

THE USE OF SIMULATION SOFTWARE FOR BUILDING PERFORMANCE ASSESSMENT IN EXISTING COMMERCIAL BUILDINGS WITH HERITAGE VALUES

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ABSTRACT

This paper explores the use of building performance simulation software in assessing the building performance of two existing commercial buildings with heritage values in Australia.

The research found that the differences between the simulation results and the NABERS assessment (a national rating system that measures the environmental performance of Australian buildings) ranged from 30% to 80% for electricity usage, and about 350% for natural gas usage. The outcome suggests that some uncertainty exists in the assessments and that these could be due to assumptions used in the operational energy modelling of the case study buildings when on-site information was not available.

INTRODUCTION

In 2011, the Department of Planning and Community Development of the State of Victoria for the Heritage Chairs and Officials of Australia and New Zealand (HCOANZ) sought to better understand the life-cycle environmental impacts of commercial buildings with heritage values. In response, RMIT University employed the life cycle assessment (LCA) methodology to quantify and compare the potential life-cycle environmental impacts of a sample of commercial buildings with heritage values in their existing state and after energy efficiency interventions. The findings of the life-cycle assessment study are reported elsewhere. This paper focusses on the outcomes of the buildings' operational energy modelling undertaken as part of the overall project scope. The findings may provide useful references for the energy efficiency assessment of older commercial buildings as case studies of the energy efficiency of heritage commercial buildings were found to be rare.

The building sector accounts for 19% of Australia's energy consumption and around 23% of the greenhouse gas emissions (DCCEE, 2010). In 2005, commercial buildings in Australia were responsible for 10% or 26 megatonnes (Mt) of the nation's greenhouse gas emissions. The Centre for International Economics has noted that energy end use for the commercial sector has nearly tripled since

the 1970s (Centre for International Economics, 2007).

A number of publications highlight the need for more comprehensive information with respect to existing non-domestic building stock typology, distribution and energy use in order to inform future policy formulation (Bruhns, 2008, Lam, 2000). Research has shown that energy consumption in commercial buildings is complex due to the wide range of building fabrics and mechanical systems employed (DCCEE, 2010, DEWHA, 2008, Kofoworola and Gheewala, 2009, Haase et al., 2010).

In order to better understand the operational impacts of heritage buildings within the wider context of the HCOANZ study, the main operational energy loads, that is heating, cooling, lighting, appliances and lift use, were investigated. Energy modelling was used to explore the operational energy use of the case study buildings in their existing state (base case) and in case when energy efficiency measures were implemented. Occupancy behaviour and their impacts did not form part of this research. The findings of this study may therefore inform a better understanding of the challenges involved in analysing the energy demand of commercial buildings with heritage value.

A key outcome of the operational energy analysis was the significant discrepancy between the outcomes of the simulated base case scenario and those derived from utility billing data. This paper investigates these discrepancies for two of the four case study buildings considered in the HCOANZ project. The paper also identifies lessons learnt and strategies that could be used to improve the building simulation results in future.

METHODS

Two case study buildings were selected from buildings constructed between the 1870s and the 1960s.

The first case study is the Lands Department Building in Sydney. The building is an example of the Free Victoria Classical Style of the 1870's. The building footprint covers a whole city block of about 3300m². The office spaces are grouped along the perimeter with the corridors arranged around two

central courtyards. A dome and a clock tower dominate the four-storeyed building form. The building's main construction materials are stone and brick. The load bearing façade is punctuated by single glazed timber windows. The second case study, the Treasury Building in Melbourne, is a 16-storey high-rise tower, built in the 1960's. In the

typical fashion of the International Style movement it consists of a concrete frame and glass façade. The square floor area (27m x 27m) provides large open plan offices around a central service core. Table 1 below summarises the characteristics of the case study buildings.

Table 1 Case study building's characteristics

	Era	Gross Floor Area, m ²	Net Lettable Area, m ²	No. of Storeys	Roof	Glazing	Walls	Skylights
Case Study								
Lands Department Building, Sydney	1870s	13,998	7,470	4	Slate metal and flat	Single clear float	Stone block, single brick and plasterboard	Single glazed
Treasury Building, Melbourne	1960s	11,127	9,382	16	Concrete and flat	Single clear float	Concrete, uninsulated	None

The building simulation software VE-Pro by Integrated Environmental Solutions (IES) was used to predict the annual operational energy demand for the case study buildings. The software takes into account a building's geographical location, its geometry and orientation of its three-dimensional form, the thermal qualities of the building materials, the type and efficiencies of the heating, cooling, hot water systems and lighting elements as well as internal heat gains from appliances, such as computers, and the building's occupants. The software main module ApacheSim was used to perform numerous dynamic thermal simulations. The building modelling process included the following tasks:

- Constructing the three-dimensional model of the building using the ModelIT module.
- Modelling of surrounding environment.
- Assignment of materials and thermal properties to construction elements.
- Assignment of thermal conditions properties to various rooms/spaces.
- Assignment of operating systems.
- Assignment of site and natural ventilation parameters.

In addition, the operational energy use of the case study buildings was rated using the National Australian Built Environment Rating System (NABERS). NABERS is a national rating system based on the actual operational energy performance of an existing building. The rating (from one to six stars) is derived by converting the measured energy data obtained from utility bills. A six star rating demonstrates market-leading performance while a one star rating means the building has considerable scope for energy improvement.

A) Data collection

The accuracy of building energy simulation results is largely dependent on the accuracy of the information input. Hence, the building owners were surveyed to provide key information on the buildings' dimensions, geometry, layout, construction materials, operational systems and fuel choice. A complete set of plans of the buildings was requested and a comprehensive questionnaire on the use of the building, its fixed appliances and heating and cooling systems was distributed. In general, building owners were able to provide the buildings' floor plans, however sections and elevations were often missing. Where insufficient information on building sizes was available, the researchers determined the main measurements on site or made informed assumptions. A quantity surveyor consultant was engaged to determine the construction types and the nature of the materials. In general, the building owners provided very limited information on the buildings' operational systems.

As the overshadowing of windows by vegetation and neighbouring buildings influences solar heat gain, it was necessary to consider the buildings' surrounding context. The size and height of adjacent structures were estimated by taking recourse to images of the buildings and their environment from the Internet.

While comprehensive utility bills are needed for the NABERS rating, they were not easily obtained. In the case of the Treasury Building in Melbourne, only combined energy bills of the case study and an adjacent building were available. The adjacent building, which was built at the same time, in the same style and from the same construction materials, was found to have similar usage i.e. office building with sole occupancy, as the case study building. Hence, according to the NABERS audit protocol, the energy consumption for the two buildings was proportioned according to their net lettable area. It

was not possible to verify the actual energy consumption of the case study building as there is no sub-metering for any of the two buildings.

B) 3-D modelling

ModelIT, which is a module of the IES VE-Pro package, allows the operator to construct three-dimensional models of the buildings. Buildings are usually constructed floor-by-floor using the module. As the manual co-ordinate input quickly proved too tedious and time-consuming, the use of attaching .dxf drawing files was explored and found to be helpful in time saving in the 3-D modelling. The building paper drawings, as supplied by the building owners, were scaled and dimension lines for the rooms and positions and sizes of openings were added. The width and breadth of rooms were measured to the middle of joint walls. These sketches were transferred into AutoCad drawings. Figures 1 and 2 shows the case study buildings as modelled in IES VE-Pro software.

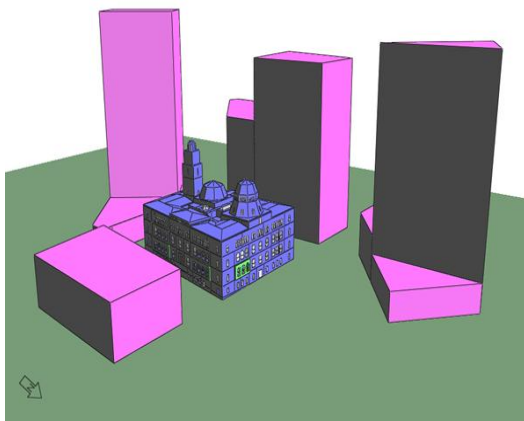


Figure 1 Model image of the Lands Department Building in Sydney

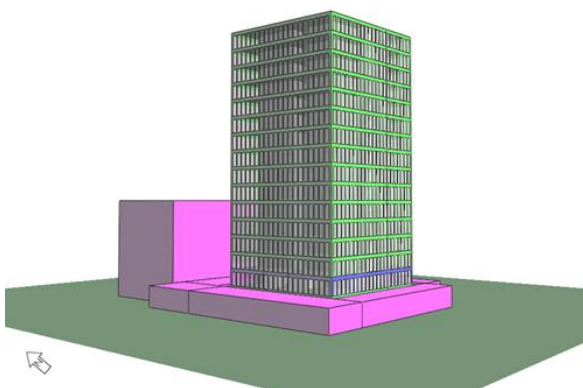


Figure 2 Model image of the Treasury Building in Melbourne

C) Assignment of building materials, thermal properties and conditions to construction elements and rooms

In the ApacheSim module, building specific construction elements were built from the pre-designed system materials database according to the specifications supplied by the quantity surveyor.

Adjustments were made to the specifications for glazing. The software default value for the Total Shading Coefficient (SC) of 0.9 was deemed too high for the timber frame single glazed windows used in the Sydney building. In Australia, solar heat gain coefficient (SHGC) is used in the glazing industry rather than SC. SC may be converted to SHGC by multiplying the value by 0.87 (ASHRAE, 2009). The single glazed, timber frame windows, as used in the Lands Department Building, was calculated to have a U-value of 5.56 W/m²K. A search on the Australian Windows Energy Rating Scheme website (www.WERS.net) for commercial windows with this U-value revealed the highest SHGC of 0.69. Using the conversion formula $SHGC = SC * 0.87$, a value of 0.79 for the Total Shading Coefficient (SC) was calculated to be used in the building model. Therefore, in the 'glazing parameter input form' of the software, the transmittance of the window was manually changed to 0.61. The software automatically adjusted the SC to 0.79.

The labelling of the rooms according to function facilitated the allocation of specific thermal condition templates. For example, all roof spaces and garages were assigned to an 'unheated space' thermal template in which the heating and cooling profile was set to be continuously off.

The software also allowed the customisation of the lighting, equipment and occupancy profiles. As building specific information was not available, the profiles for occupancy, lighting and equipment use were based on the schedules of the NABERS Energy – Guide to Energy Estimation for Computer Simulations (Department of Environment Climate Change & Water, 2009). Figure 3 below shows the appliances and equipment profile used in the modelling.

The values for the internal heat gain through human occupancy were adjusted in the software input parameters since the number of occupants per building was known. The default occupant density is 1 occupant per 15m² of office space and a sensible heat gain of 75W/person. Adjustment was required in order to reflect the actual occupancy in a building. For example, in the case of the Lands Department Building, the software calculated that the building was accommodating 717.02 occupants. Since the NABERS audit had revealed an occupant population of only 375 people, the value for the occupancy sensible heat gain was adjusted to 39W/person. The software automatically adjusted the occupancy latent heat gain accordingly.

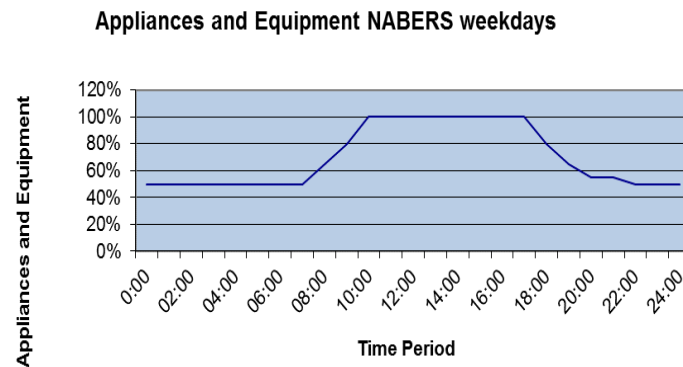


Figure 3 Appliances and equipment use profile according to the schedule of NABERS Energy – Guide to Energy Estimation for computer simulations

D) Assignment of operating systems

Due to lack of detailed knowledge about the buildings' operational systems, educated guesses about the nature and efficiency of the HVAC systems were made. In general, it was assumed that all buildings were conditioned by an inefficient central HVAC fan coil system. It was assumed that natural gas was used for space heating with the heating set point at 19°C. It was assumed that electricity was powering the central air-conditioning plant with a chiller set point at 23°C. The temperature setting of 19°C for heating and 23°C for cooling were considered a reasonable assumption as they fall within the temperature range of 18°C to 26°C, a standard parameter used to model air-conditioned reference buildings according to the Building Code of Australia Section JV3 (ABCB, 2010). The software locates the temperature sensors for its HVAC systems simulation at the centre of the room. The HVAC systems were assumed to possess unlimited power. Constant efficiencies were assumed for both the heating and cooling systems. External climatic data was provided using real data from the nearest weather station.

E) Assignment of site and natural ventilation parameters

SunCast and MacroFlo are additional modules of the IES software, which are able to take account of the effects of solar shading and of natural ventilation in the dynamic simulation.

The SunCast module manages the impact of the shading provided by neighbouring buildings and building integrated shading on the energy demand of the building. SunCast considers the date, time, orientation, as well as the site latitude and longitude (Figure 4). Daylighting effects on lighting use and subsequent impacts were not included in the simulations. The effects of trees and their shadows were not considered.

The effect of natural ventilation was modelled with the help of MacroFlo module. The windows in all buildings were modelled to remain permanently closed. This was because the building owners reported that either the windows were not designed to be openable or that the occupants kept the windows closed throughout the year. Holes in the external envelope, as encountered in the Lands Department Building in Sydney, were modelled as doors and assigned to be always open when using the MacroFlo module.

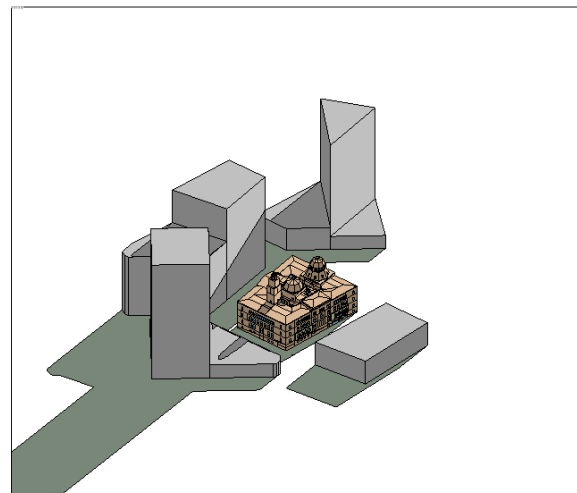


Figure 4 SunCast image showing the shadows of the Lands Department Building and its neighbouring buildings in the afternoon 15th June

F) Running of the thermal simulations

After all parameters had been assigned to the building model, the dynamic thermal simulation was run. A simulation period of one year was selected with a simulation time step of 10 minutes and a preconditioning period of 10 days. While default values of time steps vary between software packages, a simulation time interval of 10 minutes is recommended by the IES guidelines (IES, 2010).

Table 2 Parameters used in the building energy modelling

Buildings/ Input parameters	Lands Department Building, Sydney	Treasury Building, Melbourne
NLA (m2)	7470	9382
Air leakages through envelope	0.35 air changes per hour; big openings in ground floor towards internal courtyard	0.35 air changes per hour
Roofs	Slate copper and metal roofs; 100 mm insulation U = 0.551 - 0.571 W/m2K Flat (metal) roof; 100 mm insulation U = 0.571 W/m2K	Flat roof; insulated: U = 0.288 W/m2K
Glazing	Single clear float glazing, timber frames; U-values 5.56 W/m2K; SHGC 0.69	Single clear float glazing, metal frames; U-values 5.716W/m2K; SHGC 0.69
Façade/ walls	Ground Floor to Fourth Floor: Stone/brick wall U= 1.4247 W/m2K Fifth Floor: Single brick/ plasterboard wall U= 2.6164 W/m2K Sixth Floor: Single brick wall U= 3.3228 W/m2K Clock Tower: Stone wall U= 2.2562 W/m2K	Concrete, uninsulated; U= 2.0 W/m2K
Skylights	Single glazed, metal frame; U incl. frame = 6.8192 W/m2K; SHGC 0.69	None
Floors	Uninsulated concrete ground floor; timber joist floors	Uninsulated concrete floor; U-value 2.28 W/m2K
HVAC system	Ground to second floor: Fan coil system Third floor and above: Multi-split system	Fan coil system
Chiller	Cooling system - airconditioning Fuel: electricity Generator nominal EER 3.125 Generator seasonal EER 2.5 SSEER 2.00	Cooling system - airconditioning Fuel: electricity Generator nominal EER 3.125 Generator seasonal EER 2.5 SSEER 2.00
Chiller setpoint	23 ° C	23 ° C
Boiler	Ground to second floor heating: Fuel: Natural Gas Generator seasonal efficiency 0.8 SCoP 0.8 Third floor and above heating: Fuel: Electricity Heat pump Generator seasonal efficiency 2.5 SCoP 0.7548	Fuel: Natural Gas Generator seasonal efficiency 0.8 SCoP 0.8
Hot water consumption	0.5 litres per person per hour	0.5 litres per person per hour
Hot water supply	Electric DHW: Heat pump Seasonal efficiency 2.5 SCoP 0.8 DHW delivery efficiency 0.8 120 litres storage system	Central boiler
Lighting	T8 power consumption 12 W/m2 NLAMax. Sensible gain 12 W/m2 Variation profile according to NABERS Artificial Lighting, limited control	T8 power consumption 12 W/m2 NLAMax. Sensible heat gain 12 W/m2 Variation profile according to NABERS Artificial Lighting, limited control
Appliances and equipment	Power consumption 11 W/m2 NLA according to NABERS guide; Max. sensible heat gain 11 W/m2 Variation profile according to NABERS guide	Power consumption 11 W/m2 NLA according to NABERS guide; Max. sensible heat gain 11 W/m2 Variation profile according to NABERS guide
Natural ventilation through windows	Windows always closed	Windows always closed
Lifts	Energy use 8 W/m2 NLA according to NABERS guide	Energy use 8 W/m2 NLA according to NABERS guide

A shorter 5 minutes time step is considered suitable to simulate short-term occupancy (Bourgeois, Reinhart & Macdonald, 2006). For the purpose of this study, a 10 minutes time step was considered best suited to the office occupancy pattern (da Graca, Linden & Haves, 2004, Loutzenhiser et al., 2006) and to be manageable in terms of simulation time within the time constraints of the project. Table 2 summarises the parameters used to model the case study buildings.

The results for the simulations were tabulated in the software's Vista application. For a comparison with the billing data as obtained from the NABERS audit, the most important values were the buildings' demands for total natural gas and the total electricity. As the software does not take into consideration high-energy use appliances, the energy demand for lifts was estimated by using the default value in the NABERS Energy – Guide to Energy Estimation and added manually to the simulation results.

G) NABERS assessment

All case study buildings underwent a NABERS Energy assessment. NABERS currently addresses energy and water consumption as well as waste management and indoor environment quality. The building ratings for each criterion are expressed as stars, ranging from 1 to 6 stars with half star increments. A NABERS 2.5 stars rating denotes an average performance. For this research project, only the buildings' energy and water consumption were assessed according to the NABERS rating tool. Only the energy (heating and cooling) results are discussed in this paper.

RESULTS AND DISCUSSION

A) Building energy simulation results

The Lands Department Building in Sydney has been built out of stone and brick with insulated metal roofs. The punctuated façade has single glazed timber windows. The ground floor corridor has large, unglazed openings into the courtyards, which are open to the elements.

The building is equipped with two different HVAC systems. The Ground to Fourth floors are conditioned by a central HVAC fan coil system. Cooling is assumed to be provided by a central air-conditioning plant fuelled by electricity. From the Fifth floor upwards, the rooms are conditioned by a multi-split system. Figure 5 below shows the IES operational energy simulation results for the building. Cooling, was found to account for about a third of the building's energy consumption, followed by office equipment and lighting which were found to be each responsible for about a quarter of the energy demand.

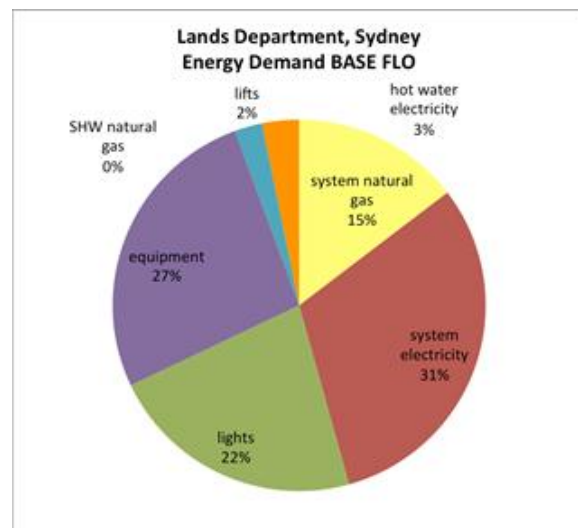


Figure 5 Operational energy simulation results for Lands Department Building

The Treasury Building in Melbourne is a 16-storey high-rise building with a concrete frame, a flat

concrete roof with some assumed insulation and a predominantly glazed facade.

The building was assumed to be conditioned by a central HVAC fan coil system. Space heating and hot water was assumed to be provided by a central boiler fuelled by natural gas. Cooling was assumed to be provided by a central air-conditioning plant fuelled by electricity. Figure 6 below shows the IES VE-Pro operational energy simulation results for the building. Cooling and office equipment were found to each account for about a third of the building's energy consumption. Lighting was found to be responsible for a quarter of the energy demand.

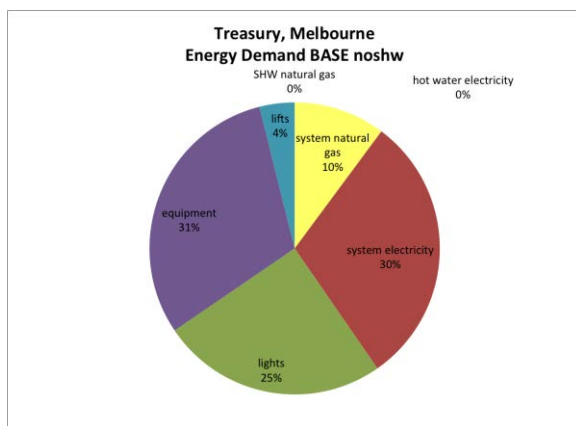


Figure 6 Operational energy simulation results for Lands Department Building

B) Correlation issues between building thermal modelling and NABERS ratings

Building thermal modelling software is used to provide an estimation of the expected energy use of a building under predetermined conditions. By varying certain parameters, a range of simulations can be run, results may be compared and changes to variables reapplied. In an energy efficiency retrofit design project, this iterative calibration process can result in an optimisation of the building features and systems for maximum energy efficiency. In this project the physical features and properties of the building could be modelled fairly accurately, yet information on the operational characteristics was scarce.

In the case of existing buildings, a close correlation of results of the base case building energy simulation with the actual energy bills as derived from the utility bills would be ideal. In the present study, however, the simulated energy demand values as calculated by the IES software did not correlate well with the actual energy consumption as determined by the NABERS assessment. The deviations varied greatly in extent and were found to be positive as well as negative. The deviations ranged from underestimations of 70% to overestimates of 245% (Tables 3 and 4).

Causes for the discrepancies may be manifold, ranging from inaccurate assumptions concerning thermal quality of the building materials, efficiencies of operational systems, thermostat settings, infiltration rates, equipment use or occupant behaviour to structural characteristics of the energy simulation software.

In the case of the Treasury Building, the modelled energy demand for both gas (heating) and electricity (cooling, lighting and equipment) were found to be less than the actual consumption. One possible explanation may be the inaccuracy due to the apportioning of the energy consumption of this case study building and its neighbour building on the basis of floor area. The discrepancy may also be due to the combination of modelling the open plan office spaces along the glass facade as one single room and the inherent inertness of the IES VE-Pro software calculation method. In the software, the room temperature that determines the heating and cooling actions is measured at a central point within the modelled room. In a large room the temperature at this central point may differ substantially from the temperature at its perimeter, especially near windows. The Treasury Building is located in Melbourne, which has a temperate climate. It has predominantly open plan offices of up to 10m in depth. The glass was modelled to be single pane glass without solar gain protection. Therefore, it may be assumed that the indoor temperature along the glass facade will fluctuate with the season, that is be significantly higher in summer and significantly colder in winter, than at a point in the centre of the room. If the existing HVAC system was designed with shallow zones along the windows, it would thus heat and cool the space for longer periods than the modelled HVAC system, which is governed by the more even temperatures in the middle of the room. This may be a possible explanation for the fact that the actual heating and cooling energy consumption was found to be higher than the simulated demand. Support for this hypothesis of the inertness of temperature changes was found when simulating an intervention in which the windows would be opened in case of high indoor temperatures. While cooling demand was reduced, the annual heating energy demand increased.

The comparison of the results of the Lands Department Building in Sydney revealed that the IES VE-Pro simulated energy demand values were higher than the actual energy consumption data as derived from the utility bills. Particularly striking is the large discrepancy in the usage of natural gas for heating the building. A possible explanation may be found in some of the heritage based architectural features of this building. The data collection of the building revealed the existence of large openings in the thermal envelope: the corridors on the ground floor are connected to the courtyards by large archways.

Table 3 Building simulation and NABERS results

Energy demands	Lands Department Building, Sydney MJ/m ² NLA	Treasury Building, Melbourne MJ/m ² NLA
Gas usage: Simulation	176	75
Gas usage: NABERS	51	251
Electricity usage: Simulation	1032	669
Electricity usage: NABERS	811	1198

Table 4 Differences between building simulation results and NABERS ratings

Energy demands	Lands Department Building, Sydney	Treasury Building, Melbourne
Gas usage: simulated demand in relation to actual use (bill)	245%	-70%
Electricity usage: simulated demand in relation to actual use (bill)	27%	-44%

During the cooler months these permanent ‘holes in the envelope’ are bound to lead to significant heat loss, which the heating system needs to compensate. In addition, the large volumes below the clock tower and the dome were found to be thermally conditioned too. When modelled in the IES VE-Pro software, the space heating system was set up with an unlimited boiler capacity. The existing heating system, however, would be limited by the capacity of the installed boiler. The much larger value for the simulated gas demand compared to the actual gas consumption indicates that the existing boiler may not be able to heat up these half-open spaces to the set point temperature of 19°C. Similarly, the heating of the large volumes below the clock tower and the dome may not achieve the desired temperature either.

Support for this hypothesis was found by modelling an intervention that assumed the sealing of the building’s envelope. This included the reduction of the natural air infiltration through the windows from 0.35 to 0.25 air changes per hour, the closing of the ground floor openings and the sealing off of upper volumes of the dome and clock tower. The simulation yielded a reduction of natural gas demand for space heating of 51%. This was a significantly higher reduction in gas demand due to sealing of the envelope than in the Treasury building. By comparison, the sealing of the windows in the Treasury Building in Melbourne only led to savings in gas demand of 8%.

CONCLUSION

Building simulation tools provide an approximate model of complex relationships in the real world. Building performance modelling tools often use simplistic and idealistic data inputs that are unrepresentative of actual building systems, resulting in discrepancies between predicted and actual energy performance. These discrepancies are typically

averaging around 30%, and are in part due to technical reasons such as weather variations or building design inaccurate assumptions (Yudelson, 2010). The provision of accurate and detailed information on the existing building and its operations before start of the modelling process is of paramount importance. After simulations have been run, sensitivity studies can identify possible reasons for incongruities.

Clevenger and Haymaker (2005) discussed extensively the uncertainty in occupancy modelling mainly due to schedules used to model occupant behaviour like occupant schedule, lighting schedule, equipment schedule and domestic hot water schedule. Energy loads influenced by occupants’ actions or presence include heating and cooling temperature setpoints, infiltration rate, occupant level, occupant sensible heat gain, occupant latent heat gain and ventilation rate. Occupant behaviour is a source of significant uncertainty in energy modelling with predicted energy usage (Azar and Menassa, 2012).

The study findings of great discrepancies between the simulated and NABERS results could be due to the insufficient information obtained for the case study buildings, the assumptions made to the heating and cooling systems, and the schedules used in the simulations. Improvement to the simulation results for both of the case study buildings could be achieved through detailed modelling of the HVAC systems using an IES advanced module called ApacheHVAC which construct heating and cooling systems componenets-ny-components from scratch. These will allow close to reality modelling of the HVAC systems that are used in the actual buildings. More accurate modelling of the lighting systems and effect of daylighting using IES Radiance module and detailed capturing of heat gain and lost through cracks and openings using IES MacroFlo module would help to improve the simulation results. These

suggested improvements would target around 95% (system natural gas, system electricity, lights and equipment) of the operational energy for both of the case study buildings and would help to close up the differences between the simulated results and actual performance of the energy demands substantially.

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