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FIRST ENERGY PERFORMANCE RESULTS OF A UNIVERSITY BUILDING AND COMPARISON TO ENVIRONMENTAL RATING SIMULATION DATA

Francoise Burgun[1,2], Jose Bilbao[2], Alistair Sproul[2], Lester Partridge[3], Peter Lowndes[3], Julie Pardon[4]
[1]CEA LITEN INES, National Institute for Solar Energy, Le Bourget du Lac, France
[2]SPREE, University of New South Wales, Sydney, Australia
[3]AECOM, Building Engineering, Sydney NSW 1230, Australia
[4]INSA, National Institute of Applied Sciences, Lyon, France

ABSTRACT

Completed in early 2012, the showcase Tyree Energy Technologies Building (TETB) is the new home for several energy research groups at the University of New South Wales. This landmark, 6 Green Star Environmentally Sustainable Design, is a state of the art of innovative energy technologies and leading architectural design. This paper investigates the performance of the building itself and of its key systems during the first year of operation, while giving an analysis of the control system. It examines and compares the operating data with the predicted results derived from the rating calculation in terms of energy generation and use.

INTRODUCTION

Integrated Green Building design is commonly supported by energy performance simulations. Furthermore, low carbon and best practice design rating schemes rely on the results of those calculations in order to assign performance merits. However, real performance is not always verified against the simulated results since it requires resources and time for advanced commissioning and monitoring processes. In addition to this, rating calculations undertaken during the design phase are required to follow strict protocols which often don't reflect real life conditions. This work has been made possible thanks to the commitment of the University of New South Wales (UNSW) to extensive commissioning and building tuning.

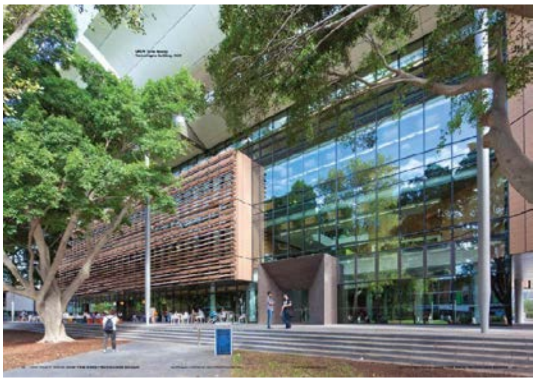

Figure 1: North façade: TETB main entrance

The TETB has received a 6 Green Star certification, the highest score awarded by the Green Building Council of Australia (GBCA), making it the fourth 6 Star education facility in Australia, representing world leadership in environmentally sustainable practices.

In this study, the following issues are investigated: the building's compliance with the original design, the limitations of simulation, and the difficulty of making monitoring figures meaningful and how these can be addressed.

UNIVERSITY BUILDINGS

Energy in the built environment in Australia

Buildings account for 19% of total energy consumption and 23% of the Green House Gas (GHG) emissions in Australia (ABARE, 2010) (Energy in built environment in Australia – page 2). The commercial sector itself accounts for 10.4% of GHG and is projected to increase by over 25% from 2009 to 2020 (ABARE, 2010) (Energy in built environment in Australia – page 2).

Energy features of University Buildings

University buildings are very specific buildings within the commercial sector. They are available almost 24/7 with a closing period of 2 weeks or so at summer time. The occupancy is very variable and there is a large variety of space types. So we are presenting this single university building as a specific case study.

More and more universities around the world are striving to achieve greater energy efficiency and hence are committed to the monitoring of their building stock. At UNSW, the Facilities Management team is monitoring the energy and water use of more than 50 buildings on its main campus. The data is displayed in real time on the Facilities Management Website[1].

Typically, the Science and Engineering faculties are amongst the biggest energy consumers as they host energy intensive labs, some of them with strict requirements of 100% fresh air with a tight humidity and temperature control. On the other hand, Commerce and Law faculties have facilities similar

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[1] http://www.facilities.unsw.edu.au/campus-development/sustainability-campus/greensense-live-energy-project

to office buildings with extended opening hours. This makes a difficult task to compare different university buildings. As a reference, a table has been included with the energy and GHG density of the Chemical Science building and the Electrical Engineering building at UNSW.

Table 1: Total Energy and GHG emissions of two UNSW energy intensive university building

	Energy Density (kWh/m^2.yr)	GHG Density (kgCO$_2$/m^2.yr)	Lab Area %
Chemical Sc	338.9	414.0	34.8
Electrical Eng	150.3	174.5	22.0

The Electrical Engineering building is similar to the TETB in the percentage of floor area and type of laboratories. However, unlike the TETB, the Electrical Engineering building does not have comfort HVAC for most of the spaces. The Chemical Science building is more energy intensive, due to the higher proportion of wet labs with exhaust hoods.

In a study of the life cycle energy and environmental performance of a new university building in Michigan (Scheuer, Keoleian et al., 2003), it is reported that for a building without labs:

- The HVAC and electricity account for 94.4% of life cycle primary energy consumption,
- Life cycle distribution of energy consumption and environmental impacts are concentrated in the operational phase of a building.

Therefore in research laboratory intensive buildings, these statements would be even more true. Consequently, the envelope design improvements are to be pursued so as to reduce cumulative burdens, even at the expense of greater material production and construction burdens. However this also means that the HVAC sizing and control must be adjusted to the demand and especially the set points must be wisely selected to ensure comfort and security whilst achieving energy efficiency goals.

GREEN STAR CERTIFICATION SCHEME

Green star is a LEED like voluntary environmental rating system for buildings. It was launched in 2003 by the Green Building Council of Australia, a chapter of the World Green Building Council. The system considers a broad range of practices for reducing the environmental impact of buildings and to showcase innovation in sustainable building practices, while also considering occupant health and productivity and cost savings. The related rating tool covers a wide range of buildings and amongst those, education and university buildings. It assesses a project against a number of categories defined in Table 2, below (Green Star, Education V1, 2008). The results for the TETB are also given in Table 2.

Table 2: Green star categories/credits &TETB score

Categories	**Points available**	**TETB points achieved**	***TETB category score %***	**Weighting factor %**	**TETB weighted category score**
Management	14	14.0	*100.0*	10.0	10.0
Indoor Environment Quality (IEQ)	**24**	**12.0**	***50.0***	**20.0**	**10.0**
Energy	**29**	**22.0**	*75.9*	**25.0**	**19.0**
Transport	12	12.0	*100.0*	10.0	10.0
Water	16	15.0	*93.8*	15.0	14.1
Materials	20	17.0	*85.0*	10.0	8.5
Land use and ecology	8	2.0	*25.0*	5.0	1.3
Emissions	12	7.0	*58.3*	5.0	2.9
Total	135	101		100	**76**
Innovation	+ 5				**+1**

The Green Star rating system aims to recognise and reward projects that achieve best practice outcomes or better, the certified ratings are shown in Table 3.

Table 3: Green star rating scale (according to GBCA)

Point Score Out of 100	**Green Star Rating**	**Outcome**
45 – 59	4 star	Best Practice
60 – 74	5 star	Australian Excellence
75 +	6 star	World leader

In the **IEQ category**, there are 3 points for daylight and 3 points for thermal comfort (i.e. 12.5% each of the IEQ category). These aspects are very important in a university building; nonetheless TETB scores 0 out of 3 for both of them. From Green Star university building benchmark we know that artificial lighting represents 37% of the total electricity consumption (Green Star, Education V1, 2009), so optimised daylight is an essential feature, hence one could expect that a minimum score could be required for this particular criteria. The other points are mainly for indoor air quality, but also for internal noise levels, glare control, etc.

In the **energy category**, there are points allocated for low greenhouse gas emissions (calculated with the Green Star energy calculator), for peak energy demand reduction on the energy supply infrastructure, and also for accessible and highly visible stairs, for design that minimises energy use for spaces when unoccupied, etc…Thus, several points may be easy to obtain no matter the means; e.g. a tri-generation system can help to reduce the peak energy demand on the energy supply infrastructure but it doesn't help to spread the demand of the building during the day.

The TETB was awarded maximum points for 'project management' and 'transport' categories, as well as a high score for 'water' and 'materials' criteria; but it doesn't perform very well in the 'IEQ' and 'energy' which are major categories regarding life cycle primary energy consumption. Despite that, the TETB has received a 6 Green Star certification just reaching the minimum score expected with 76 points.

DESCRIPTION OF THE BUILDING, ITS USE AND MANAGEMENT SYSTEM

Description of the building

The TETB consists of a 5-storey building, one storey being below ground level. The lower ground and ground floors are predominantly educational facilities; while the labs and the office spaces, the meeting rooms, and open plan workspace, are located on levels 1 to 4, with level 5 containing the main plant room. In this 16,000 m^2 building, the research laboratories represent about a quarter of the total useful floor area (UFA). A central atrium space with access stairs and pedestrian bridges connects the floor levels through the full height of the building.

Figure 2: Central Atrium

Key design features contributing to the rating include use of fly ash in the concrete, a tri-generation system, 1,100 m^2 of roof mounted photovoltaic array, a solar hot water system, use of groundwater together with rainwater capture and reuse, mixed mode natural ventilation, and air conditioning including underground thermal labyrinths for pre-treatment of incoming air, displacement air delivery, and high levels of outside air.

Energy conservation features

UNSW TETB has been designed to meet energy and environmental benchmarks and the main energy features are the following:

- Office facade facing north and benefiting from natural shade from existing trees.
- High performance envelope including double glazing to allow maximum daylight penetration and minimise solar heat load into the building envelope (see Table 4).
- Fixed external terracotta sunshade louvers as part of the building façades, to avoid direct solar heat gain and control internal glare.
- A thermal labyrinth to precondition air for the lower ground and ground floor.
- Groundwater circulated to air handling coils to pre-heat or cool the outside air to the first floor to third floor open learning spaces.
- Spill air from the horse shoe theatres is used to condition the adjacent circulation spaces.
- Natural ventilation purge of the building is used to introduce night time cool air to pre-cool the building structure ready for the next day's occupation.
- Economy cycles are provided where practical to make use of free cooling when outside conditions are favourable.

Envelope features

Table 4: Building elements thermal performance

ELEMENT TYPE	**DESCRIPTION**	**R-value (m^2.K/W)**
External wall facade Type #1	Curtain wall with terracotta tile infill	2
External wall facade Type #2	Curtain wall with external vertical sunshade	3
External wall facade Type #3	Curtain wall with external horizontal sunshade	3
External wall facade Type #6	Curtain wall with metal cladding infill	2.6
Roof	Flat roof over south west pod	4.7
Roof	Main roof	4
Floor	Floor exposed to exterior	2.45
ELEMENT TYPE	**DESCRIPTION**	**U-value** (W/m2.K)
Glazed Façade	6 /12 / 6mm Neutral low emissivity glass	2.16

Equipment features

The tri-generation plant, an MPower of 800 kWe, and is operated to generate electricity using natural gas. The waste heat is used to produce hot water or chilled water via the absorption chiller. The design target for the tri-generation system is to cut the CO$_2$ emissions by 55%.

The tri-generation and the 150 kWp photovoltaic array systems are connected to the campus wide grid. Under present conditions and internal loads, the building is exporting electricity during the daytime.

The building also receives chilled water from the campus Central Energy Plant (CEP). The absorption system operates more efficiently at higher temperatures so the absorption system is used to pre-cool the chilled water returning to the central plant.

The HVAC system is organised by zones and controlled by set points related to the mode of occupancy.

Use and occupation of the building.

For the Green Star rating calculation, the occupancy of the building has been estimated in accordance with the Green star's occupation scheme (Table 5). During the period of metered data, it is estimated that occupancy is about two third of the maximum.

The HVAC system in each separate enclosed space within the UFA is designed to automatically shut down when not in use for areas with comfort HVAC. The laboratories HVAC system must operate 24/7 in order to comply with Australian Standards regarding laboratories. However the temperature control is designed to allow a wider temperature control band when not in use – that is, a minimum of an additional 2 degrees in either direction.

Table 5: TETB Space breakdown

Space type	Occupancy (m2/person/day)	Space type area (m2)	Percentage of total space
Teaching	9	2,126	16.1%
Dry labs/Special learning spaces	9	2,034	15.4%
Office/Administrative	20	3,444	26.1%
Common spaces	20	4,095	31.1%
Wet labs	20	1,498	11.4%
Total Usable Floor area		13,179	100%

Building management system

The integrated Building Management System (BMS) controls and monitors the functionality of the building in terms of mechanical and electrical services. As such, the BMS assists in optimizing the building equipment for comfort, safety and efficiency. However, we have observed a disagreement between the temperature set points currently programmed on the BMS and the Green Star operating conditions, and simulation model. This is shown in the following table 6. The TETB facility manager is responsible for the set points and he chooses them so as to avoid any complaints. Consequently the set points for heating and cooling are very close, respectively 22°C and 23°C, with a band gap of only ± 1°C so a as to maintain a stable ambient temperature. This discrepancy in the set points results in an over consumption of the building in comparison with Green Star prescriptions.

Table 6: Comparison of HVAC setpoints of the BMS and Green Star requirements

HVAC control	BMS Setpoints **Occupied**/ (unoccupied)	Green star model **Occupied**/ (unoccupied)
Heating	**22** (22) °C ± 1°C	**20** (18) °C
Cooling	**23** (23) °C ± 1°C	**24** (26) °C

BMS strategy for Lighting

In the offices, the meeting rooms, and teaching rooms, the lights are controlled by occupancy sensors. Elsewhere, in the circulation spaces, the open plan spaces, the BMS controls the lighting circuits with a combination of occupancy sensors and time clock arrangements for 15 separable zones.

Use of the Tri-generation plant

The tri-generation plant operates to maximise the electricity generation during peak and shoulder time, that is to say 15 hours a day (from 7am to 10pm) during working days. These operating hours are chosen due to the greater cost difference between gas and electricity tariffs during these times. Currently, the absorption chiller is manually operated by the building operations manager, due to the complexity of the dynamics with the campus CEP. In the near future, the automatic control will be activated after the re-commissioning of the CEP, using the experience acquired during the first year of operation of the building. The use of the absorption chiller is prioritized over the direct use of heat for two reasons. Firstly, absorption chillers need to run a certain number of hours per week, and secondly, to provide chilled water to the central chilled water plant to reduce the load on the main chillers. If the absorption chiller is not using all the excess heat from the generator, then the heat is used in the building, or in case of low heat demand, the heat is wasted using a cooling tower.

METHODOLOGY

The purpose of this work is to assess the performance of the building during its first year of operation. This is a period of learning, fine tuning, and adjustments. With newly installed equipment the facility managers are discovering the thermal behaviour of the building; and the occupancy is gradually increasing. The first occupants moved into the building at the end of January 2012, hence for this study it was decided to take into account the data from July to December 2012, considering that data began to become available and reliable after a few months of operation. This approach avoids the most 'unsteady period'. In order to obtain a rough first estimation of the yearly performance, we doubled the measured figures from July to December 2012, checking that the climate data and the occupancy pattern were consistent with this rough assumption. This 6 month period complies well with the average data of the Bureau of Meteorology for the same interval over the last 30 years. The semester breaks are rather evenly spread over the year (one in April, one in October) and there is a 2 weeks shutdown end of December, beginning of January; and the building is mainly occupied by postgraduate.

Finally, the object of this first analysis is:

- To collect measured data, question their meaning (what, where, with which sensor?) and select reliable figures (checking their consistency with benchmarks and/or one against another)
- To check the global building consumption measurements and compare them with the calculations done for the accreditation
- To assess the energy generation from the two embedded energy production systems, a roof mounted PV array and a Tri-generation plant.

Access and Availability of Data

The building has two main sources of data: the data contained in the BMS and the data from the extensive energy and water metering system. Sensors installed in the BMS system are temperature sensors for zones, water temperature sensors, differential pressure sensors, humidity sensors, flow meters, etc. Meters installed in the energy and water metering system are power meters, gas meters and water meters.

The meters and sensors were checked by the facility management during the commissioning of the building and some of them were faulty, hence for our study we selected reliable meters and sensors.

Only 14 meters are linked to the UNSW general server in which data is stored for up to 3 years. In the case of the electricity meters, the system saves a data set every 15 minutes; in the case of gas and water meters, it saves the pulse signals as consumption happens. In the BMS system, only a selected number of sensors are trended and the generated data are not easily exploitable. The interval between data points is between 5-15 minutes. Thus, the information system acquiring and logging the data from the meters is still not operational in a way that would allow extensive analysis of the data. However, this is expected to change in the near future. Once the extensive network of meters is available for research purposes, a more detailed analysis will be carried out.

For this study, most of the information used comes from readings of the BMS and a select group of electricity, gas, and water meters. However, with the limited available results, it is possible to allow a comparison between tracked figures for accreditation purpose and operational consumption.

It is also important to mention that the Green Star process does not consider the energy use for the equipment in the building, other than for the estimation of the HVAC load. Hence, the electricity load from electrical appliances such as computers, lab equipment, and appliances other than the building embedded equipment (HVAC, lighting, lifts, etc.) is not taken into account in the certification modelling. In order to compare the operational data to the simulation results, an estimation of their load was carried out using the parameters and guidelines stipulated by Green Star for the calculation of the HVAC load.

MODELLING, RATING, TARGET DATA

Method and tool

In order to qualify the performance of the building and verify the compliance with the Green Star certification, a study was carried out by an independent consultant (AECOM) utilising the software package Integrated Environmental Solutions 'Virtual Environment' (IES:VE) version 6.4.0.5 incorporating the Apache Thermal software module. A three-dimensional computer model of the facility was created and an analysis was carried out to ascertain the predicted building energy consumption.

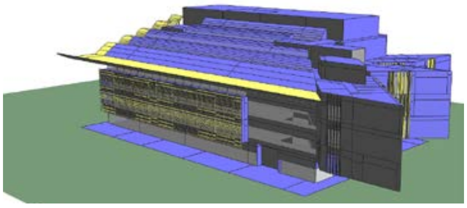

Figure 3: IES 3D model showing north-east elevation

The simulation has been carried out in accordance with the Green Star methodology for the assessment of Educational buildings. Hence the standard operation hours, occupancy, lighting and equipment loads were as specified by as the Green Star – Education V1 Energy Calculator Guide. These standardised settings enable effective comparison between different buildings and models and therefore do not directly reflect the actual operation of the building. Therefore, the results of this simulation give an order of magnitude assessment of the building's performance rather than predicting the building's energy use in actual operation.

Energy Targets

According to the energy model developed for this project, the annual operational energy targets for the Tyree Building UNSW are shown in Table 6.

Table 6: Simulated Energy Targets

TOTAL CONSUMPTION OR GENERATION	**ENERGY and UNIT**	**MODELLED TARGET (rounded figures)**
HVAC	Elec.(MWh/yr)	603
HVAC HHW	Gas (MWh/yr)	7.8
Tri-generation	Gas (MWh/yr)	2,124
Lighting	Elec.(MWh/yr)	222
Lifts (3 lifts)	Elec.(MWh/yr)	43
Domestic Hot water	Gas (MWh/yr)	40
Equipment*	Elec.(MWh/yr)	526
PV Array	Elec.(MWh/yr)	+ 235
Tri-generation	Elec.(MWh/yr)	+ 825

**Estimated by the Authors from the HVAC load data*

These energy targets are based on Green Star utilisation protocols and may vary depending on final use of building. Tri-generation and PV electrical generation will be highly dependent on local weather conditions and system operation.

The HVAC Tri-generation value shown in Table 6 refers to the gas consumed for the purpose of operating the gas engine which provides waste heat to the HVAC system and electricity for by the building.

Indoor Environment Quality Targets

All usable floor area spaces are provided with temperature, CO_2 and VOC sensors that are connected to the BMS to ensure comfort conditions defined by the targets displayed in Table 7.

Table 7: Standard Green Star IEQ conditions

ITEM	**TARGET**
Operating Temperature	20 - 24 deg. C
CO_2 level	Less than 700ppm
VOC detection	0.5mg/m^3

ENERGY PERFORMANCE REAL DATA COMPARISON WITH SIMULATION

As can be seen from Figure 4, the building is at present generating more electricity than it consumes.

This is because the tri-generation plant is running 15 hours per day (instead of 8 hours in the modelling), with the exception of July and September when the plant was under maintenance for a couple of weeks.

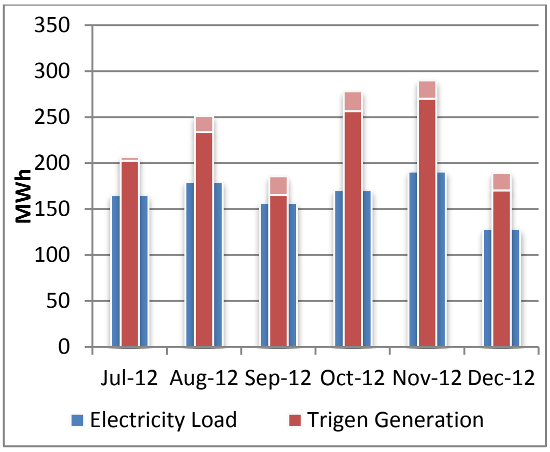

Figure 4: Measured Electricity Load (grid) and Export (Tri-generation and PV plant)

Figure 5 shows the building and tri-generation plant energy consumption during the last six months of 2012. The gas consumption of the tri-generation from July to December 2012 is 3,693 MWh (i.e., 174% of the original estimations – see Table 6) and a total electricity generation of around 1,300 MWh. During the same period the building has consumed 992 MWh of electricity. The original estimate of generating 825 MWh/year (see Table 6) would have only covered roughly half of the building electricity use. Under the current 15 hours scheme, the annual gas consumption of the tri-generation system is expected to be close to 7,800 MWh.

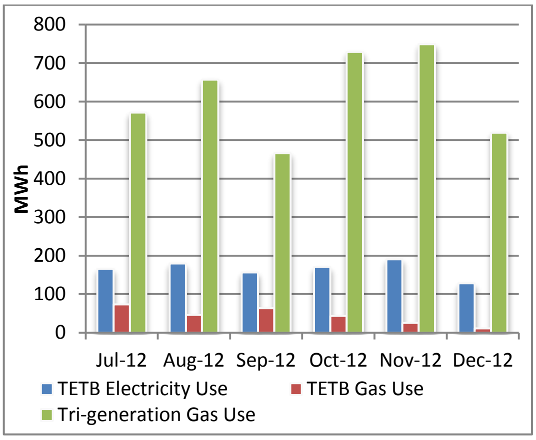

Figure 5: Measured energy consumption of the building and tri-generation plant

Assumptions

In order to compare the metered data with the modelled data, we assumed that the six months of data from July to December are representative of the building performance, and therefore, a whole year is roughly estimated by doubling the total figure for the six month period. This "extrapolated" annual energy consumption can then be compared (order of magnitude) with the simulated results.

Considerations regarding the metered data

An important detail to notice is the actual lack of data concerning the use of the heat produced by the tri-generation plant. According to the specifications, the heat energy recoverable from the jacket water is 430 kW and 490 kW through the exhaust for the engine at full capacity (1965kW).

In this early phase of the operation of the building, the amount of waste heat produced is known, but we do not have records on how it is shared between the HVAC heating loop, the absorption chiller or sent to the cooling tower. This issue is about to be solved and the input of heat into the HVAC system is going to be available in the near future. This means that although we have the global figures for electricity and gas consumption of the building, we do not have the total real energy use of the building. Consequently, the results shown in this section have to be analysed with that in mind. In Table 8, the resulting Green House Gas emissions density is calculated for the metered and the simulated data.

Table 8: GHG Density comparison (kgCO$_2$/m^2)

	Energy Density (kWh/m^2)		**GHG Density (kgCO$_2$/m^2)**	
	Meter	Model	Meter	Model
Electricity	117.0	82.0	124.0	86.9
Gas[*]	31.2	2.8	8.3	0.7
Total	148.1	84.8	131.4	87.6

[*] *Not including HVAC Tri-generation portion*

Those results are consistent with the benchmark data of other energy intensive UNSW buildings, which range from 174 to 414 kgCO$_2$/m^2 (see Table 1).

Comparison of real data and simulation results

Currently, there is no clear explanation for the difference in electricity use. The modelled data included in the tables takes into account the estimation of the equipment load undertaken by the authors using Green Star guidelines for the calculation of HVAC load. This is a potential source for error, given that Green Star does not include this load as part of the certification. However, it is expected that the building would be using less electricity due to the level of occupation achieved so far, which is estimated about two third of maximum occupancy, during the period of metered data. Another possible source of error is that there is still some room for, control optimization, and fine tuning of the BMS, particularly, in the room temperature set points. All these questions will be answered once more detailed data is available.

The sections that were possible to compare with the available data are presented in Table 9. The metered and simulated consumption of gas for Domestic Hot

Water can be considered in good accordance even though we could have expected a lower real consumption as the occupancy is not 100%. The metered PV generation is more than 10% lower than the prediction but this is due to an exceptionally low yield for July 2012 due to low solar irradiance.

Table 9: Energy Comparison

GAS (MWh)	**Metered**	**Modelled**
HVAC HHW (Boiler)	96.8	7.8
DHW	38.6	40.0
ELECTRICITY (MWh)	**Metered**	**Modelled**
PV	+ 204.8	+ 235.0
TRIGEN	+ 2,596.1	+ 825.0

From the metered values, the building is using far more gas than estimated for HVAC heating hot water (HHW), despite the fact that the tri-generation plant is running for extended hours, hence producing heat.

There are different explanations for this discrepancy. One of them can be derived from Figure 1, showing several big trees on the northern façade which are very dense and are as tall as the building. These trees have not been taken into account in the model as can be seen on figure 3, so there is far less solar gain in reality than in the model. Yet, according to Green Star guide 'the overshadowing from the surrounding environment must be considered' (Green Star, Education V1, 2010); so it seems that there is a lack of safeguards in the Green Star methodology.

The second explanation has already been mentioned, that is the difference of heating set points between the BMS (22°C) and the model (20°C), and that is a major source of discrepancy. Indeed, on account of this extra 2°C, the building is heated more, and longer as the heating period is correlatively extended during the mid-season.

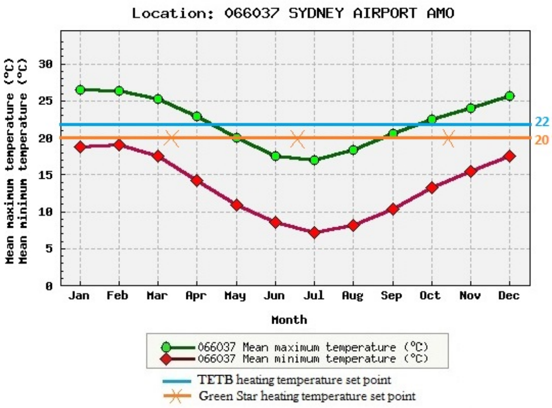

Figure 6: Mean maximum / minimum temperatures in Sydney and heating temperature set points

From the mean average maximum and minimum temperatures in Sydney on figure 6, we can see that the difference between the outdoor and indoor temperature is rather moderate all through the year, hence the impact of the set points is relatively more important than in a continental climate.

The other reasons for the discrepancy could the lower occupation load as the building is not fully occupied, and a higher infiltration rates which are different between the model and the reality (recommended typical default values have been applied in the model).

Comfort and Energy use

Living in the building, we observe that the heating is 'on' not only in the winter period, but sometimes also in autumn and spring, especially early in the morning. This results from the specific Sydney climate, which is quite cool at night in the intermediate season. This is also the result of the HVAC settings. A change of minus 1 or 2°C in the heating set points would induce noticeable energy saving and could possibly meet comfort requirements, provided occupants dressed accordingly. Similarly the cooling set points could be adjusted a bit higher.

Lighting controls are currently under the process of adjustment to better meet the needs of the occupants, as some spaces were measured as being over lit and some others were lit even when not necessary.

These observations partially explain the differences between the measured data and the calculations.

DISCUSSION, CONCLUSIONS and FUTURE PROSPECTS

Unfortunately, for this study, the information system acquiring and logging the data from the wide range of meters installed was not operational in a way that would have allowed extensive analysis of the data. This situation stems from the fact that the monitoring tool has been developed specifically for this building and does not interface easily with the existing facility management network. Hopefully, this should change in the near future and once the extensive network of meters is available for research purposes, more detailed analysis will be carried out.

Several challenges aroused during this study. Some of them were related to the fact that we were working on a new building, hence, not everything was operational; the BMS was still in a learning phase, at times was operated manually, and some sensors were not connected or faulty. Others were due to the complexity of the building facilities and it was difficult to track imports and exports of electricity and heat. The tri-generation plant in particular was difficult to apprehend, firstly because the heat recovery scheme was not completely monitored in the beginning, secondly because its operation differs greatly from what was assumed within the rating tool, or in other terms, the rating tool lacks the flexibility to accommodate the operation of the plant.

At this stage, the data available both from simulation and from calculation is not enough to draw strong conclusions. Nevertheless it is possible to observe some trends in the consistency of the simulated and the metered data (for the domestic hot water, the PV system) and to identify ways of improving the energy efficiency of the building whilst ensuring comfort. Hence, even if the monitoring process is difficult at the early phase of the operation of a building it is worthwhile and helps to tune the BMS relevantly and more quickly. Furthermore, it helps to define complementary simulation studies for better management strategies.

The combination of monitoring and simulation is essential to the achievement of energy efficiency and comfort in a building.

Conclusion

Green Star rating system aims to give benchmark and rank buildings within a specific frame precisely defined. It considers a broad range of categories for reducing the environmental impact hence pushes in the right direction and it rewards the best practices. The certification process is highly prescriptive and requires a substantial modelling work, amounting, in the case of a complex building like TETB, to about 0.5 AUSD. From the screening of the TETB credits obtained in the different categories we discovered that some essential low energy building features such as daylight and thermal comfort were not weighing much and that no minimum requirements were demanded. Moreover, there is a lack of safeguards in the methodology as it is possible for example to not take into account some overshadowing in the model. The Green Star methodology could be improved by implementing threshold scores for some essential categories, instead of considering only the global score.

The Green Star tool being a benchmark tool, we made the assumption that it would give an estimate (order of magnitude) of the real consumptions of a building. For this particular building, with its specific operation mode, it is not the case; and we found some significant differences for the electricity and the gas consumption largely due to the difference of heating and cooling set points but not only.

Nevertheless this preliminary audit provides a summary of energy usage in the TETB, (unfortunately incomplete because of lack of data) as well as some clues to understand the differences between simulated and metered data. Additionally, it pinpoints achievable savings, and gives an outlook for further simulation work to support the controls and monitoring. The process undertaken in this research reflects the difficulty with comparing simulation data to metered data, due to the disparity in how data is displayed and summarized, uncertainty about assumptions taken in the simulation process, how some of the assumptions differ from the real operation of the building, and the difficulty of obtaining and processing real data.

In this particular case of a University building, the exercise is even more difficult as benchmarks are not readily available and comparing university buildings is typically not possible (different usage patterns, occupancy behaviour, and lab energy intensity and type of labs). In this sense, more data from other university buildings is needed.

Future Prospects

The study of the potential gain on HVAC consumption derived from mitigated heating and cooling set points, for occupied and unoccupied modes, will be soon investigated by simulation.

Once the full monitoring data will be available, the analysis of the performance of the building as a whole as well as in-depth explorations of some specific equipment (tri-generation, absorption chiller, HVAC strategies) will be carried out and contribute to a fuller understanding of the energy efficiency of the TETB.

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