TESTING THE SENSITIVITY OF USER PATTERNS IN BUILDING ENERGY PERFORMANCE SIMULATION

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ABSTRACT

In this study, the sensitivity of occupancy behaviour on building energy simulation is investigated. Given the changing nature of the office environment as well as advances in technology, standardised user patterns may have become out dated. This research investigates the importance of reliable occupancy patterns by simulating a representative office building in the Adelaide CBD, varying the hours of use, thermostat settings, lighting use and ancillary appliances, which are all largely user dependant, and comparing the results against variations in the building envelope. This in turn helps demonstrate the importance of Post-Occupancy Evaluation (POE) as an energy conservation measure.

INTRODUCTION

The construction sector is responsible for over 42% of the world’s total annual energy consumption. A large percentage of this energy is used to provide lighting, HVAC systems and electricity based office appliances (DOE/EIA 2007). In Australia, 70% of the end use energy consumption in non-residential buildings is committed to HVAC and 15% to lighting (AGO 1999). These figures have brought about increased environmental concerns and the need for government regulations associated with the energy performance of buildings.

The Australian Building Codes Board (ABCB) have since developed a protocol for building energy rating software based on standardised patterns which are essentially assumptions of occupants’ thermal comfort, hours of operation, as well as heating and cooling loads. In order to simulate building energy performance more accurately, the user’s behaviour regarding energy consumption must be thoroughly analysed and well defined before its application to a case study. Occupants are not static but rather interacting with the building, adjusting air conditioning systems and lighting to suit their requirements (Mahdavi et al. 2008).

Post Occupancy Evaluation (POE) offers insight into how buildings actually function as well as how they are perceived (Meir and Cicelsky 2009) and can also be used to develop algorithms for future predictions (Yu 2010).

Results from POE studies are also used to evaluate the density of office use, and through surveys, provided a measure of new office practices. The drive for greater economic efficiency has brought about changes to the corporate office space (Warren 2003; Preiser 2002). As such, technological innovations, changing space allocations, different modes of working in and out of the office are some of the factors that are variable and need to be considered when developing occupancy profiles. The option of working from home is one that many office workers are finding desirable, due to improvements in communication and the increase of part-time jobs (ABS 2011). Therefore, the occupancy patterns, office layout, appliances, as well as heating and cooling loads will be different to those assumed in the building code. These social trends are likely to have a significant impact on total energy use in a building. The results can then be analysed to optimise energy performance as well as to inform the future regulatory process.

In building energy simulation and conservation, certain variables are given greater emphasis and are deemed more significant than others. Often great significance is placed on the building envelope and copious amounts of money are invested in improvements to the building envelope as a means of energy conservation (Leung 2005).

Therefore, the main objective of this study is to develop an integrated simulation method, taking into consideration the unreliable user behaviour rather than trusting in generic constants. This study aims to provide a more accurate energy profile and representation of a real world scenario. This in turn will improve understanding and aid the future decision making process for architects and other involved stakeholders and optimise energy performance during the entire life cycle of a building.

BACKGROUND

POE studies are sparsely conducted within Australia and the results are either unpublished or appear to have a positive outcome. In most scenarios, they are carried out from a profit-maximisation and productivity outlook rather than an energy conservation one (Paevere 2008). If Australia is to effectively respond to, and continue to manage the issue of energy conservation, it is vital to design and construct buildings that embody better environmental performance over their entire life cycle.

Findings from a comparison of actual energy use against the predicted energy use in a commercial building, carried out by the ABCB (2002) have shown significant variations in the results, most notably, a poor projection of heating and cooling loads. However, the study suggests several approaches that would produce a more efficient building design. These include full energy simulation runs undertaken by the design team during the design process to assist in the selection of components and systems as well as a further analysis of building performance after 12 months of occupation. Bordass (2004) suggested an as-built certification of buildings to ensure energy targets are being met and such studies confirm the need for this ongoing assessment. Baird (2010) uses these tools to assess thirty case studies across the world, including several in Australia. The indoor environmental quality, perceived comfort, health and productivity are all extensively addressed across mixed-use, institutional, and sustainable commercial buildings for a broad analysis. Baird (2010) also identifies how office buildings are currently being used, in particular ones that claim to be environmentally sustainable.

Users are more aware of sustainable behaviour and have greater control over building energy systems. Occupant interaction with thermostatic controls and windows vary with different comfort perceptions and cultural differences. Although the accepted practice in commercial buildings is to condition internal spaces to 21°C to 24°C, Peterson et al. (Peterson, Williams et al. 2006) state that a much wider range of temperatures is tolerated, particularly by occupants adapted to hot weather. The study establishes a greater range of operative temperatures than those identified in the ASHRAE standards (ASHRAE Handbook - Fundamentals 2005), which are 20°C to 23°C in winter and 23°C to 26°C for summer, and proves conclusively that occupant comfort is not universal but rather reflects their geographical location as well as social and cultural ideals. It is also noted that occupants can tolerate discomfort or a wider range of operative temperatures if they have a means of controlling it (Leaman and Bordass 2005). Furthermore, occupants of buildings classified as ‘green’ are also more tolerant of conditions which would fall outside the defined comfort range (Deuble and de Dear 2010).

In a study conducted in the UK the occupant was reluctant to open windows because they perceived there to be a security risk in doing so and this increased the energy use of the building (Hancock 2009).

Similarly, the density of office use is important not only as a measure of how efficiently space is being utilised but also as an energy conservation measure. Mahdavi et al. (2008) recognizes the relationship between occupancy and electrical lighting operation and states that the potential for electrical energy savings for lighting through the installation of occupancy sensors amounts to 66-71%. Their observations of several case studies in Austria demonstrate a lower level of occupancy than the standardized patterns and workstations which are unoccupied half the time during a typical working day. Warren (2003) conducted a study with the aim of better defining current office occupation density in Australia. It establishes that the Australia-wide benchmark is 20.6 m^2 per employee, which is significantly higher than the UK average of 16.3 m^2.

In 2006, the ABCB office compared the simulation of a medium sized office building that complies with the BCA deemed-to-satisfy provisions and the Australian Green Building Rating (AGBR) scheme. The change in energy consumption for such a building varies by 23%. The studies identified differences between the energy consumption in the BCA Verification Method JV2 and those in the ABGR scheme because of differences in the occupancy and equipment profiles and the equipment loads used (ABCB 2006).

Building energy simulation using results of POE studies have shown significant energy savings without the need to compromise occupant comfort (Rahman 2010). Furthermore, these energy conservation measures can be applied to improve the performance of existing buildings.

This study looks at ways in which user behaviour can be implemented in building energy simulation. The development of accurate, case-based user profiles will result in a more realistic assessment of the built form and empirical measurements from POE studies can be used to alleviate the ambiguity of assessment using standard patterns.

METHOD

Building Description

To achieve the above objectives and demonstrate the sensitivity of occupancy and other use patterns, in this study a representative office building is modelled based on the data provided by the ABCB (2001). It states that the most common type of office building found in Australian capital business districts is the 10 storey, open plan with a basement car park (Fig. 10). This base model (Fig.1), a square office building of 31.6 m x 31.6 m dimensions, is modelled with a non-air-conditioned central core, an 8 m deep perimeter zone, a floor-to-floor height of 3.6 m and the most common construction materials for an office building (Table 1). The model represents all the essential features of a multi-storey commercial building including the building envelope system, which includes its physical dimensions and construction material properties, building zoning, internal loads such as occupancy, lighting and equipment use as well as the design parameters of its HVAC system.

The whole building energy simulation will be carried out using data from the nearest available hourly weather station, in this case Kent Town, Adelaide.

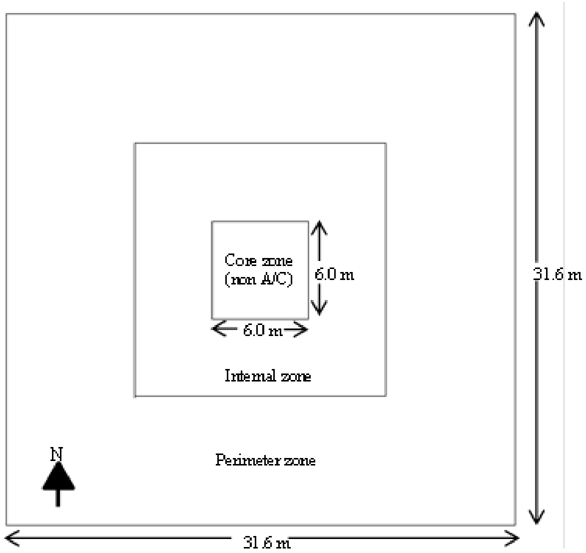

Figure 1 Plan of base model

Table 1
Physical characteristics of base model

Location	Adelaide CBD, Australia (latitude 34° 50'S - Longitude 138° 30' E)
Geometry	
Building footprint	31.6 m x 31.6 m
Total height (above ground)	36 m
Floor-to-floor height	3.6 m
Gross floor area	9985.6 m^2
Windows	Curtain wall system
Constructions	
External wall	110 mm medium weight concrete block, R1.5 EPS insulation, 13 mm plasterboard
Internal partitions	90 mm steel frame, 25 mm plasterboard
Floors	150 mm reinforced concrete slab, 9 mm felt underlay, 11 mm wool carpet
Glazing	Pilkington Suncool HP neutral double glazing, SHGC=0.462, U-value=1.522 W/m^2 K
Systems and internal loads	
Infiltration	Fixed at 0.5 ACH
Occupant load density	10 m^2/person
Lighting density	10 W/m^2
Equipment density	15 W/m^2
Illuminance set point	320 lux
HVAC system	Variable air volume
Set point temperature	22^{o}C in winter, 24^{o}C in summer

The base model is varied as follows:

Variation 1

This generic base model is then subjected to simulations under the current standard user profiles from the National Australian Built Environment Rating System (NABERS) using Design Builder, a graphical user interface tool which implements EnergyPlus simulation.

Occupant densities presenting recent trends are obtained from Warren (2003) and applied to the base building for variations in energy consumption. These range from 10-25 m^2/person.

Variation 2

When illuminance levels are 200 lux at the workstations, studies have shown that the probability of switching on task lighting is significantly higher and occupants are also shown to switch lights off more frequently if they are away from their workstations. Furthermore, lighting levels are largely determined on the type of tenant and the work being conducted (Mahdavi et al. 2008). Hence, lighting levels are adjusted to investigate these scenarios on the energy consumption of the representative building. The target illuminance is reduced to reflect the current trend towards increased levels of day lighting and then, increased incrementally with the addition of task lighting at a gain of 10 W/m^2. Occupancy schedules are applied to the task lighting, which assumes the building users switch off lights when leaving their workstation.

Variation 3

Thermostat set points are varied both within the prescribed comfort zone and beyond it based on ASHRAE standards (2005) and previous studies which show occupants' tolerance to indoor temperature settings (Peterson, Williams et al. 2006). They are initially varied individually, then combined for comparison.

Variation 4

The base model is then simulated using mean occupancy levels for three types of tenants in office buildings (Mahdavi 2008), whilst keeping the occupancy density at a constant 20 m^2/person. These variations accommodate for different work patterns than those identified in the BCA. Scenario A assumes that the building is occupied by an educational institution, such as a university. Scenario B uses occupancy data monitored from an open plan office used by a multinational organization, while scenario C uses data logged in a government office, where employees may have flexi-time and rather than working the assumed 9AM to 5PM, employees are shown to work 8AM to 2PM without a lunch break (Fig.12). Scenario D uses occupancy profiles developed by Warren's studies on office use in Australia (2003) as per Figure 11.

Variation 5

Equipment usage is a large contributor to a building's energy consumption. The base building was simulated with the NABERS equipment profile, as shown in Fig. 6, E1. This is then altered to reflect different user patterns, assuming some equipment are switched off at the end of the day, shown in E2. Computer use is also added to this model at a gain of 10 W/m^2 and the results are plotted in Fig. 6. Computer use with the NABERS equipment profile is shown in E3 and a more realistic occupancy profile in E4.

Variation 6

To test the significance of building envelope on energy consumption, and a basis for comparison, the model is simulated with varying window areas.

RESULTS

The intention was to simulate key variables influenced by the user's action and compare it to the building envelope loads to observe differences in energy consumption. The range of data was simulated for an entire year, and the resultant energy loads presented in GWh in the following graphs.

Figure 2 indicates the variations in annual energy consumption due to changes in the occupancy density of the offices. The NABERS occupancy schedule was applied to the whole building simulation.

Figure 3 shows the general lighting usage for the entire office, simulated with the NABERS prescribed lighting schedule.

Figure 4 shows the effects of slight variations in the thermostat set point and its potential for energy conservation.

Figure 5 clearly establishes that building energy consumption is affected by occupancy patterns and shows large variations between the base case and more realistic user profiles.

Figure 6 shows significant energy savings can be obtained by changing the equipment use profile.

Figure 7 maps window-to-wall ratios to assess the effect of building envelope on energy consumption.

Further to this, Figure 8 shows a breakdown of heating and cooling loads in the building, and Figure 9 compares the CO_2 emissions of the building in relation to each variable.

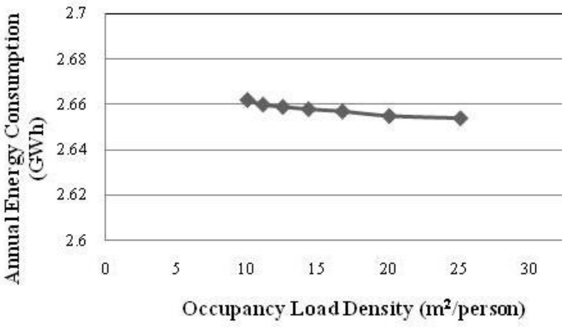

Figure 2 Variations in occupancy load density and its effect on energy consumption

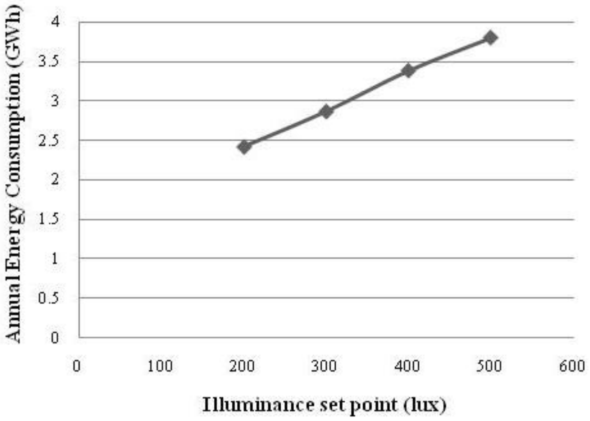

Figure 3 variations in lighting levels and its impact on energy consumption

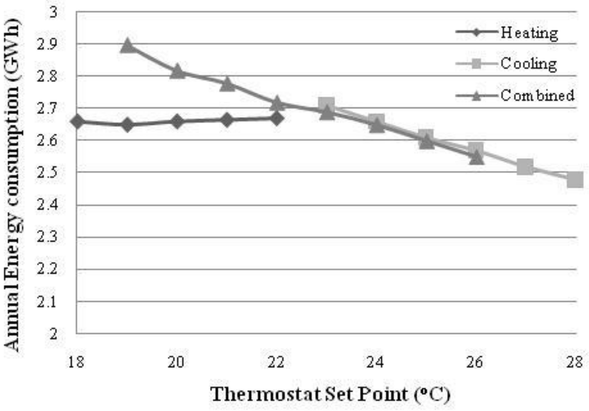

Figure 4 Comparison of thermostat set points for heating and cooling against total energy

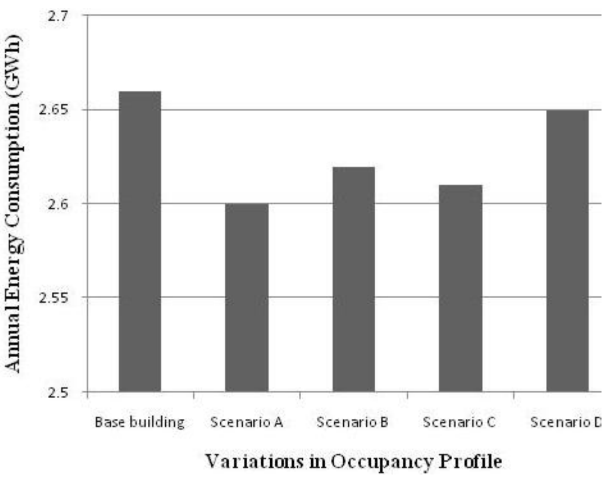

Figure 5 Comparison of different occupancy profiles and their effect on total energy consumption

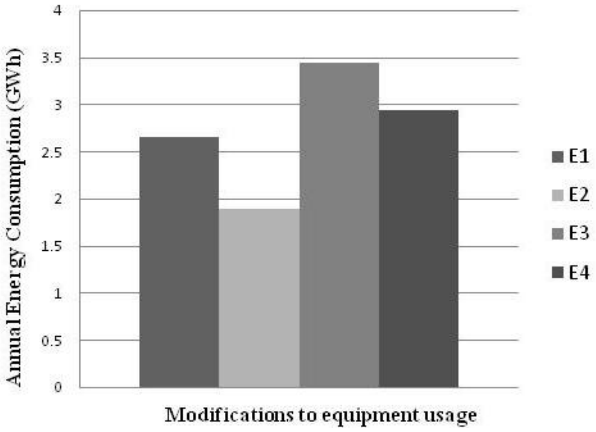

Figure 6 Comparison of equipment profiles and computer usage and their effect on total energy use

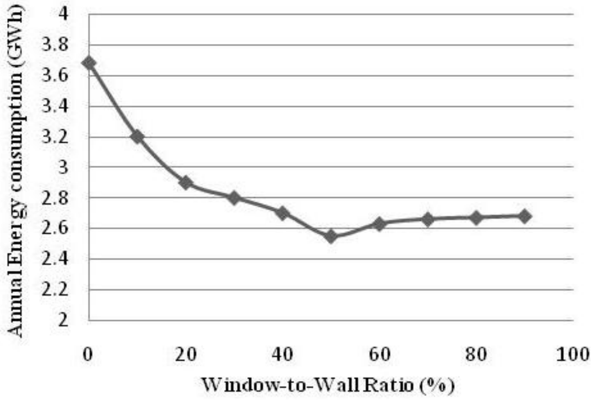

Figure 7 Comparison of window-to-wall ratios and the resultant energy consumption

DISCUSSION

By simulating the model using inputs that vary with the users' action, it is possible to gain an understanding of their effect on energy performance. Minute variations in occupancy profiles were initially applied to the ground level retail as well as the basement to reflect current trends in their usage, against simulating the entire building with the prescribed schedule for an office building (Fig. 2). Simulation conducted for office buildings in Australia, for example, should use the relevant occupancy load density of around 20 m2/person, as shown in the study by Warren (2003), to ensure that the energy consumption is not underestimated. However, in certain office buildings, such as call centre offices, a higher load density may need to be used in order to not over estimate the energy use. Though not too significant, the difference in simulated energy consumption between 10m2/person and 25 m2/person of occupancy load density is still notable (5%).

A more significant change is seen when user-controlled task lighting, with an occupancy schedule were applied to the simulation model along with reduced levels of illumination (Fig. 3). The NABERS occupancy schedule was applied to task lighting assuming that they are only used when occupants are in the building, to emulate a more realistic scenario of using task lighting. The measured difference with the base case amounts to 240000 kWh (0.24 GWh) which amounts to energy savings of about 9%.

Occupants have very little control over the internal temperature settings in an office building. However, in the case study building, adjustments to the thermostat set point can result in some savings of 50000 kWh in a year, achieved by increasing cooling temperature from 24°C to 25°C (Fig. 4). Varying the heating set point from 22°C to 19°C had little effect on the total energy, as it is a cooling dominated building. This study found that for every degree of increasing or decreasing the cooling thermostat setting, the energy use is reduced or increased by nearly 2%.

Occupancy patterns are shown to have a clear effect on the energy use (Fig. 5). The difference between the base building and patterns identified in scenario D amounts to 10000 kWh per year. It is also occupants who control equipment and computer use in a building, and they may not behave to the prescribed schedule. Varying the equipment usage according to different user patterns showed some reduction in the energy use, cementing the aforementioned notion.

Fig. 6 shows that adding computers to the case study increases energy use by 23%. This sharp increase is not always taken into consideration when assessing the environmental performance of a building. Typical equipment profiles assume that 40% of equipment is left on during the night. In most contemporary offices, especially those with a green agenda, computers are switched off, and to take this into consideration an occupancy profile was added to the simulation model. Assuming users switch off computers when they leave their workstations, a large reduction in energy use is seen, amounting to 330 MWh or 14%.

Fig. 7 shows the relationships between the key building envelope design variable, the window-to-wall ratio, and annual energy consumption. It is well established that integrating daylighting can help achieve significant energy savings (Li 2001). However the results show that if careful consideration is not given to the design, excess glazing can result in solar heat gains, increasing cooling loads. More importantly, this study found that increasing or decreasing the window-to-wall ratio between 30% to 90% has little impact on the building energy consumption compared to changing the occupancy patterns, equipment use, load density, lighting levels and thermostat settings, with the change in lighting levels having the greatest impact on energy consumption and hence carbon dioxide production (Fig. 9).

In a contemporary open plan office with a curtain wall system, natural lighting is well utilised and thereby the target illuminance can be set much lower than the default 320 lux (AS1680.2.0). Users have much greater control over lighting systems in contemporary offices (Baird 2010) and workstations are placed as close to the façade as possible. As such, considering these factors would greatly reduce the energy consumption within a building.

CONCLUSION

The extensive use of daylighting with large areas of glazing can reduce annual energy demand, as well as cooling energy (Fig.2). However, it is always accompanied by solar heat gains and therefore the benefits of increased daylighting will eventually be negated by the increased solar heat gain, which results in greater demand for space cooling.

Over estimation of lighting levels, electricity use as well as luminaires due to the incorrect simulation of these parameters not only wastes resources but increases the cooling loads required to maintain the indoor environmental quality. As seen in Fig. 6 of all the variables tested, lighting produces the highest levels of greenhouse gases.

Most commercial buildings are largely cooling dominated due to the amount of electronic equipment and occupancy loads, resulting in greater amount of heat generated inside (Fig.8). Activity and equipment produce significant amounts of heat hence thermal loads are primarily internal rather than from external elements. Results from this study also show significant variations in the predicted energy use as a result of changes in occupancy and use patterns (Fig. 5). The total building energy is affected by variations in lighting and equipment use, which are largely user dependant. It therefore can be deduced that for commercial buildings, accurate simulation of the building occupants' activity is as great if not greater a contributor to energy conservation as building envelope.

The complexities inherent in the subjective and interactional nature of lighting or temperature parameters highlight the importance of empirical measurements and the feedback POE offers. Simulating the building with standardised patterns may result in over or under estimation of the whole-building energy use, which will not be effective in alleviating environmental problems. This study builds on previous research and shows that more realistic and evidence-based user patterns based on POE can help determine how specific buildings in certain climates are used. Furthermore, it can bridge the gap between design estimates and actual performance and aid the regulatory bodies in developing a more effective framework for building performance assessment in order to advance the practice of environmentally sustainable architecture.

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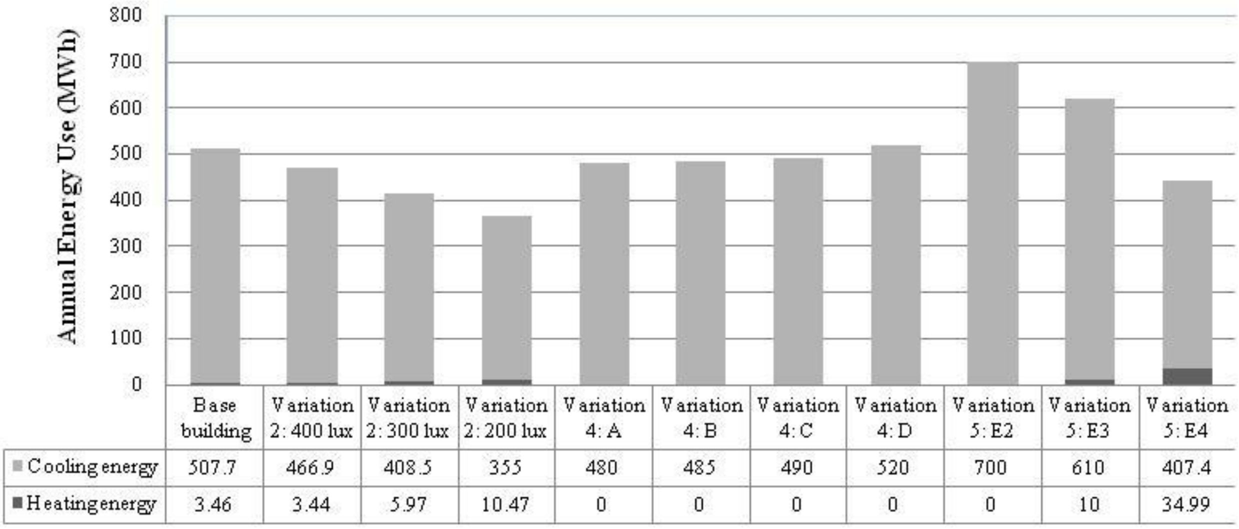


	Base building	Variation 2: 400 lux	Variation 2: 300 lux	Variation 2: 200 lux	Variation 4: A	Variation 4: B	Variation 4: C	Variation 4: D	Variation 5: E2	Variation 5: E3	Variation 5: E4
■ Cooling energy	507.7	466.9	408.5	355	480	485	490	520	700	610	407.4
■ Heating energy	3.46	3.44	5.97	10.47	0	0	0	0	0	10	34.99

Figure 8 Annual heating and cooling loads for the case study

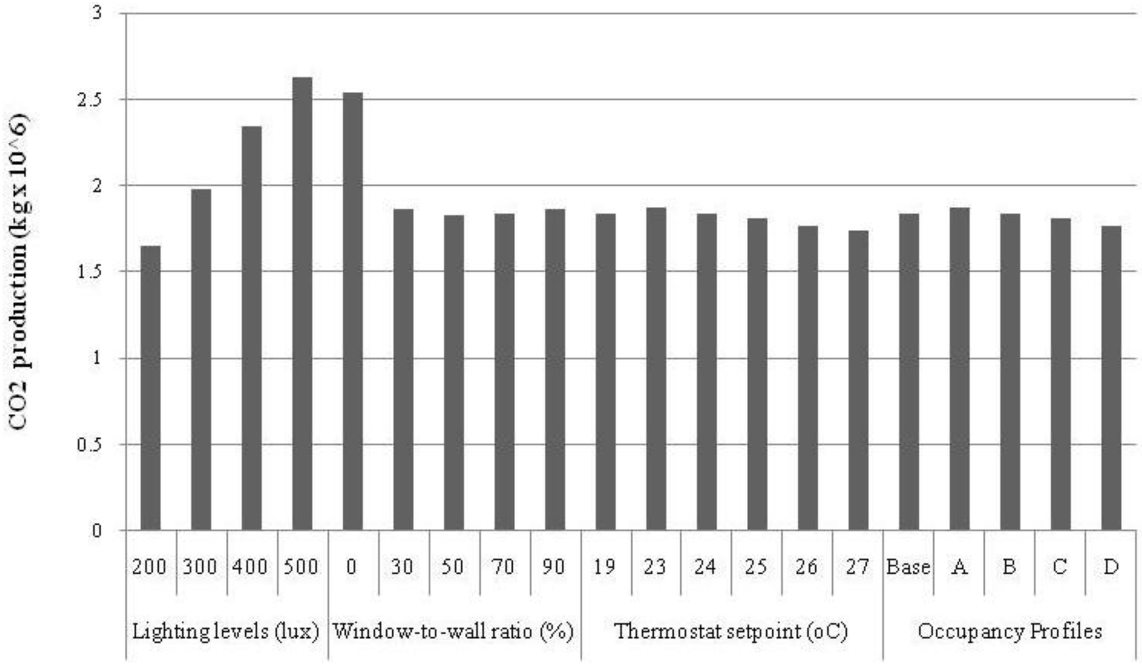
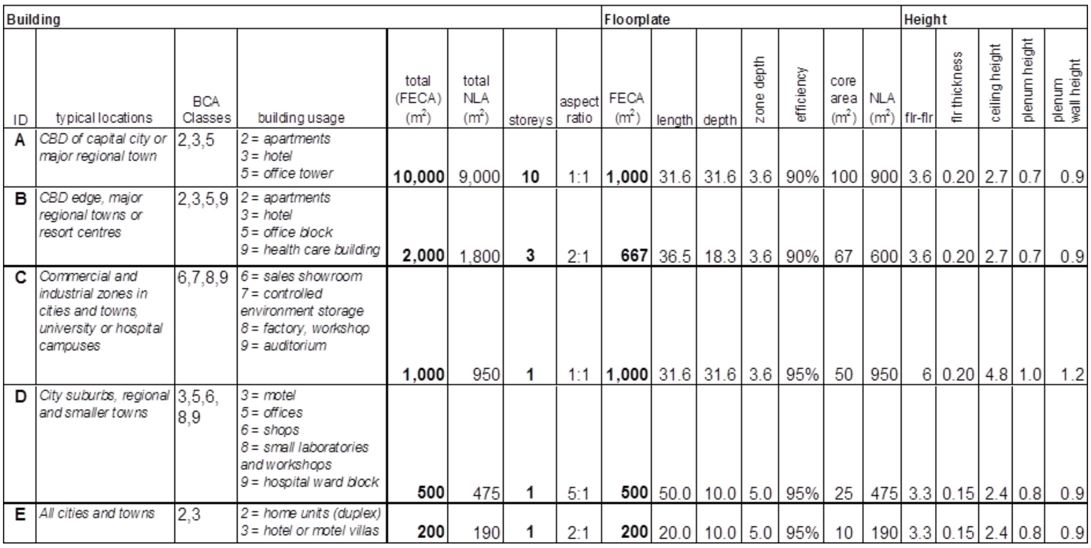


Figure 9 Carbon dioxide emissions corresponding to each of the variables



Building								Floorplate							Height				
ID	typical locations	BCA Classes	building usage	total (FECA) (m^2)	total NLA (m^2)	storeys	aspect ratio	FECA (m^2)	length	depth	zone depth	efficiency	core area (m^2)	NLA (m^2)	flr-flr	flr thickness	ceiling height	plenum height	plenum wall height
A	*CBD of capital city or major regional town*	2,3,5	*2 = apartments* *3 = hotel* *5 = office tower*	**10,000**	9,000	**10**	1:1	**1,000**	31.6	31.6	3.6	90%	100	900	3.6	0.20	2.7	0.7	0.9
B	*CBD edge, major regional towns or resort centres*	2,3,5,9	*2 = apartments* *3 = hotel* *5 = office block* *9 = health care building*	**2,000**	1,800	**3**	2:1	**667**	36.5	18.3	3.6	90%	67	600	3.6	0.20	2.7	0.7	0.9
C	*Commercial and industrial zones in cities and towns, university or hospital campuses*	6,7,8,9	*6 = sales showroom* *7 = controlled environment storage* *8 = factory, workshop* *9 = auditorium*	**1,000**	950	**1**	1:1	**1,000**	31.6	31.6	3.6	95%	50	950	6	0.20	4.8	1.0	1.2
D	*City suburbs, regional and smaller towns*	3,5,6, 8,9	*3 = motel* *5 = offices* *6 = shops* *8 = small laboratories and workshops* *9 = hospital ward block*	**500**	475	**1**	5:1	**500**	50.0	10.0	5.0	95%	25	475	3.3	0.15	2.4	0.8	0.9
E	*All cities and towns*	2,3	*2 = home units (duplex)* *3 = hotel or motel villas*	**200**	190	**1**	2:1	**200**	20.0	10.0	5.0	95%	10	190	3.3	0.15	2.4	0.8	0.9

Figure 10 Representative building forms as proposed by the ABCB (2001)

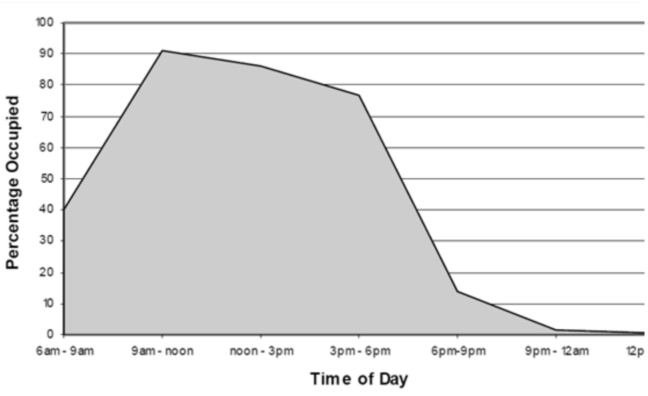


Figure 11 Occupancy profile for Australian offices based on POE data (Warren 2003)

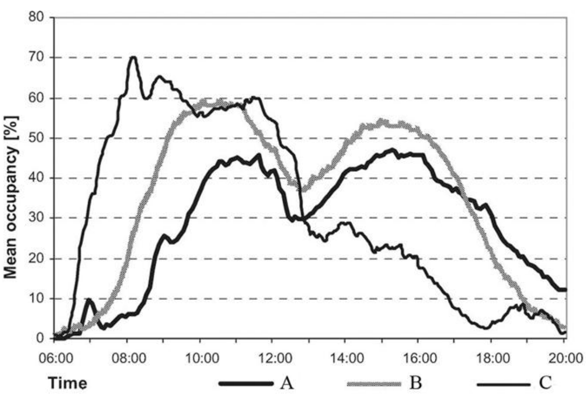


Figure 12 Occupancy profiles for offices A, B, and C based on POE data (Mahdavi 2008)