THE CONTRIBUTION OF SIMULATION TO THE BUILDING TUNING PROCESS FOR 2 VICTORIA AVENUE

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ABSTRACT

2 Victoria Avenue is the first building in WA to achieve a 6 Star Green Star rating and a 5 Star NABERS Energy rating.

A modelling process was undertaken for the building, where predicted energy consumption levels for each component of the building's services were derived and compared to the actual building performance.

Over the first 12 months of operation, it was found that the predicted performance of the building was within 3% of the measured overall building usage. Furthermore, it showed the efficacy of the 'what-if scenarios' in identifying and mitigating risk to building performance. Finally, the review also shows the effectiveness of building tuning, with marked energy performance improvements occurring steadily after practical completion of the building.

This paper presents an overview of the modelling process, its influence on design, the commissioning and tuning process and finally reviews the overall building energy performance against industry benchmarks.

INTRODUCTION

Energy modelling for new building developments is becoming commonplace, to the point where it is almost mandatory for any major new office building development.

Energy modelling can influence building design in several ways. The ability to concurrently model several options enables easily to assess design options against each other and consequently optimising the entire design process. Additionally, it is useful as a predictive tool, such that the energy consumption of the building can be predicted, to some degree of accuracy, before the building has even commenced operation.

The building at 2 Victoria Ave undertook the extensive process of building modelling during design, and the consequent predictions of energy consumption were considered to be a benchmark for the levels that the building should achieve in reality. For 2 Victoria Ave, the predicted figures were tracked on a monthly basis against the monitored values.

Actual energy consumption figures were derived from a combination of the electrical meters installed on various distribution boards and the variable speed drives integrated into the building management system. This allowed the energy consumption of each device to the collected which once compared to the predicted consumption will give an indication of the building performance or energy efficiency.

Performing such an analysis enabled diagnosis of any malfunctioning or incorrectly commissioned equipment within the building and thus also assisted with future commissioning and tuning of the building services. This will be further explored throughout this report.

MODELLING PROCEDURE

Software

The energy modelling study was carried out utilising the Integrated Environmental Solutions' (IES) Virtual Environment software package, incorporating the Apache Thermal Software module.

IES has passed the BESTEST validation test and as such conforms to the NABERS Energy software requirements.

Climate Data

The Perth test reference year (TRY) of 1982 was used for this simulation, as specified in the NABERS Energy Guide to Building Energy Estimation. The TRY, which is set by the Chartered Institute of Building Services Engineers (CIBSE), is determined to be a year that is highly representative of the weather of a typical year for a certain location.

It should be noted that a simulation was also run based on 2007 weather data, as means of comparison to potential changes in weather patterns. Although the results are not published in this report, it was found that the energy consumption of the building was less for the 2007 weather in comparison to the TRY, the use of which can thus be considered to be a conservative measure.

3D Simulation Model

The simulation includes a heating, ventilation and air conditioning (HVAC) system incorporated into the model, which closely follows the actual as-selected HVAC system, including controls, for the building.

As a result, the absolute values of energy use obtained from the simulation are a close representation of the expected energy use of the as built building. The building's mechanical plant was designed by AECOM.

The air conditioning plant for the building is a thermally zoned active chilled beam (ACB) system, with a water-cooled cooling system and a gas fired heating plant providing chilled or heated water to air handling units. Each air handling unit serves a single zone on a single floor. Neither electric duct heating nor reheating is provided anywhere in the building. Heat rejection from the chillers is by means of cooling towers. A dedicated tenant condenser water system provides condenser water to the office floor for supplementary air conditioning units as per the requirements of the Property Council of Australia's Grade Matrix.

The Apache simulation software used for the analysis is an advanced dynamic thermal simulation module that is capable of predicting building performance and annual energy consumption. The program is based upon finite difference methods for energy and environmental modelling to model the transmission and storage of heat in the building fabric.

Bulk air movement through infiltration and internal airflow between zones is predicted dynamically as a function of buoyancy. The effects of airflow in and out of the building due to wind, temperature stratification and the opening of windows are also dynamically predicted.

Building Form

The building was modelled completely from basement level and above. The modelling considers window form and location, as well as shading and orientation.

The simulation includes the shading effect surrounding buildings, as required by Section 2.3 of the NABERS Energy Guide to Building Energy Estimation. The building occurs in a built-up area of the Central Business District and consequently the model includes the majority of the surrounding buildings to the site.

A major design feature of 2 Victoria Ave is that is has an active Western façade which prevents direct solar radiation from penetrating onto the Western façade. This shading device works by automating a set of louvres, which shut when there is direct sunlight on them and are open when there is not. Due to limitations in the modelling software, however, it was not possible to model the automation of these shading devices. As such, they were modelled as fixed at their fully open position, which was determined to be the worst-case scenario and this was consequently considered to be a conservative measure.

Figure 1 is a 3D view of the exterior of the building, with shading devices, as created in IES.

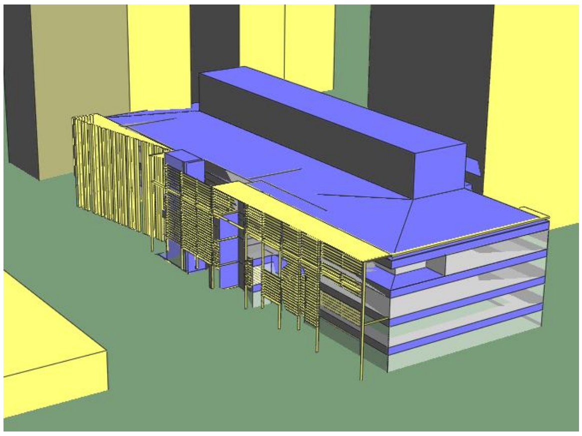

Figure 1 Simulation model, view from South West

Glazing

External glazing installed to the majority of the building is Viridian EVantage Blue/Green double glazing and the glazing type was modelled as such to meet the properties of this glass. The glass only U-value was 1.9, with a Solar Heat Gain Coefficient (SHGC) of 0.45. In addition, the glazing frame was modelled as taking up 10% of the window, which added approximately 20% to the U-value of the total window (including frame) for thermal bridging.

It should be noted that, in reality, the bridging effect of the frame will increase the U-value by a greater factor than this. However, modelling of the 2 Victoria Ave building showed that the energy consumption of the building is actually not largely affected by the U-value of its façade. In fact, an increase in thermal bridging actually served to reduce the overall air conditioning load of the building, since it allows the heat generated from the significant overnight loads being more easily able to escape the building.

This is possible just an anomaly of energy modelling based on the NABERS Energy protocol, since this specifies 50% of equipment load to remain on overnight.

Insulation

Insulation was modelled to match the levels as specified in the design specifications for walls, floors, ceilings and roofs. All construction types comply with the minimum Building Code of Australia (BCA) 2009 criteria. For the external walls, this was 50mm of mineral fibre slab and 75mm glass fibre quilt insulation on the roof. This is equivalent to R1.8 and R3.2 insulation for the

Floor Area

Table 1 provides a summary of the modelled floor by floor net lettable areas as compared to those specified architecturally. The modelled Net Lettable Area (NLA) for the building and system design is

7178.61m^2. It can be seen that each floor is within 2.6% of the architectural floor areas.

Table 1
Area Comparison between modelled and measured.

FLOOR	ARCH. AREA (M^2)	MODELLED AREA (M^2)	% CHANGE
Ground	1695	1716.93	1.29%
First	1665	1691.19	1.57%
Second	1895	1928.79	1.78%
Third	1795	1841.7	2.60%
TOTAL	7050	7178.61	1.82%

Although the lobby areas are air-conditioned in the HVAC system, as per the Mechanical design, these areas have not been included in the overall NLA as they are not deemed to be NLA in accordance with the PCA's Method of Measurement. These lobby areas do, however, support the function of Class 5 areas and as such its energy consumption must be included in this analysis so as to conform with the NABERS Energy Guide to Building Energy Estimation.

All other areas that are not considered Class 5 commercial office areas, such as the basement retail section, were excluded from the NLA for the purpose of estimating the NABERS Energy performance of the building. The building's sub metering system reflected this, enabling a clear delineation to be made between the energy used by the Class 5 areas as distinct from other areas.

Building Envelope Infiltration Levels

The level of infiltration between the building's envelope and the external environment can have a large effect on the performance of the building. A well-sealed external envelope will minimise heat losses/gains and therefore reduce the energy consumption of the air conditioning plant. It is a necessity for the Mechanical Design that the building be tightly sealed so that the Active Chilled Beams can properly function.

The simulation models a constant air infiltration rate from ambient conditions of 0.25 air changes per hour for all perimeter spaces, with infiltration levels of 1.0ACH to lobby spaces.

Ancilliary Energy Consumption

In addition to the energy consumption of the building's air conditioning plant, which is predicted by the modelling process, allowances were made through the modelling process for all other base-building energy consuming elements. This includes:

- Base building lighting
- Domestic hot water
- Lifts
- Sundry HVAC
- Diesel Generator
- Tenant Condenser Water Loop

The energy consumption of all of these items were tracked against the predicted figures. However, since these numbers were not derived from the energy modelling process, this is excluded from this report.

INTERNAL LOADS

The NABERS Energy protocol specifies default internal loads and profiles to be input into the model in order to simulate the loads within the building during operation. These loads are outlined below.

Equipment

The NABERS Energy protocol requires the internal loading to be randomised across floors to include some areas with 5W/m^2, 7W/m^2, 11W/m^2, 15W/m^2 and 19W/m^2 at a ratio of approximately 1:2:2:1:1. This ensures a diversified load of approximately 11W/m^2.

Lighting

For the purpose of determining the base building HVAC plant energy consumption, the lighting load in the building's office areas was modelled as 8.5W/m2, which includes a 2W/m2 allowance on the calculated 6.5W/m2 for the office zones. Similarly, the lighting levels in the lobby areas is modelled at 10W/m2. 40% of these loads was applied to the occupied space, with the remaining 60% assigned to the ceiling plenum.

The base building has high standards of lighting control, meaning that lights are highly unlikely to be left on overnight. Consequently, the NABERS Energy default 'Automated time of use control' schedule was used.

People

The average occupant density (for energy consumption) was set at 15m2/person, and the occupancy hours are set to the default schedule as specified in the NABERS Energy Guide to Building Energy Estimation. The occupancy loads were assumed to be 70W/person of Sensible Heat and 60W/person of Latent Heat.

HVAC SYSTEM

The HVAC system modelled for the building is a thermally zoned active chilled beam system, as per the mechanical design. The simulated air conditioning central plant includes two water-cooled chillers, four associated chilled water pumps, three cooling towers, two condenser water pumps and thirty-two chilled-water constant air volume air handling units (AHUs). Additionally, there are 2 additional Fan Coil Units installed to serve the double height lobby areas on the Ground floor.

The AHUs supply air to active chilled beam induction units in the central and perimeter zones. Natural gas-fired boilers provide supply air heating in the AHUs.

There are seven exhaust fans serving the carpark and toilets, two tenant exhaust fans and a total of eight outside air fans in the building.

There is a tenant supplementary condenser water system which has two condenser water pumps and a separate cooling tower.

The HVAC system is modelled as per the Mechanical schedules, including coil capacities and air flows as specified in the schedules. The chillers, boilers, cooling towers and related pumping systems were also modelled with part load COP's, energy consumption figures and efficiences which correlate strongly to manufacturer's data.

HVAC CONTROL STRATEGIES

AHU Cooling Coil

ON if:

- Room air temperature of any zone served is > 24°C (with 0°C deadband); OR
- Relative humidity in any zone supplied by AHU is >70% (with 0% deadband); OR
- The off-coil relative humidity within any Active Chilled Beam served by AHU exceeds 95% (with 0% deadband).

If the AHU has the call for cooling, the AHU cooling coil supplies air at the nominated supply air temperature.

AHU Heating Coil

ON if:

- Room air temperature of any zone served is <20.5°C (±0.5°C)

If the AHU has the call for heating, the AHU heating coil supplies air at the nominated supply air temperature.

ACB Cooling Coil

On if:

- The temperature of the zone served by ACB is > 23°C (with 0°C deadband)

If the ACB has the call for cooling, the ACB cooling coil supplies air at the nominated supply air temperature.

MODELLING CONSERVATISMS

A 5% margin was included onto the modelled calculation for the energy consumption figures for the Chillers, Fans, Pumps and Heat Rejection. This allowance is there to account for factors such as control errors, hysteresis, the degradation of equipment over time and manufacturer's performance optimism.

However, it should be noted that there are already inherent margins in the model itself. The Cooling Tower Fans, Chilled Water Pumps and Condenser Water Pumps have been modelled based on motor size, not absorbed power. Additionally, the modelled Chillers do not take into account condenser water relief, which should only serve to improve its performance.

The Supply and Outside Air fans modelled in the HVAC were specified with a constant 55% efficiency. However, 2 Victoria Ave system is a constant flow system, and as such the fans should be operating close to peak efficiency at all times, which is likely to be greater than this. Additionally, since it is a constant flow system, no allowance must be made for VSD losses. As such, this assumption is assumed to be a conservative measure.

A 40% margin was allowed on the boiler energy consumption. This accounts for the operation of the boilers typically cycling on-off, generally early in the morning. Once the boilers are switched off, there remains hot water within the pipework, the heat from which dissipates and is wasted.

ENERGY COVERAGE

The energy coverage for the purposes of this assessment is all base building house services. It does not include tenancy lights, small power, supplementary exhaust, or make up air systems. These will be installed & provided by the tenant and wired to the tenant distribution boards.

MODELLING RESULTS

In accordance with the NABERS Energy's Validation Protocol for Energy Simulations, a base case analysis was undertaken whereby the systems were simulated in accordance with the design parameters and controlled. The energy consumption, resultant greenhouse gas production and projected NABERS Energy Star Rating of the Base Case Analysis. The Cooling, Heating, Fans, Pumps and Heat Rejection Energy usage are imported directly from the Apache Energy Model.

Entering the results from this into the NABERS Energy calculator yielded a 5 star NABERS rating with 55 kg CO2/m2 p.a of normalised CO2 emissions, which represents a 21% improvement on the cutoff mark of 70kg CO2/m2 per annum to achieve a 5 star rating.

A breakdown of the CO2 emissions from each of the energy consumimg components of the building is displayed in Figure 2.

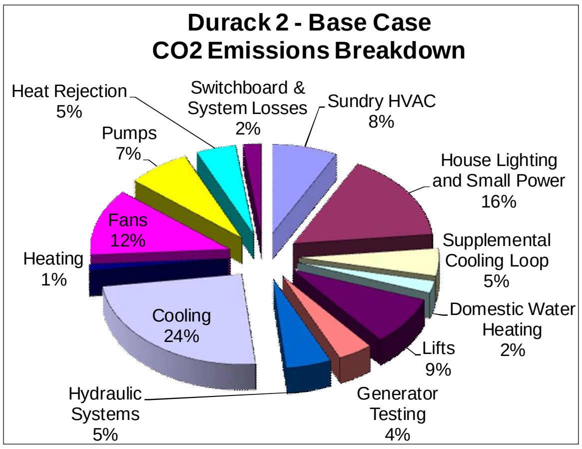

Figure 2 Emissions breakdown pie chart

Off-Axis Results

Six off axis scenarios were analysed investigating a series of off axis parameters bringing faults to the base building systems. The Off Axis Scenarios that were simulated were:

- Increased Overnight Loads
- Small Tenancy Running 24/7
- Increased Fan Pressure
- Increased Equipment Loads
- 75% Occupancy
- Increased Infiltration
- Combined Off-Axis Scenario

The combined off-axis scenario is supposed to simulate an absolute worst-case of the building's operation. Nonetheless, it was found that the building still was able to achieve a 5 star NABERS rating with 69 $kgCO_2/m^2$ p.a. of normalised CO_2 emissions. As such, there was a ~25% increase in the CO_2 emissions when compared against the base case. Although this increase is significant, the building still achieves the 5 Star rating with a 1% margin over the 5 Star NABERS Energy cut-off. As such, the energy modelling of the 2 Victoria Ave development showed that the building design was capable of meeting a 5 Star NABERS Energy base building rating, indicating that the design of the building was very robust.

TRACKING AND MONITORING

Consequently, the energy modelling process showed that the building was assessed as theoretically capable of achieving a 5 Star NABERS Energy rating. However, an 'actual' NABERS Energy rating is assessed on the building's energy performance, derived from its electricity and gas consumption for a 12 month period.

Actual energy consumption figures were be derived from a combination of the electrical meters installed on various distribution boards and the variable speed drives integrated into the building management system. This allowed the energy consumption of each device to the collected which once compared to the predicted consumption will give an indication of the building performance or energy efficiency.

The level of submetering in the 2 Victoria Ave allowed the tracking of individual energy usages, so that they could be compared to their modelled values.

MONITORING RESULTS

AECOM's role

Predicted Cumulative Energy Consumption

The predicted cumulative energy consumption for the 2 Victoria Ave base building services was plotted against the actual cumulative base building energy consumption as shown in Figure 3. This gives a direct comparison between the predicted and actual figures ever since 76% occupancy of the building was achieved. Figures have been adjusted for the occupancy rate and after-hours component.

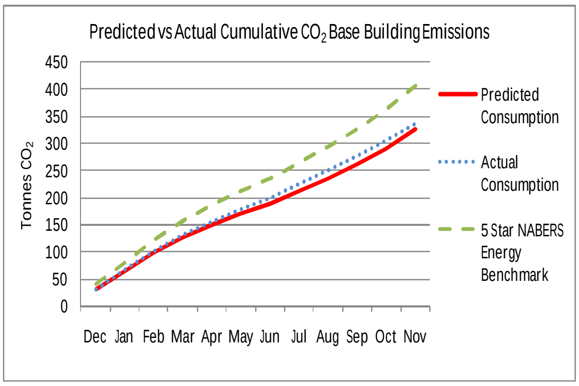

Figure 3: Predicted Cumulative vs. Actual Energy Consumption (Rating Period, Occupancy & Hours Adjusted)

The building is well below the cut off benchmark to achieve the 5 Star NABERS Energy rating and tracked well with the predicted figures. Care must be taken to ensure that excess energy is not used in the building's operation, which could jeopardise the building's NABERS Energy rating.

Predicted Monthly Energy Consumption

The predicted CO_2 output of the building was plotted against the actual measured performance for the December – November period, as given in Figure 4 As was shown in the cumulative graph, it can be seen that the building tracked closely to the predicted consumption.

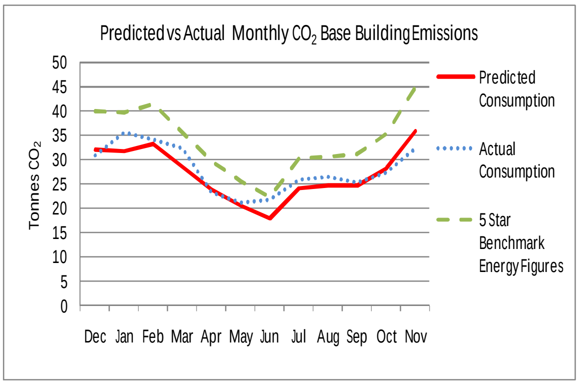

Figure 4: Predicted vs. Actual Cumulative Base Building Energy Consumption (Occupancy & Hours Adjusted)

Base Building Occupancy Adjusted Summary

A tabulated summary of these results (from December 2009 onwards) is given in Table 2. In these figures, the modelled emissions were occupancy and hours adjusted to match with the measured number of after hours and building occupancy percentage.

Table 2
Area Comparison between modelled and measured.

DATE	MODELLED EMISSIONS (TONNES CO2)	BMS MEASURED EMISSIONS (TONNES CO2)	% DIFF
Dec 09	31.9	31.0	-3%
Jan 10	31.7	35.5	12%
Feb 10	33.2	33.9	2%
Mar 10	28.5	32.4	14%
Apr 10	23.8	23.2	-3%
May 10	20.5	21.3	4%
Jun 10	17.9	21.7	21%
Jul 10	24.1	25.9	7%
Aug 10	24.6	26.5	8%
Sep 10	24.8	25.2	1%
Oct 10	28.2	27.4	-3%
Nov 10	35.9	32.4	-10%
TOTAL	**325.1**	**336.3**	**3%**

From the period of December 2009 – November 2010, the cumulative total of the building has been operating at 3% higher than the modelled emissions. Although it is of some concern that this number is higher than modelled, this is considered to be well within the margin of accuracy of the modelling process, and well within the 5 Star NABERS Energy cutoff margin

COMPONENT RESULTS

Heating and Cooling Plant

The energy consumed by the water cooled chillers and gas-powered boilers servicing the building's air conditioning plant are given in Figure 4 and Figure 5.

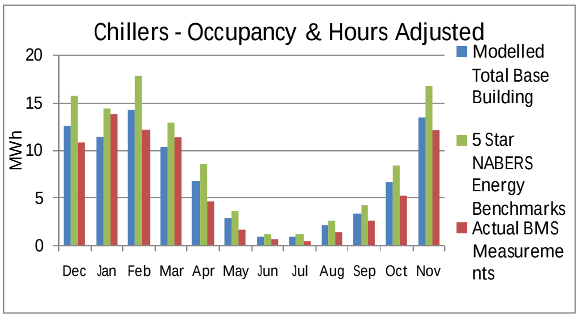

Figure 4: Modelled vs. Actual Chiller Energy Consumption

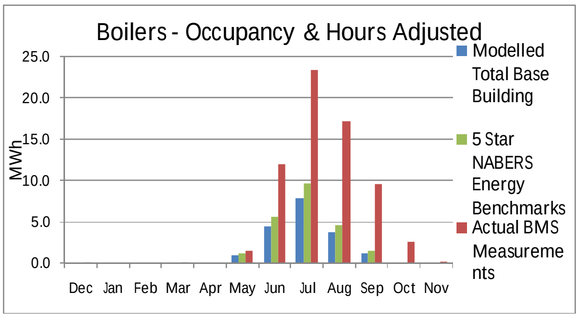

Figure 5: Modelled vs. Actual Boiler - Energy Consumption

Energy consumption associated with the chilled water plant has approximately followed the modelled values for each month, despite the summer of 2009/10 being the hottest on record. The measured overall chillers energy consumption was approximately 10% less than what was predicted by the energy model, suggesting that the conservatisms in the model were sufficient in providing a large enough safety margin for the chillers.

However, the energy consumption of the boilers has been consistently been higher than expected for the Winter months, as well as in Spring. For all other month, however, this is almost negligible, since there is virtually no heating required for six months of the year.

These results would appear to be indicative of a cooler winter than usual. However, the mean maximum temperatures for Perth throughout the winter in 2010 were higher than average. Possibly a major contributor to this was that the average minimum temperatures were cooler, meaning that during the peak early morning warm up period, the temperatures were generally cooler and the boilers were required to work harder and for longer. Additionally, the cooler overnight temperatures would allow the building to cool down more overnight, compounding this effect.

Additionally, the modelling process allows for significant overnight lighting and equipment loads, accounting for lights and computers not being switched off after hours. It is possible that the actual overnight loads are less than this in reality. Consequently, the building may be cooling down significantly more at night than predicted, also accounting for a reduction in overall building cooling, particularly in reducing the early morning start-up peaks.

Air Handling, Cooling Tower & Outside Air Fans

The energy consumption associated with the air handling units, cooling towers and outside air fans is given in Figure 6.

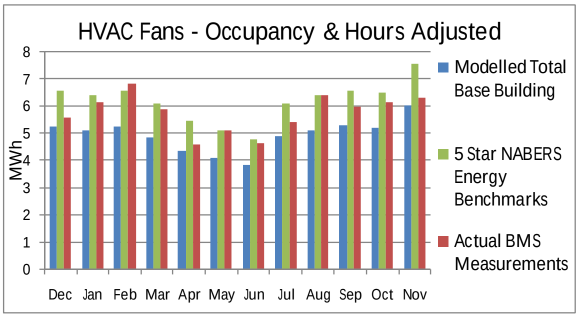

Figure 6: Modelled vs. Actual AHU, Cooling Tower & OA Fan Energy Consumption

The HVAC fans energy consumption has tracked pretty well for most months with the predicted values. It has exceeded the modelled consumption for November, but is still slightly less than the 5 Star NABERS Energy benchmark, despite the cooling energy consumption being lower than predicted. It would be expected that a reduction in cooling would result in a reduction in the fans energy usage, given that the consumption of the cooling tower fans, in particular, should reduce accordingly.

However, given the historical trend for these to track approximately in accordance with the modelled values, the slight increase of the fans over the predicted figure does not seem to be a major concern.

Pumps

The chilled water, condenser water and heating water pump energy consumption is displayed below in Figure 7.

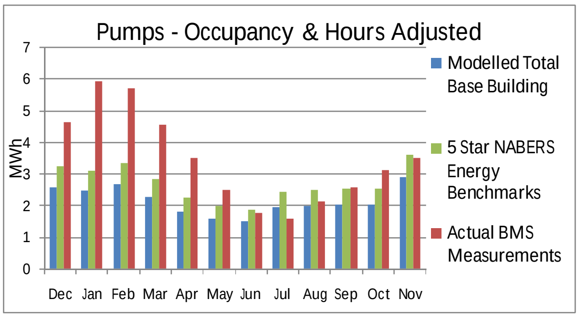

Figure 7: Modelled vs. Actual CHW, CCW & HW Pump Energy Consumption

The pumps energy consumption has increased above the 5 Star NABERS Energy benchmark figures in November. The trend for the pumps energy consumption appears to be higher than predicted during the hotter months, and slightly lower than predicted during the cool, winter months. Given that November is a precursor for the warmer months, it is slightly concerning that the pumps energy has again crept above the modelled values.

THE CONTRIBUTION OF SIMULATION TO BUILDING TUNING

Given that the energy results for individual components was tracked monthly, large spikes in the consumption of a particular item was quickly highlighted and enabled a quick investigation and resolution of any potential issues that arose. Then energy consumption of the pumps is a prime example of this.

It can be seen in Figure 7 that, for the first few months of the energy tracking process, the energy consumption of the chilled and heating water pumps were consistently exceeding the predicted levels.

Consequently, an investigation was carried out and it was discovered that the pumps were running for far longer than was expected. The average weekday hours of operation of the pumps (excluding the heating water pumps) is summarised in Table 3.

Table 3
Pump average weekday hours of operation.

MONTH	CHWP-1	CWP-1	CHWP2	CWP2
February	20.55	18.5	5.6	4.75
March	10.26	9.57	6.91	6.35
April	7.50	7.14	6.86	6.45
May	6.19	6.00	4.81	4.43
June	4.09	4.00	2.95	2.86
July	4.43	4.33	3.38	3.33
August	5.48	5.38	4.48	3.10
September	6.00	5.86	4.55	4.45
October	7.38	7.29	5.62	5.48
November	7.73	7.55	6.59	6.32

It can be seen that the pumps, especially in February, were running for particularly long hours, accounting for a much greater than expected energy consumption. It is additionally possible that the pumps were running on weekends, which skews these numbers slightly.

Once this was highlighted, the operation of the pumps was reviewed and rectified, to the point where for the latter 6 months of building tracking, the pumps were operating in almost exact accordance with the modelled predictions. Consequently, the modelling and tracking process was able to identify a major problem with the running of the building, with a consequence that both energy and cost savings were provided to the client.

Similar improvements were also observed with the house lighting energy use. However, hese results are not presented here since the house lighting predicted energy usage was not derived on the basis of a building simulation, rather a simple calculation based on the energy consumption of individual light fittings and expected time of use.

CONCLUSION

A detailed building simulation model of the 2 Victoria Ave building development in the Perth Central Business District was undertaken, from which predicted levels of energy consumption of the building's air-conditioning plant were derived.

These levels were compared on a month-by-month basis against the metered energy consumption for individual components for 12 months, from the period when the building commenced its operation with at least 75% of its area occupied.

Analysis of the results indicates that the base building has consumed only slightly more energy on a cumulative basis since December 2009 than was predicted by the building simulation. For the first 12 months of operation of the building presented in this paper, the difference between the predicted and measured figures was only 3%.

Consequently, this highlights both the accuracy of building simulation as well as its contribution to ongoing monitoring and performance. Through the comparison of predicted component energy levels with predicted levels, excess energy sources were able to be identified and rectified.

The 2 Victoria Ave building was pre-committed to a 5 Star NABERS Enery rating based on the initial energy modelling process, which is the highest rating that a building can achieve under this tool. The tracking process has verified the relevance of the simulation, and given light to the previously "black-art" of building modelling. Additionally, it has also highlighted some areas where the modelling process can be reviewed, such as the high overnight equipment loads, which are more than likely overstated, particularly in new and energy efficient buildings and management systems.

ACKNOWLEDGEMENTS

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