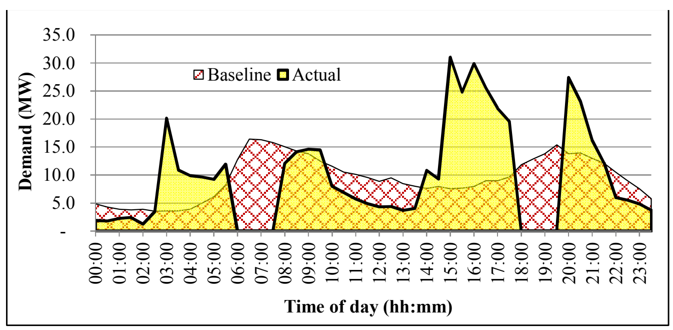


Figure 5. Load shift component of the homes which received both geyser timers and low flow shower roses or flow restrictors

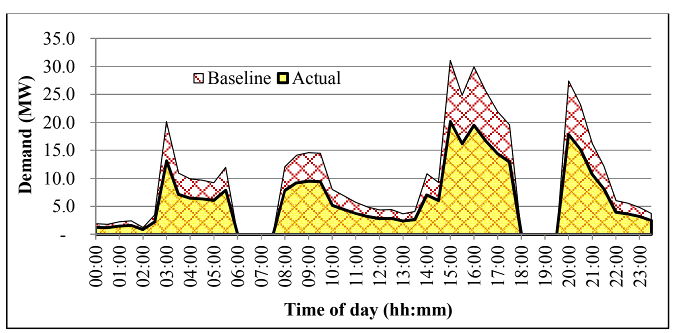


Figure 6. Reduction in hot water demand due to installation of shower roses and flow restrictors in homes with geyser timers

## IV. Pool Pump Load Control

The pool pump's power consumption depends on:

- pool pump motor power consumption,
- pool pump running hours before the intervention, and
- pool pump running hours after the intervention.

The pool pump motor power demand (kW) was measured on site using handheld True RMS power meters during the M&V survey. The vast majority of motors were found to have ratings of either 0.75kW or 1.1kW with an average power consumption of 748W which can be assumed to be constant.

Homeowners were queried on the operating hours of the pool pumps prior to the intervention. Most homeowners were using timers to operate their pool pumps with the operating hours being during the day. The new pump running hours were determined by reading the settings on the new timers installed in the distribution boards of the participating houses.

The power savings for the pool timers are given by:

$$P_B\,[t] = M_B[t]\sum_1^K N_k \times P_k - M_A[t]\sum_1^K N_k \times P_k \qquad (5)$$

Where:
$M_B[t]$ and $M_A[t]$ are the percentage of pumps on during the $t$'th ½ hour of the day for the Baseline and Actual respectively
$k$ is the number of different pool pump motor ratings, $k \in \{0.75\text{kW}, 1.1\text{kW}\}$
$N_k$ is the number of pool motors of the $k$'th type
$P_k$ is the average measured power of the $k$'th pool pump motor type

$M_B[t]$ and $M_A[t]$ are determined by averaging the individual operating hours of the sampled pool pumps. Fig. 7 shows the calculated demand profiles for the pool timers. Only 14% of the pool pumps were on during the evening peak prior to the installation of the new timer. The impact per pool timer was 104W as opposed to the targeted 140W.

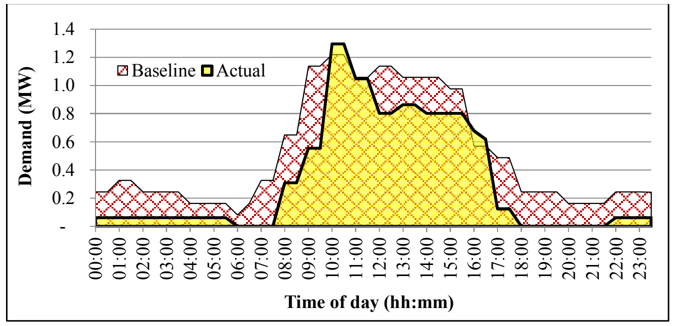


Figure 7. Pool pump demand profiles before and after new timer installation

## V. Conclusions

The M&V process is designed to provide an impartial quantification and assessment of the project impacts and savings that resulted from this initiative. The advantages of the M&V of a project of such a nature is not only to determine the savings independently but also to help manage the risk of a project. Feedback on future savings will also provide and the sustainability of the savings.

This publication described the methodology and calculations used to M&V the mass roll-out programme in the residential sector. The overall demand impact for the evening peak was 87.2MW. The energy reduction for the first year of the project was 77.505GWh. The savings will be tracked for another 2 years and the reduction in savings due to failures and removals will need to be determined on a regular basis.

## Acknowledgment

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