Negative energy impacts in the absence of proper baseline studies - a South African case study

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***Abstract*— Energy Conservation projects have become a focus area throughout the world in an attempt to reduce greenhouse gasses. These projects encompass various energy efficient technologies of which the retrofit of old technologies with new technology has become a common phenomenon. Energy savings are usually quantified by comparing actual post-retrofit energy consumption levels with baseline levels representative of the pre-retrofit status quo, adjusted for changes in energy drivers (e.g. weather). Baseline adjustments during energy conservation projects are of the utmost importance if operating conditions, occupancies, ambient temperatures, production levels and other factors have changed between the baseline period and the post-retrofit period. During a recent case study in South Africa, an HVAC retrofit was done on a multistorey building where old technology air-conditioners were replaced with heat pump based units with inverters. To the disappointment of the landlord, the post energy measurements exceeded the baseline energy consumption by approximately 12% without any changes in operating conditions. This paper illustrates the catastrophic effects when an energy efficiency project is accelerated to the implementation stage without due consideration of operating conditions during the pre-implementation stage. A qualitative analysis prior to baseline establishment is proposed.**

***Index Terms*—Measurement and Verification, energy efficiency, underground ventilation, composite fans, axial flow fans, demand side management.**

I. INTRODUCTION

It is not uncommon to measure increased energy consumption following a dedicated energy efficiency retrofit process due to one or more of the following reasons:

a) Production output increased,
b) Occupancy increased,
c) Seasonal changes, etc.

The above factors are usually accommodated for by adjusting the baseline upwards or downwards as shown in Fig.1 to create a scenario of the pre-retrofit consumption at the time of assessment as if no intervention had taken place [1]-[8].

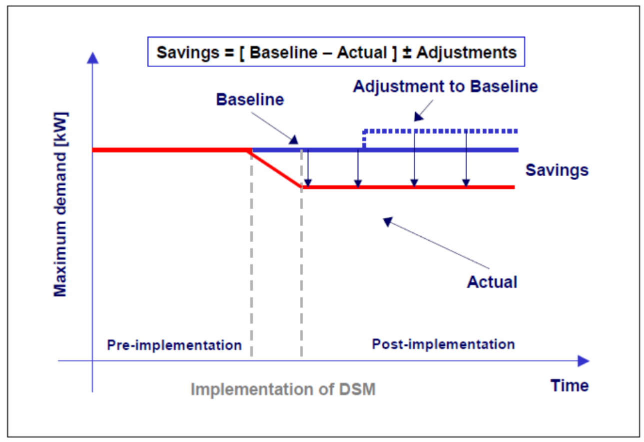

Fig. 1. Savings calculation making use of a baseline adjustment for a change in operating conditions from the baseline period to the assessment period.

Energy savings can be affected in many ways, of which the following are the most common:

a) Energy efficient lighting retrofits;
b) VSD control of centrifugal pumps and fans;
c) Heat pump based cooling and heating retrofits;
d) HVAC optimization;
e) Compressor optimization;
f) Renewable solutions;
g) Building automation or load control systems.

All of the above can be affected by varying operating conditions which must be understood and analysed for each application [1]-[8].

The importance of a proper qualitative study of the condition of the ineffective equipment before baseline development cannot be over emphasized, as will be explained in this paper.

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II. THE HVAC CASE STUDY

A. *The Project*

The objective of the energy efficiency project was to retrofit 208 old type split unit air-conditioners with heat pump based units, which have DC inverter driven compressors. The targeted power saving was 108kW for a 12-hour period from 06:00–18:00, on weekdays and Saturdays. This would result in an energy impact of 400 MWh per annum.

The project developer believed that -as per manufacturer's specifications- their heat pump based air conditioners with inverters would use 2kW less in heating mode and 0.76kW less in cooling mode compared to the old units. When calculating the target, the project developer assumed that ALL the air-conditioners would work at maximum capacity for 8 hours of the 12-hour period and that there would be 4 months of heating and 8 months of cooling per year. That calculation obviously excludes any provision for diversity or, alternatively stated, the non-simultaneous operation of units. Furthermore, the operation of any of the units (new or old) in a lower power mode for part of the day was also not considered. This was highly unrealistic and optimistic - choosing to believe that ALL the air conditioners are on and operating at their maximum consumption for 8 hours of the day. It is highly unlikely that an occupant would need the air conditioner to be operating at full tilt for such a large part of the day.

In addition to this oversight, it was later discovered that a significant number of air conditioners were either switched off at the time of baseline establishment or completely out of service due to neglected maintenance. However, the developer chose to go ahead with the project despite warnings about the dubious target.

III. MEASUREMENT AND VERIFICATION (M&V) METHODOLOGY FOR HVAC RETROFITS

There are various factors to be taken into account with HVAC retrofits, amongst others, changes in weather. During different seasons of the year, more or less energy is required to heat or cool an area. This can be related to the number of cooling or heating degree days in a year. A heating degree day is a day where the average ambient temperature was 1˚C less than a reference temperature at which heating is not required [1]. The reference, or change over temperature, is generally taken as 15˚C in South Africa [6]. A cooling degree day is one where the temperature was 16˚C. Therefore, a 25˚C day would represent 10 cooling degree days.

As the outside temperature moves away from the changeover temperature more energy is consumed by the air-conditioning system(s). Fig. 2 shows an example.

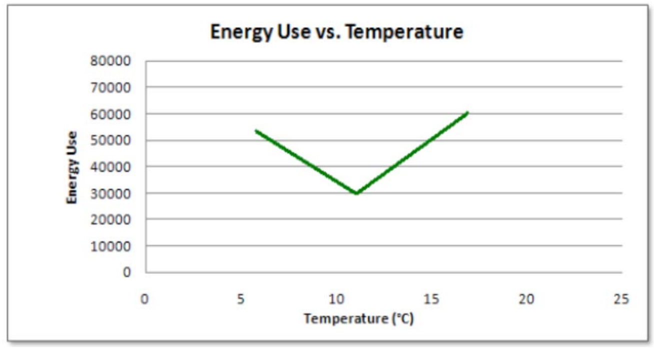

Fig. 2. Change in building energy consumption with temperature

Therefore, energy consumption is usually correlated with outdoor temperatures using regression analysis. A relationship of the form "Energy = m x DD + c" is usually obtained where m is the slope of the curve and DD is the number of heating (or cooling) degree days and c is a constant. If measurements are taken over a specific period e.g. one specific month and the average temperature is taken over the same period a similar relationship of the form "Energy = m x (average ambient temperature) + c" can be developed. Separate relations are obtained for heating and cooling for distinct operating modes e.g. weekdays and weekends [6]. In some cases, it may be necessary to correlate energy with the indoor and outdoor temperature and / or humidity.

The HVAC system energy consumption is either measured separately from that of the building or the entire building consumption (including other loads; e.g. lighting and plug loads) is measured. Under the International Performance Measurement and Verification Protocol (IPMVP) [1] these are known as the M&V Options.

- Option A – retrofit system energy is isolated from that of the rest of the building and only key parameters are measured. E.g. energy of a sample of units and outdoor temperature.
- Option B – retrofit system energy is isolated from that of the rest of the building and all parameters affecting energy use significantly are measured. E.g. energy of a sample of units, indoor and outdoor temperature and possibly humidity.
- Option C – the energy consumption of the whole facility is measured and correlated with one or more energy drivers (e.g. outdoor temperature).
- Option D – a simulation model is developed of the original HVAC system and building.

For this project the client was eager to implement the project and it was decided that Option C would be the most expedient option. Energy data from the building's billing meter was available and from the national weather service for temperature data. The other 3 options would have required installing additional metering and gathering additional data which would have delayed project implementation.

IV. M&V BASELINE & PERFORMANCE ASSESSMENT

Fig. 3 shows the average baseline demand profile for weekdays.

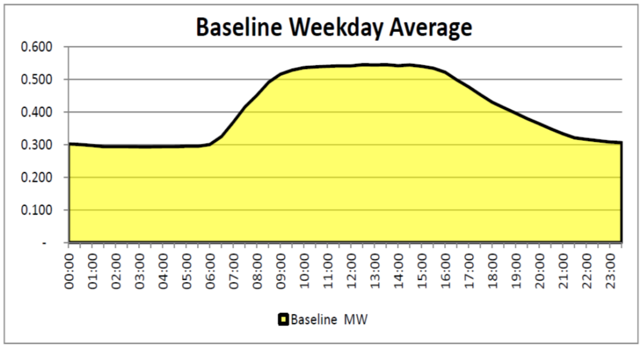

Fig. 3. Weekday baseline profile (adjusted for temperature)

Weather affects the operation of HVAC systems in buildings and results in varying levels of demand. As outlined earlier, this would usually imply an adjustment to the baseline depending on whether the assessment period is hotter or colder than the baseline period. The baseline was established during the winter season at an average ambient temperature of 17.9°C.

For this reason, a graph of daily energy consumption of the specific building for the past few years was plotted against the average daily ambient temperature. This provided a means to adjust the baseline upwards or downwards to compensate for changes in ambient temperature. Two different correlations were developed: one for weekends and one for weekdays.

Fig. 4 shows the correlation which shows a very small movement in overall building energy consumption with increasing ambient temperature and none for winter. This indicates that there was probably less potential for savings than was previously imagined (especially during winter) and should have resulted in further investigations being made into air-conditioner use.

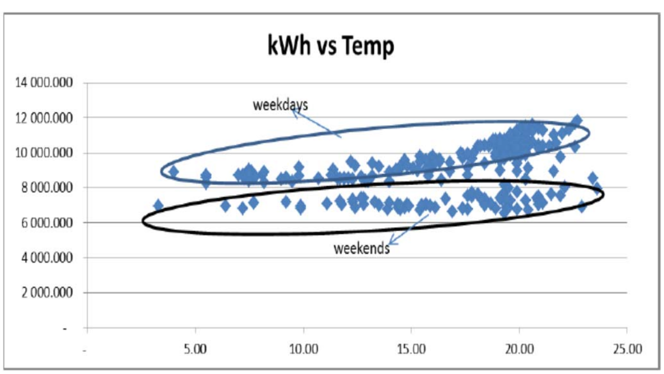

Fig. 4. Variation of building energy with temperature for the case study

The baseline profile shown in Fig. 3 has already been adjusted for the specific ambient temperatures measured during the assessment period, which was 13.37°C. Adjustments were made in accordance with the ratios outlined below:

$$E\ (\text{Baseline}) = 8330.5 - 66.26\ (17.9) = 7144.4\ \text{kWh} \tag{1}$$

$$E\ (\text{Actual}) = 8330.5 - 66.26\ (13.37) = 7444.6\ \text{kWh} \tag{2}$$

$$\text{Baseline Adjustment} = 7444.6/7144.4 = 1.04$$

The original baseline developed at the inception of the project was therefore adjusted upwards by 4% to compensate for increased energy consumption of the old type air conditioners at the time of post-assessment.

Fig. 5 shows the actual demand-post retrofit-for the case study.

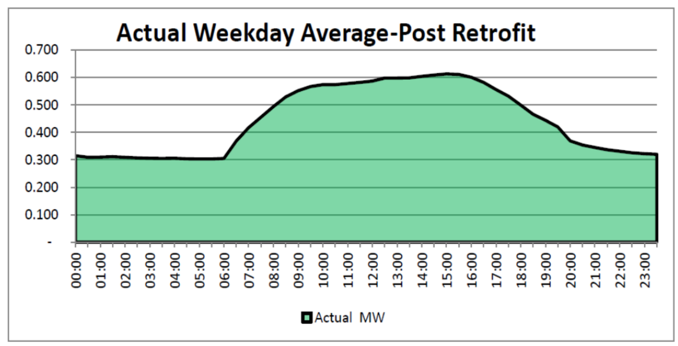

Fig. 5. Average weekday impact

It is clear from the above baseline and actual graphs that power consumption actually increased after the retrofit especially from 06:00 to 19:00 which seems to have been the operating hours for the units.

Table 1 summarises the impacts for the different periods of a typical weekday which is the average of a 6-month period following the retrofit

Table 1: Summary of impacts (active power in megawatts (MW)

	AM Off Peak	AM Std.	AM Peak	PM Std.	PM peak	PM Peak	6:00 to 18:00
Baseline	0.30	0.31	0.46	0.53	0.40	0.34	0.49
Actual	0.31	0.34	0.50	0.59	0.46	0.35	0.55
Impact	-0.01	-0.03	-0.04	-0.06	-0.06	-0.01	-0.06
Impact	-3%	-9%	-9%	-11%	-15%	-3%	-12%

The Time-of-Use periods above refer to the South African electricity utility's published time intervals [9].

The important impact to note is the contractual 12-hour daily impact of –52 kW versus the expected impact of 108 kW. This implies an increase in demand (and energy consumption) of 12%. Approximately USD 350,000 was spent on the program to attempt to save energy.

After investigating the matter further, it was found that approximately 20% of the old air conditioners were not in working order at the time of baseline establishment (as shown in fig. 3) and many building occupants reported a preference of not using the old units due to high noise levels.

V. Lessons Learnt

A. *The importance of site surveys and questionnaires*

Developers or owners of property are usually anxious to implement energy conservation initiatives as soon as possible to reduce monthly energy bills. New technology with reduced nameplate power ratings sounds attractive and straight forward to implement and energy engineers are very often not afforded the opportunity to properly ascertain conditions on the ground before rushing into the retrofit process, as was the case with the above mentioned HVAC project.

A qualitative survey of the target environment would in most cases provide a sound foundation for an energy conservation project and could consist of the following steps:

a) An exploratory study
b) Interviews
c) Questionnaires

An exploratory study of the proposed HVAC project would have involved an investigation into the performance of the old technology and an evaluation of the appropriateness of the new heat pump based technology. Baseline information like occupancy and internal room temperatures would have gone a long way in assisting with the scaling of the baseline at the time of performance assessment.

Detailed interviews with users of the old technology would have reflected their discomfort in the old environment and allowed the energy engineers to documents the details.

Lastly the use of correctly designed questionnaires for occupants in the targeted building would have extracted useful information which would have assisted in reporting a realistic energy impact.

B. *Review of the selected M&V Option*

The selected M&V Option (Option C), while being the least costly and quickest to implement has some disadvantages, especially in this case. The energy consumption of the air conditioners is not separated from that of the rest of the site, thus it is not clear from looking at the meter data alone that the old air-conditioners were not being used. This was however confirmed by the client after receiving the impact report for the project.

An Option A or B approach where data loggers would have been placed on either a sample or all air-conditioners would have shown the lack of use of the old air-conditioners. But if individual air-conditioners were logged, the diversification effect would have been lost which would then again have overstated the forecast savings.

Indoor air temperature measurements, even on a short term basis, may also have aided in detecting the lack of air conditioning and possibly provided a means to adjust the baseline upwards to account for a more realistic baseline scenario.

A building simulation (option D), although by far the costliest and most difficult M&V methodology may have also provided a means to adjust the baseline upwards. Additionally, the large number of measurements that a calibrated simulation would have required would also have revealed more about the actual operation of the building but would have had a significant cost implication for the owner.

VI. Conclusion

No M&V methodology is ever perfect. It is mostly a trade-off between affordability of the investigation versus projected energy savings. However, it remains important for energy efficiency and M&V practitioners to always assess actual baseline conditions of projects at pre-implementation stage which in this project refers to, amongst other factors, the operating habits of building occupants as well as the utilization of the old technology. It is therefore important to inform a client of the risks involved in not adequately assessing a site prior to the implementation of energy conservation measures.

The case study reported on in this paper illustrated the consequences of a process which was accelerated to the implementation stage without due consideration of operating conditions during the pre-implementation stage.

Conducting a survey of the site and providing a questionnaire for the occupants to complete could have provided valuable information to the client on the likely outcomes of the project as well as facilitating an adjustment model to realistically report on future energy impacts.

Acknowledgment

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