Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 00 (2017) 000–000

Procedia Engineering

www.elsevier.com/locate/procedia

International High- Performance Built Environment Conference – A Sustainable Built Environment Conference 2016 Series (SBE16), iHBE 2016

Load resilience in high performance buildings

Paul Bannister*, Hongsen Zhang

Energy Action, PO Box 546 Belconnen ACT 2616 Australia

Abstract

In the past 15 years there has been a sea change in the performance of the base building services of office buildings in Australia, particularly in the upper echelons of the market, with achieved efficiency levels far exceeding what had previously been considered possible. This has been achieved through innovations in control and operation of existing HVAC system types and the emergence of newer HVAC types. At the same time, there have been changes in how we occupy office buildings, with changes in computing loads and adoption of new work practices such as “agile working”. With these changes it is worthwhile to re-examine the fundamental assumption that underlies the NABERS base building rating, being that the performance of the base building is sufficiently independent of occupancy to enable the rating to be formulated without significant reference to the operations of the tenancies.

In order to test this, a computer simulation model in IES has been developed and tested against a range of equipment and occupant density scenarios representing the traditional and agile workplaces to determine the extent to which the base building performance is sensitive to these factors.

Peer-review under responsibility of the organizing committee iHBE 2016.

Keywords: Office building; NABERS; Base building; HVAC load; energy consumption

1. Project Overview & Objectives

The original work underlying NABERS Energy for offices [1] dates from the late 1990s. Since then, there have been many changes to office workplaces and workplace technology. Furthermore, during the intervening period, the

* Corresponding author. Tel.: +61-2-6257-7066;
E-mail address: paul,bannister@energyaction,com.au

Peer-review under responsibility of the organizing committee iHBE 2016.

issue of the impact of tenancy loads on base building ratings has been raised several times as a potential issue with the rating. Work undertaken in response to this has generally identified very limited impacts of tenancy loads.

Recently, a number of workplaces have adopted activity-based work practices, which eliminate the traditional one-desk-one-person approach and as a result create higher occupant densities. Indeed, proponents of activity-based work practices suggest that a decrease in floor area requirement of 25-50% can be achieved through hot-desking approaches, equating to an increase in occupant density of 30-100%. Conversely, activity based working tends to be associated with the use of laptops and by implication reduced overnight loads (because the desktop equipment is packed away each night) which would significantly reduce consumption.

Therefore the purpose of this study was to address the following questions:

- Does activity based working produce significant changes in occupancy loads; and
- Do such changes produce a significant effect upon the base building rating beyond that envisioned under the design of NABERS?

2. Methodology

2.1. Data Gathering

Two activity-based workplaces in Sydney were used to collect data for this study, each consisting of an entire floor; for purposes of anonymity these will be designated Site A and Site B throughout this paper. At each site an hourly count of the computers/occupancy was taken for an entire working day, lighting and equipment counts were taken as well. This site-measured data was then compared with time interval electricity metering data to develop an occupancy profile, equipment density and lighting profile.

2.2. Occupancy Profile

At Site A an hourly occupancy count was performed between the hours of 9am till 6pm for a single day. The data from the count was used as the basis for the occupancy profile. 20% occupancy was assumed for 8am-9am and 5% occupancy was assumed for 6pm to 7pm. For all other hours occupancy was assumed to be 0%.

An hourly occupancy count was also performed for Site B. However for this site there was also data available from the building’s security gate control system. This data was compared to the occupancy counts (based on laptop presence) made during the site visit in order to validate its accuracy.

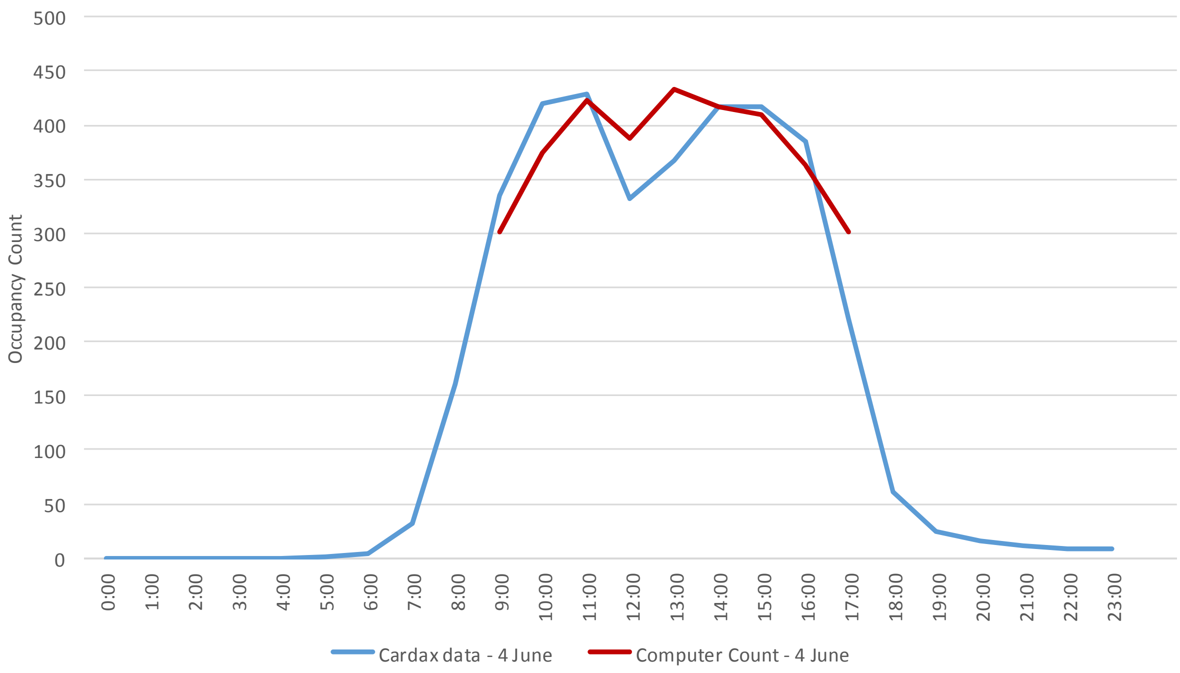

Fig. 1. Comparison of observed occupancy vs. data from the security system – Site B

The comparison (Fig. 1) showed that the data from the security system closely matched the occupancy observed on site, with the following exceptions:

- Between the hours of 12:00 and 14:00 the security system data shows lower occupancy compared to the computer count. This is due to people leaving the building for lunch, but leaving their laptops at their desks
- Between 19:00 and 23:00 the security system data shows a small residual occupancy. This is due to people ‘tailgating’ others out of the building without swiping their cards through the gate. Therefore the system thinks these people are still inside the building because they didn’t sign out. However the effect of tailgating on the data is minimal (typically less than 10 people per night) and was ignored for the purpose of this study.

The data from the security system was considered reliable enough to use for the study. Five weeks of security logs were used to build an average weekday occupancy profile for Site B.

2.3. Lighting and Equipment Power Profile

Interval data from the sub-metering systems in both tenancies were used to establish the profiles for both the lighting and general power. Energy from the computer server rooms was included in the equipment profiles. Five weeks of interval data were used to compile average weekday profiles.

A summary of the data collected is displayed in the table below:

Table 1. Tenancy Profiles

Hour	Site A Lighting	Site A Equipment	Site A Occupancy	Site B Lighting	Site B Equipment	Site B Occupancy
0	7%	25%	0%	8%	21%	0%
1	7%	25%	0%	7%	21%	0%
2	7%	25%	0%	6%	21%	0%
3	7%	25%	0%	8%	21%	0%
4	7%	25%	0%	7%	21%	0%
5	10%	25%	0%	7%	22%	0%
6	20%	25%	0%	21%	25%	1%
7	50%	30%	0%	54%	33%	7%
8	95%	60%	20%	91%	61%	37%
9	100%	85%	85%	96%	86%	86%
10	100%	100%	100%	99%	96%	100%
11	100%	100%	88%	100%	95%	100%
12	100%	100%	70%	99%	97%	79%
13	100%	95%	38%	99%	100%	88%
14	100%	100%	75%	100%	91%	100%
15	100%	95%	77%	100%	88%	99%
16	100%	90%	78%	100%	86%	90%
17	100%	80%	74%	98%	64%	51%
18	80%	40%	34%	94%	38%	17%
19	70%	30%	5%	78%	29%	6%
20	40%	25%	0%	62%	26%	3%
21	30%	25%	0%	47%	22%	2%
22	10%	25%	0%	33%	23%	1%
23	7%	25%	0%	26%	21%	1%
Maximum	6.3kW	10.8kW	99 People	22.4kW	39.6kW	398 People
Density	5.0W/m^2	8.6W/m^2	12.8m^2/person	5.2W/m^2	9.2W/m^2	9.6m^2/person

Using this data, two activity based scenarios were used for the simulation, a high density scenario (based on Site B densities and profiles) and low density scenario (based on Site A densities and profiles).

2.4. Internal Loads and operation schedule

The changes to the internal load densities and associated hourly profiles are the key factors in this project. The building loads are described in detail as follows:

NABERS default model [2]:

- Occupancy – 15 m²/person, Sensible load of 75 W/m² and 55 W/m² latent load, NABERS default hourly profile;
- Equipment – 11 W/m², NABERS default profile;
- Lighting – 5.1 W/m² (Average of Site A and B's lighting power densities), NABERS default hourly profile. In simulation the lighting heat gains are distributed equally between plenum and zone.

Low occupancy activity based model (based on Site A data):

- Occupancy – 12.8 m²/person, Sensible load of 75 W/m² and 55 W/m² latent load, Site A hourly profile;
- Equipment – 8.6 W/m², Site A hourly profile;
- Lighting – 5 W/m², Site A hourly profile. In simulation the lighting power density distributed equally between plenum and zone.

High occupancy activity based model (based on site B data):

- Occupancy – 9.6 m²/person, Sensible load of 75 W/m² and 55 W/m² latent load, Site B hourly profile;
- Equipment – 9.2 W/m², Site B hourly profile;
- Lighting – 5.2 W/m², Site B hourly profile. In simulation the lighting power density distributed equally between plenum and zone.

Zero internal load model:

- Zero for the occupancy, equipment and lighting load. This is a hypothetic extreme case to examine the impact of the zero internal load on the HVAC consumption.

2.5. Simulation

An existing standard simulation model of a VAV building was used to investigate the impact of the changed occupancy, equipment profiles and densities relative to the NABERS defaults [2]. Two activity based scenarios were simulated, a high and low occupancy model derived from the site data. We also establish a zero internal load model to examine the impact of the internal load on the energy consumption. The NABERS default, activity based working and zero internal load models were run for Darwin, Brisbane, Sydney, Melbourne and Canberra (4 models per centre, thereby covering the national climate for the four occupancy scenarios). Then the outputs from the models were used to generate estimated NABERS impacts for each case.

Modelling was executed in IES<VE> which was developed by Integrated Environmental Solutions Limited and has passed BESTEST accreditation. The program has been widely used in Australia and has widespread international acceptance.

The TRY weather file appropriate to the region was used. Building was modelled in Sydney, Melbourne, Brisbane, Darwin and Canberra.

Details of the model are provided in Appendix A.

3. Results

The simulation results for the base building are given below together with the NABERS rating using the consumption data. Detailed results are provided in Appendix B.

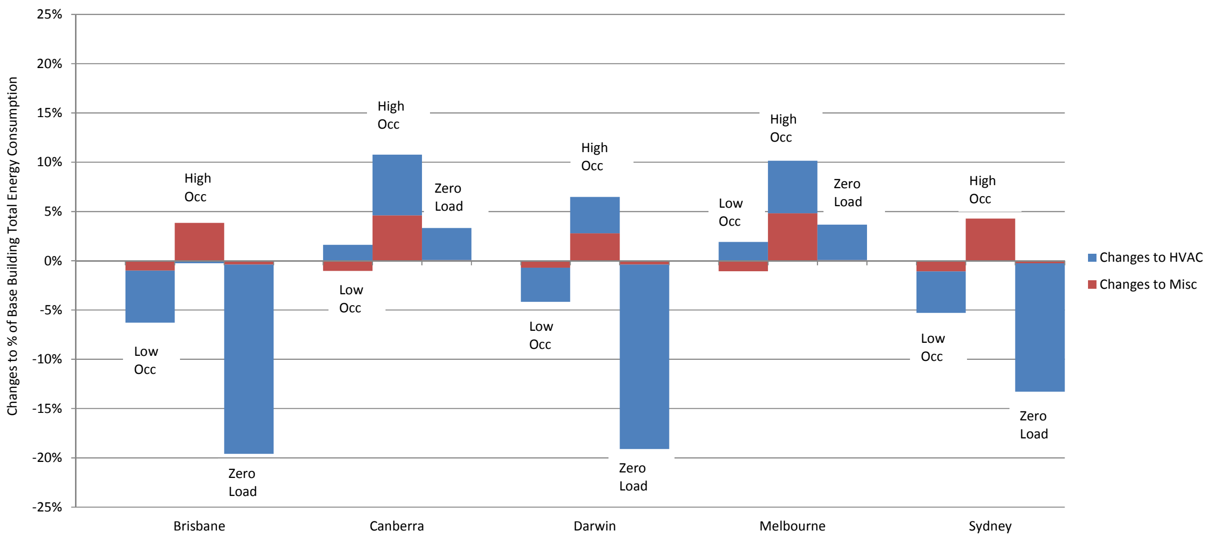

Fig. 2. Base building energy consumption changes compared with the NABERS default models

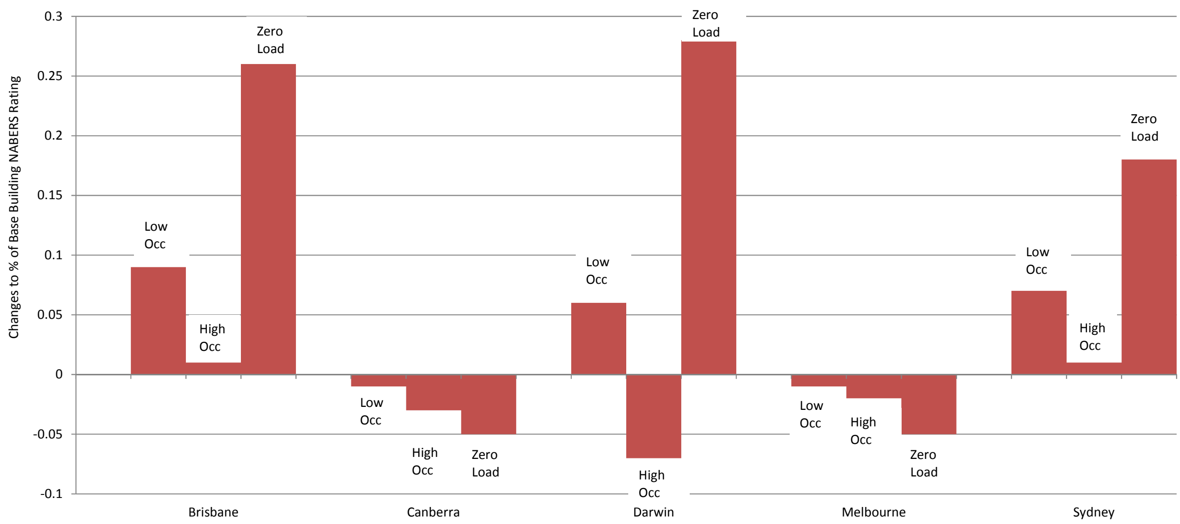

Fig. 3. Impacts on base building NABERS rating

4. Discussion

The simulation results show that the base building NABERS ratings of the low occupancy (12.8m²/person) activity based models are slightly higher than those of the NABERS default models with the impacts ranging from 0.01 to 0.11 stars. Low occupancy (12.8m²/person) activity based models have less cooling energy and more heating energy due to the reduction of occupancy and equipment load. Especially in warm climate zones (Brisbane, Darwin and Sydney), the reduction of the occupancy makes the major contribution to the energy savings. This results in the positive impacts ranging from 0.06 to 0.09 stars in those locations. In mild climate (Canberra and Melbourne), low occupancy models use more heating energy so that the NABERS rating is slightly lower (-0.01 stars) than those of the NABERS default models. The HVAC energy changes make the major contribution in Brisbane, Darwin and Sydney, and is comparable to the changes in miscellaneous energy in Canberra and Melbourne.

The high occupancy (9.6m²/person) models have higher occupancy load but lower equipment load compared to the NABERS default models. The combination of this make the models in Brisbane, Canberra, Melbourne and Sydney use slightly less cooling energy. However high occupancy models are operating 1 hour longer. This results in higher heating energy consumption in Canberra and Melbourne, and higher cooling energy consumption in Darwin. The miscellaneous energy changes make the major contribution in Brisbane and Sydney, and is comparable to the changes in HVAC energy in Canberra, Darwin and Melbourne. The overall contributions have the positive impacts on Brisbane and Sydney (0.01 stars), and negative impact on Canberra, Darwin and Melbourne (-0.01 to 0.07 stars)

It is notable in all cases that the percentage impacts of the different load scenarios on HVAC energy use by itself are higher than for the overall base building rating. This is because of the more fixed nature of many of the miscellaneous loads, which have limited responsiveness to occupancy.

From the above discussion, it can be seen that the overall the impact of the activity based workplace on the base building NABERS ratings is within a minimal range. Both the high and low density scenarios were modelled with the entire building using activity based working. For a building with only one or two floors using activity based working, the impacts on the base building ratings would be much lower.

From the zero internal load simulation results, we can see the internal loads save more HVAC energy in warm climate zones because zero internal loads results in a significant reduction in cooling load and heating is not highly required in such zones. In contrast its impact is minimal in mild climate zones because the savings in cooling is offset by the extra heating requirement.

4.1. Recommendations for further work

The simulations performed for this analysis did not take into consideration any issues of humidity control. It is arguable that systems with humidity control (such as chilled beams) may have a higher level of load responsiveness, particularly in relation to occupant density.

It is also noted that the degree of load resilience will be affected by the ratio of façade loads to internal loads. A building with a higher floor to surface ratio, or with a significantly better façade, would be expected to show a higher level of response to the internal load on a proportionate basis; similarly, buildings with high surface to floor area ratios or poor facades would be expected to be less responsive to internal load.

In both cases, it would be worthwhile for further work to be undertaken to investigate the scale of such effects.

5. Conclusions

Based on the analysis in this paper it is identified that:

- Activity based workplaces have minimal impacts (-0.07 to 0.09 stars) on base building NABERS performance. The scale of impact is limited by the balancing effects of heating and cooling in response to internal load and by the presence of relatively constant non-HVAC loads.
- Without consideration of lift or DHW energy, removal of internal lighting, occupancy and equipment loads has a marginal impact on NABERS base building rating ranging from -0.05 stars in Melbourne to +0.28 stars in Darwin. This is again a fairly low impact, reflecting the comparative load resilience of the base building metric to internal load.

These results support the hypothesis that agile workplaces and indeed internal load scenarios are secondary determinants of base building performance as measured under NABERS. However, it has been noted that humidity control, and the ratio of façade load to internal load will affect the degree of load resilience, and that further work needs to be undertaken to understand these effects better.

5.1. Acknowledgements

The work in this paper was funded by the NABERS team at the Office of Environment and Heritage, NSW Government. The contribution of Dennis Lee and Carlos Flores from the NABERS team in commissioning and reviewing this work is gratefully acknowledged.

Appendix A: Simulation details

A.1 Basic characteristics

- 8 storey building with underground car-park
- 50% WWR, double glaze with tint
- Uninsulated walls, R2.5 roof
- 25m by 25m floorplate, 4 perimeter and 1 centre zone per floor, the total building area is 5,000m^2
- HVAC: VAV system with electric terminal heating
- Floor to ceiling height 2.7m
- Plenum height 0.9m

A.2 Building Construction

Double glazing with the characteristics shown in Table 2 was used in the simulation.

Table 2. Glazing characteristics

Construction (from inside to outside)	U-value (W/m^{2}K)	Shading Coefficient	Light transmittance
6mm Pilkington Optifloat Green/ Air Cavity/ 6mm Clear float	2.8	0.53	76%

The following opaque constructions were used in the simulation:

Table 3. Opaque construction details

Construction description	Material (From outside to inside)	Thickness (mm)	Total R-Value ($m^2 \cdot K/W$)
External wall	Concrete	150	0.53
	Air cavity	25	
	Plasterboard	12	
Floor	Carpet	6	0.41
	Concrete	150	
Underground carpark floor	U-value correction layer	50	3.39
	Ground contact correction layer	3,069	
	Concrete	200	
Ceiling	Acoustic tile	17	0.488
Roof	Metal sheeting	5	2.72
	Glass fibre	100	

Note that the total R-Values above include the surface resistances and represent typical figures in the existing building stock. The R-Value of the ground floor has been adjusted using EN-ISO 13370 method.

A.3 Ventilation and infiltration

The minimum outside air requirement during occupied hours was set at 7.5 l/s/person. The ventilation rate was calculated based on this figure and the peak occupancy density of each scenario. But it does not vary based on the occupancy hourly profiles.

The infiltration through the windows was simulated by the MacroFlo module of IES. The wind pressure coefficients were determined by the ratio of the height of the window location to the building height. A median crack flow coefficient of 0.23 $l/(s \cdot m \cdot Pa^{0.6})$ was selected to represent the average leakage through the windows. The crack length is equal to the window perimeter.

A.4 HVAC

Separate AHUs were provided for each facade and for the centre zone. All AHUs were configured with a temperature economy cycle with a dewpoint lockout at 14°C and a dry-bulb lockout at 24°C. Minimum supply air temperature was set to 12°C. Supply air temperature reset from minimum to 24°C when the high select zone temperature drops from 23.5°C to 21.5°C. AHU fans were modelled as having an efficiency of 70%, motor efficiency of 90% and an x2.7 turndown (representing variable pressure control). A total fan pressure of 800 Pa was used.

The heating was assumed to be direct electric so that the heating required from the model was used to establish the annual energy required.

The chillers used in the model were a York low load water cooled scroll chiller (YCWL0260HE50) of capacity 246.2 kW and two York centrifugal chillers (YMC2-S0800AA) of capacity 798 kWr. The chilled water temperature was fixed at 6°C for the base case. Part load performance data at a range of condenser water temperatures were used to look up the Coefficient of Performance (COP) over a range of operating conditions. Three cooling towers with 7W/kW of heat rejection were modelled.

The zone temperature control was to 22.5 °C with a dead band from 21.5 °C to 23.5 °C and 0.5 °C proportional bands either side of this. The VAV box minimum turndown was set to 30% for perimeter zones and 50% for centre zones.

A.5 Miscellaneous loads

The following miscellaneous loads were assumed:

- Exhaust fans. It was assumed that there were 3 kW of general and toilet exhaust fans running 15 hours per day during workdays. The car park exhaust fan was modelled as 2 kW running 6 hours per day during workdays.
- Domestic hot water. In the NABERS default model, the electricity consumption for the DHW was calculated on the basis of 2 kWh/m² consumption. A 25% circulation loss was assumed and 95% electric boiler efficiency. In the activity based models, the DHW energy was adjusted by the occupancy hot water consumption. We assumed the daily hot water consumption is 2 l/person with 20°C for the cold water temperature and 45°C for the water temperature out of taps. Then the DHW energy was adjusted to be 12,681 kWh for the low occupancy activity based models and 15,417 kWh for the high occupancy activity based models. DHW consumption for the zero internal load models remained to be the same as that of NABERS default models. A 400 W circulation pump was assumed to run 24/7 using 2,453 kWh. The heating requirement was 13,200 kWh. The associated pumping energy was calculated as shown in Table 5.
- External lighting. The total power of the external lighting was assumed to be 3 kW running 12 hours a day for weekdays;
- Fire stairs and circulation space lighting. The total power was assumed to be from two sets of fire stairs consuming 144 W per floor or approximately 1.2 kW running 24/7.
- Circulation space lighting. Based on 5% of the building area with lighting power density of 15 W/m² giving approximately 4 kW running 24/7;
- Car Park Lighting. It was assumed that there was a 2,500m² underground car park with the 2 W/m² lighting power density running 24/7. No ventilation fans were included.
- Security system. The security system power was assumed to be 1 kW running 24/7.
- Fire monitoring. The fire monitoring power was assumed to be 0.2 kW running 24/7.
- Lifts. The lift energy was calculated based on 8 kWh/m² for the NABERS default models. Due to the changes to the occupancy, the lift energy has to be adjusted for the activity based models. However there is little literature about this problem. In this project we used an empirically derived lift energy formula [3] and adjust the NLA proportionally to the occupancy to reflect the impact of the occupancy changes on the lift energy. Then the lift energy was calculated to be 37,704 kWh for the low occupancy activity based models and 49,819 kWh for the high occupancy activity based models. Lift energy for the zero internal load models remained to be the same as that of NABERS default models.
- Electrical reticulation loss. The electrical reticulation loss was assumed to be 2%.

Appendix B. Simulation results

Category			Brisbane				Canberra			
			NABERS Default	Low Occupancy Activity Model	High Occupancy Activity Model	Zero Internal Load Model	NABERS Default	Low Occupancy Activity Model	High Occupancy Activity Model	Zero Internal Load Model
			KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh
Base Building	HVAC	Chiller	85,597	73,762	84,022	34,289	25,086	21,188	23,347	8,140
		Chiller pump	16,443	14,387	15,923	7,251	6,349	5,462	5,906	2,324
		Cooling tower	5,107	4,379	4,998	2,143	1,808	1,511	1,669	641
		Reheat	1,413	1,556	3,079	9,538	35,519	45,985	54,023	69,157
		AHU fan	19,884	17,532	19,628	14,116	16,175	15,253	16,894	13,612
	Miscellaneous	Exhaust fan	14,820	14,820	14,820	14,820	14,820	14,820	14,820	14,820
		DHW	13,200	12,681	15,417	13,200	13,200	12,681	15,417	13,200
		DHW pump	2,453	2,453	2,453	2,453	2,453	2,453	2,453	2,453
		Common area lighting	102,492	102,492	102,492	102,492	102,492	102,492	102,492	102,492
		Security system	8,760	8,760	8,760	8,760	8,760	8,760	8,760	8,760
		Fire monitoring	1,752	1,752	1,752	1,752	1,752	1,752	1,752	1,752
		Lift	40,000	37,704	49,819	40,000	40,000	37,704	49,819	40,000
		Reticulation loss	6,238	5,846	6,463	5,016	5,368	5,401	5,947	5,547
	Base Building Total		318,160	298,124	329,628	255,831	273,782	275,463	303,301	282,898
	NABERS Rating	Postcode	4,000	4,000	4,000	4,000	2,600	2,600	2,600	2,600
		Area	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
		Hours	50	50	55	50	50	50	55	50
		Rating	5.5	5.5	5.5	5.5	4.5	4.5	4.5	4.5
		Fractional rating	5.67	5.76	5.68	5.93	4.85	4.84	4.82	4.8
		Changes to the rating	N/A	0.09	0.01	0.26	N/A	-0.01	-0.03	-0.05

Category			Darwin				Melbourne			
			NABERS Default	Low Occupancy Activity Model	High Occupancy Activity Model	Zero Internal Load Model	NABERS Default	Low Occupancy Activity Model	High Occupancy Activity Model	Zero Internal Load Model
			KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh
Base Building	HVAC	Chiller	185,536	177,853	202,316	128,985	28,827	24,027	26,924	9,594
		Chiller pump	27,294	26,052	29,207	20,909	6,812	5,630	6,210	2,445
		Cooling tower	10,293	9,691	11,165	6,626	2,012	1,634	1,838	688
		Reheat	5	-	58	309	18,860	31,160	34,700	55,691
		AHU fan	35,625	29,522	32,631	17,401	16,093	15,151	16,896	13,574
	Miscellaneous	Exhaust fan	14,820	14,820	14,820	14,820	14,820	14,820	14,820	14,820
		DHW	13,200	12,681	15,417	13,200	13,200	12,681	15,417	13,200
		DHW pump	2,453	2,453	2,453	2,453	2,453	2,453	2,453	2,453
		Common area lighting	102,492	102,492	102,492	102,492	102,492	102,492	102,492	102,492
		Security system	8,760	8,760	8,760	8,760	8,760	8,760	8,760	8,760
		Fire monitoring	1,752	1,752	1,752	1,752	1,752	1,752	1,752	1,752
		Lift	40,000	37,704	49,819	40,000	40,000	37,704	49,819	40,000
		Reticulation loss	8,845	8,476	9,418	7,154	5,122	5,165	5,642	5,309
	Base Building Total		451,074	432,256	480,308	364,860	261,202	263,429	287,722	270,778
	NABERS Rating	Postcode	800	800	800	800	3,000	3,000	3,000	3,000
		Area	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000
		Hours	50	50	55	50	50	50	55	50
		Rating	5.5	5.5	5	5.5	4.5	4.5	4.5	4.5
		Fractional rating	5.5	5.56	5.43	5.78	4.89	4.88	4.87	4.84
		Changes to the rating	N/A	0.06	-0.07	0.28	N/A	-0.01	-0.02	-0.05

Category			Sydney			
			NABERS Default	Low Occupancy Activity Model	High Occupancy Activity Model	Zero Internal Load Model
			KWh	KWh	KWh	KWh
Base Building	HVAC	Chiller	59,906	50,454	56,790	20,455
		Chiller pump	13,032	10,934	12,081	5,147
		Cooling tower	3,829	3,199	3,602	1,401
		Reheat	3,313	5,184	7,412	20,071
		AHU fan	18,337	16,546	18,346	13,859
	Miscellaneous	Exhaust fan	14,820	14,820	14,820	14,820
		DHW	13,200	12,681	15,417	13,200
		DHW pump	2,453	2,453	2,453	2,453
		Common area lighting	102,492	102,492	102,492	102,492
		Security system	8,760	8,760	8,760	8,760
		Fire monitoring	1,752	1,752	1,752	1,752
		Lift	40,000	37,704	49,819	40,000
		Reticulation loss	5,638	5,340	5,875	4,888
	Base Building Total		287,530	272,318	299,620	249,298
	NABERS Rating	Postcode	2,000	2,000	2,000	2,000
		Area	5,000	5,000	5,000	5,000
		Hours	50	50	55	50
		Rating	5.5	5.5	5.5	5.5
		Fractional rating	5.6	5.67	5.61	5.78
		Changes to the rating	N/A	0.07	0.01	0.18

References

[1] NABERS, www.nabers.gov.au

[2] Office of Environment and Heritage NSW, NABERS Guide to Building Energy Estimation June 2011, available at www.nabers.gov.au

[3] P. Bannister, C Bloomfield and H. Chen Empirical Prediction of Office Building Lift Energy Consumption, Proceedings of Building Simulation 2011, The 12th Conference of the International Building Performance Simulation Association, Sydney November 2011.