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ANALYSING BUILDING ENERGY USE USING SUB-METERING AND EXTERNAL WEATHER DATA

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Abstract. The Intergovernmental Panel on Climate Change and the McKinsey Greenhouse Gas abatement studies have highlighted reduction of building energy consumption as a primary cost-effective element in the abatement of Global Warming. Nevertheless, the energy investigation in most of our existing building stock remains at a novice level at best. Building sub-metering, by which we mean any secondary, hourly, metering (after the main) of various circuits, provides substantial information on when and where energy is used in specific buildings. Furthermore, combining this information with external weather data provides information beyond basic metering results. This paper discusses three case studies and explains how sub-metering, augmented by external solar and temperature data, benefits energy management and identified problems. It explains how different methods of analysing energy usage allowed: justifiable sizing of a solar photovoltaic system; with a calculated Cooling Degree Unit, identified the absence of savings from a proprietary chiller controller; and the energy variation due to user schedules and external conditions indicated anomalies in energy use. The advantages of wireless access are noted. Extracting information in graphical formats suggests better strategies to understand and control energy use.

Keywords. Buildings; energy; sub-metering; solar-energy, weather.

1. Introduction

The Intergovernmental Panel on Climate Change (2007) and the McKinsey Greenhouse Gas abatement studies (McKinsey Report 2008) highlight reduction of building energy consumption as a primary cost-effective element in the abatement of Global Warming. Nevertheless, the energy investigation in most of our existing building stock remains at a novice level at best.

Building sub-metering, (in this paper, electrical only), by which we mean any secondary metering (after the main) of various circuits on an hourly basis, can provide substantial information on when and where energy is used in specific buildings. Furthermore, combining this information with external climatic and weather data provides information beyond basic metering results.

This paper discusses three case studies and explains how sub-metering benefits energy management and identified problems. In addition to analysing sub-metering, external solar and temperature data are also analysed. It explains how different methods of analysing the data provide information about energy usage and period of use.

In one particular case, the sizing of a solar photovoltaic system (PV) for the project's energy load could be more precisely justified based upon actual hourly data. In another case, a building management consultant made a claim that significant energy savings resulted from a proprietary control implementation on the chiller plant. Our metering, together with a calculated Cooling Degree Unit, illustrated otherwise. Other sub-metering results highlight the varying energy use at particular periods of the week according to user schedules, external temperature and solar profiles, suggesting anomalies in energy use.

The advantages of wireless access are noted. Extracting information calculated from collected data in usable graphical formats suggests better strategies to understand and control energy usage.

2. A background to sub-metering

As there is no standard definition, in this research, energy sub-metering means any metering or branch circuit level monitoring, after the mains to a building, of an individual piece of equipment or an end user device or of an area.

According to Plourde (2011) the rationale for installing energy meters is twofold: to control energy consumption and costs, and to improve equipment energy use and reliability. Meters eliminate the guesswork and save time by quickly pinpointing problems. The CIBSE TM-39: 2009 *Building Energy Metering* report suggests that metering should provide sufficient evidence to pinpoint avoidable wastage without requiring expensive and time-consuming detective work.

The TM-39 methodology requires a boundary to be selected on a floor plan and identifies all the items within the boundary that will be supplied energy. It then considers those items of interest within this boundary that should be sub-metered.

The purposes of energy metering include:

- Whole building benchmarking
- Billing or management of parts within a building whole
- Technical energy analysis by end-use
- Building profile demand management

The reasons for energy sub-metering are many and the objectives must be defined and understood before developing a strategy and implementing sub-metering.

Installing a meter will not save energy on its own. There must be a system in place to ensure periodic reading of the meter. Energy-saving actions must be carried out as a result of the information provided by the meter. For example, metering may show that pumps do not need to be running continuously and may save a large portion of this energy. Metering by difference should be used where appropriate (i.e. the total and another item are both metered and the difference yields another significant component). Metering for different fuel types is also desirable but it can be a challenge to find the right instrument.

2.1. ENERGY ASSESSMENT REPORTING

Perhaps the bigger picture in sub-metering is that of an overall building energy assessment. According to the CIBSE TM-22 *Energy Assessment Reporting Method* (CIBSE 2006), there are several reasons for engaging with such assessments of a building. An assessment process not only will tend to improve energy management, but resulting investigations and actions to improve energy efficiency will tend to improve building design and management and also occupant satisfaction.

The assessment procedure offers three main options. The first two are directed at actual carbon dioxide emissions per unit floor area based on metered energy and vary only according to different energy types used in different zones of the building. The third option relates to an assessment based upon the benchmarks developed for the building systems.

2.2. ENERGY AUDITING

The Australian Standard *Energy Audits* (AS/NZS 3598:2000) complies with similar methods and reports elsewhere, such as CIBSE TM 22 (2006) and CIBSE TM39 (2009) and the ASHRAE Research Project *Procedures for Commercial Building Energy Audits* (ASHRAE 2004). The energy auditing process is split into three levels:

- Level 1 gives an overview on the general magnitude of savings and costs. It determines whether energy use is reasonable or excessive. It may take the form of a desktop study.
- Level 2 identifies the sources of energy to a site and what it is used for. It analyses areas of costs and associated savings, provides recommendations and involves on-site inspection and review of utility bills.
- Level 3 provides a detailed analysis of energy usage and a firm estimate of savings and costs. The analysis may involve sub-metering and simulation.

All methods state that there is overlap between these levels of reporting and output. Auditing is essential to establish a reference, as savings can only be estimated; they cannot be measured after an intervention.

3. Case Studies of Sub-metering

In the following, we provide three different projects where electrical sub-metering was applied to help discover energy usage patterns. The details of each project explain the reasoning behind the objectives of the metering. Most importantly is the association between the metering and external air temperature and solar energy.

3.1 A SCHOOL CAMPUS NEAR MELBOURNE

In this case sub-metering is used to identify energy loading to assess the sizing of a solar PV system. Actually, this is an after study of the reasons for sub-metering. Initially, sub-metering was used to ascertain where and when energy loads were active. Preliminary results indicated that there was excessive energy waste in exterior night lighting. The split-systems, sporadically installed, provoked another energy crisis in terms of high peak loading during summer. As a result of the sub-metering analysis, the client took action to control consumption and reduce waste.

3.1.1. PV System Sizing

Apart from using sub-metering, the school wanted to set a visible image in terms of environmental sustainability for its students and staff. To address this, a solar PV system was being considered. A particular issue was to have evidence to justify the size of PV system to be installed. We combined the electrical metering data with concurrently collected weather data, in particular, solar global radiation.

In sizing a system, there are a number of factors to consider. These are whether a gross or net feed-in tariff is used, whether energy metering is ac-

cumulation or interval based, the actual tariffs used to buy and sell energy, the patterns of energy use and the weather conditions.

In the absence of local energy storage and a net feed-in tariff (at present \$0.08/kWh) lower than the purchase price of energy (about \$0.25/kWh), the best value of a PV system is achieved when its size is such that *little* energy is sold to the grid. This is because a large saving is made by avoiding the purchase of energy rather than a small saving by selling it.

Figure 1 shows the total demand measured from metering data and an estimate of PV system output based on solar global radiation during a December (summer-time) week. The total height of each bar is the power demand for each hour from 8 a.m. till 6 p.m. The dark portion is the estimated power derived from a 50 kW PV system. The graph shows that, early in the week, demand is high and available solar energy is low. Later in the week, the demand is lower and the solar energy higher, almost satisfying the demand. With extra PV capacity, solar energy would be exported at this time, but at 8c/kWh, an extra 50kW capacity would save less than the first 50kW. Higher PV capacity would cover winter months better, but provide excessive energy in summer. Of course, if the feed-in tariff were larger than the tariff to purchase electrical energy, exporting energy to the grid would make economic sense.

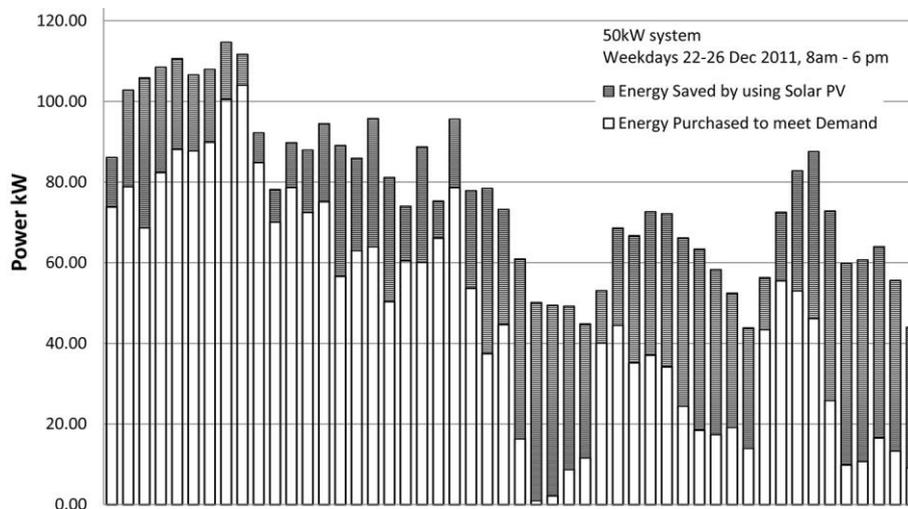


Figure 1 Main Power - Solar Generated Power: 50kW PV System

This study began as an exploration of sub-metering to identify the waste of energy and developed into a study of PV system sizing. Sub-metering helped to identify the campus electrical load at various periods during the

week and, together with concurrent solar energy measurements, determined how those loads can be matched to a suitably-sized solar PV array. By knowing the metered energy requirement, and extending the analysis to account for seasonal variation, the sizing of a PV system can be better determined.

3.2 ASSESSING ENERGY RETROFITTING AT A SHOPPING CENTRE:

This study investigated the outcomes of a retrofitting project at a shopping centre in Victoria, Australia. It is a result of a long on-going investigation into potential measures to achieve energy efficiencies and introduce reductions in the cost of conditioning air in the premises. A Victorian company, Air Barrier Technologies Pty Ltd., was commissioned to undertake initial air pressurisation testing of the building, to measure air leakage through the building envelope. Extensive pressurisation testing identified an air permeability rate of 47 Air Changes per Hour (ACH) at 50 Pa pressure. This compares to an acceptable international maximum leakage rate of 10 ACH at 50 Pa pressure for this type of building. In other words, the building is excessively leaky.

The objective of energy metering, in this case, was to determine a before and after retrofit of air leakage energy consumption of the chiller plant during a cooling period. Sub-metering was used on the chiller to verify that less energy was used to cool the building after sealing of the building envelope.

3.2.1. Cooling Degree Units

A system was needed to analyse different days. Some days are hotter than others and require more cooling capacity. An initial evaluation to compare different days was performed using the concept of a Cooling Degree Unit (CDU). The concept is derived from the well-known cooling degree day measure, but is determined hour by hour. The external air temperature for an hour is compared to a set-point temperature (of 20°C in this case). If the external temperature is 1°C above the set-point then it counts as 1 CDU. If the external air temperature is less than 20°C the chiller is not required (or barely needed) and external outside air could be used directly. External air at low temperatures does not need expensive chilling and this should be considered seriously in the Building Management System (BMS) programming of existing mechanical equipment.

Table 1 provides the findings of this study. It is noticed that the air leakage sealing, over the original 'unsealed' building case, performed approximately 35% better in energy consumption for the total kWh usage per CDU. For an average kWh use per CDU this was analysed at an improvement of

8.4%. It is uncertain as to what method of evaluation would be considered reasonable. However, a definite improvement is indicated here.

There were claims made by the chiller maintenance and Controls Company that a new device added to the chiller was providing substantial savings to the client. This was implemented for the period after the building was sealed; however, the figures in Table 1 indicate that this intervention proved otherwise, increasing energy use over the original base case.

Table 1. Chiller Energy Consumption Analysis

Chiller Energy Evaluation Period	Chiller kWh total/CDU total*	Comparison with Original	Chiller kWh average/CDU*	Comparison with Original
Original System: 23 Dec – 9 Jan 2012	30.7	N/A	42.9	N/A
Sealed Building: 17 Jan – 10 Feb 2012	20.1	-34.5%	39.3	-8.4%
BMS Retro: 14 Feb – 6 Mar 2012	31.5	2.6%	55.6	30%
Jan-Feb v. Feb-Mar 2012		57% increase		41% increase

* CDU= Cooling Degree Unit

3.3. A MULTISTORY UNIVERSITY BUILDING

The excessive energy use in a university building was investigated. Following an initial analysis of the existing mains meters, which monitored HVAC and lifts on one meter and power and lighting on another, sub-metering was applied. The top half of Figure 2 shows the HVAC and lift electrical energy use for the building and the energy that would be generated by a 150 kW solar PV system. The bottom half shows the weather conditions at the same time. The plant-room ambient temperature was measured on-site. The hourly outside ambient temperature has been obtained from a site at Melbourne's Tullamarine Airport, about 19Km distant from the building. The solar global was estimated from the daily total of solar global radiation recorded at the Bureau of Meteorology in central Melbourne, about 2Km from the site. The graph is an interpolation based on solar altitude, which was considered to be accurate enough for this purpose.

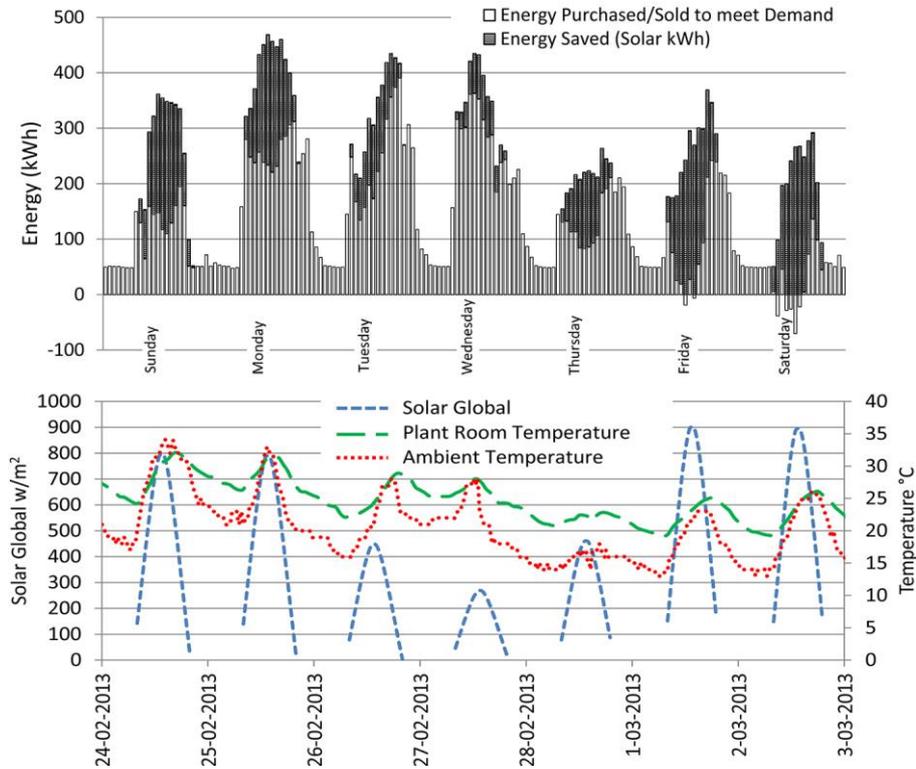


Figure 2 Electrical and Solar Energy (estimated for a 300kW system) and Weather Conditions

Data was recorded from 30 February to 27 March 2013. Figure 2 shows the week beginning on Sunday, 3 March, when the temperature peaked above 30°C on most days. For the whole period, on weekends, the HVAC energy consumption averaged 3252kWh/day, which is higher than expected, being 65% of the weekday average energy use of 5009kWh/day. At night-time the power level was about 50kW, so the weekend energy level could be as low as 1200kWh/day. So, up to 2000kWh of energy can be saved every weekend day.

HVAC power consumption as a function of external air temperature is plotted in Figure 3 **Error! Reference source not found.** This shows that there is a tremendous variance in energy use at higher external temperatures. The reasons and causes of this have yet to be investigated.

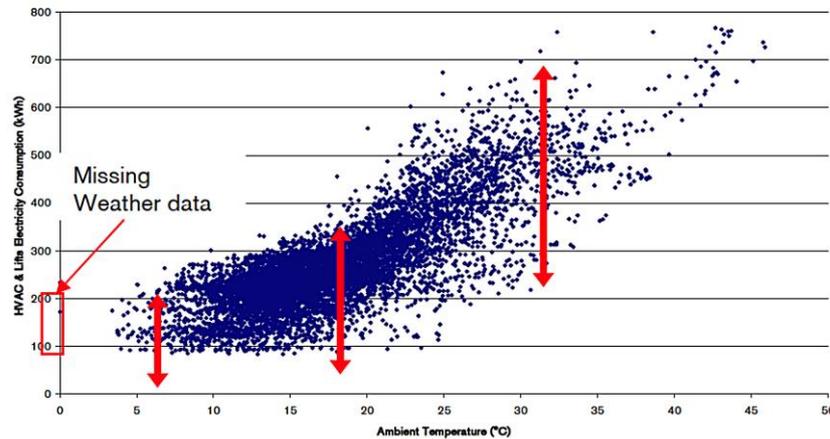


Figure 3 Electrical Energy as a function of ambient temperature (860 hours)

The sub-metering study of the conditioning equipment and its operation showed many anomalies. In particular:

- The unnecessary 24/7 operation of AHU's (air handling units) for the lecture theatres.
- The unnecessary 3-4 hour prior start-up of the main plant room chillers before the operation of any AHU.
- The unnecessary 24/7 operation of chiller pumps.
- The excessive use of lighting during unoccupied hours.
- Continuous exhaust and lighting in the bathrooms.

4 Overall Findings of Sub-metering and Energy Auditing

All of the above sub-metering case studies lead to substantial energy savings. It was noticed that most of the improvements were related to addressing three specific culprits:

- waste;
- missed opportunities;
- mis-scheduling of equipment operation.

Discovering these culprits is a direct outcome of sub-metering analysis. Exploring the results of sub-metering often requires an inquisitive analytical approach, not mere recipes or checklists. The researcher needs to query the energy use based on experience, often asking why a particular piece of equipment is in operation when it is. Nevertheless, the implementation or action taken to remedy such problems is generally very cost effective, often being a simple re-programming of the Building Management System (BMS).

Furthermore, this research indicated the importance and value-adding role of external air temperature and solar radiation in regards to energy use and its diagnostics. The combination of the two, sub-metering and weather data, revealed strategies to improve the operation of various pieces of equipment in buildings. Using both sets of data provided a novel approach to determining a ‘justifiable sizing’ of a photovoltaic system when realising that there is no storage available and while the buy-back for excess energy is low.

The sub-metering in the above research projects uses wireless technology to store data on a server allowing it to be accessed via the Internet. Although other conventional data-logging sub-metering systems have been used in the past, this form of data-collection is very useful for immediate access to the results of several projects running simultaneously.

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