HVAC CONTROL SIMULATION STUDY FOR AUSTRALIAN OFFICE BUILDINGS

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ABSTRACT

This paper presents a generic model developed as a base case to represent a mid-sized Australian office building with possible best practice HVAC configurations. A number of common control methods or failures were assessed by the simulation. The methodology used in developing the models is given and the simulation was carried out in four Australian capital cities – Sydney, Melbourne, Brisbane and Canberra. The impact of the control methods or failures were compared and analysed. It is demonstrated that zone temperature control, fan control and supply air temperature control have a significant impact (~10%-40%) on energy use, while economy cycle, minimum outside air and chilled water temperature reset have a less impact (<10%). Combined failure scenarios show that the difference between best practice and poor control can range as high as 50% to 90%, demonstrating the fundamental importance of control. Sensitivity to control is considerably greater in milder climates.

INTRODUCTION

Australian office buildings consume a large amount of energy in the provision of air-conditioning. The temperate Australian climate means that the associated controls play a significant role in the determination of air-conditioning efficiency. As a result, optimisation of HVAC controls is a common technique for efficiency improvement. However, the estimation of the energy savings impact of individual control measures in the energy management industry tends to be crude and indeed the selection of control measures is frequently based on intuition rather than science. With improvements in building simulation packages, it is now possible to robustly assess the savings and impacts associated with common control methods and failures to develop a more analytical understanding of the potential of each to assist or detract from building efficiency.

In this study, a base case model and a series of scenarios with common control failures or improvements have been developed. The modelling has been carried out with a standard VAV configuration, representing the most common building servicing type for medium to large buildings in Australia. The simulation results of the base case and the scenarios have been analysed and compared to evaluate the importance of each control method.

BASE CASE MODEL

A typical Australian commercial building with possible best practice HVAC system was modelled as the base case for this study. The simulation follows *NABERS Energy Guide to Building Estimation Version 2011-June*. NABERS is The National Australian Built Environment Rating System, which provides a benchmarking system for energy consumption of Australian commercial office buildings.

Basic characteristic

The base model has these characteristics:

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

Diagrams of such a building as shown in Figure 1 and Figure 2:

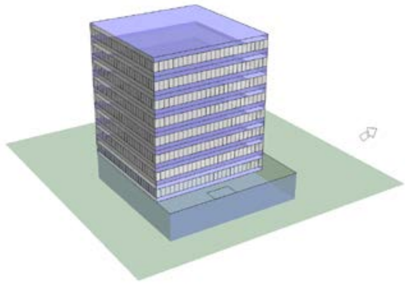

Figure 1: View of simulation model

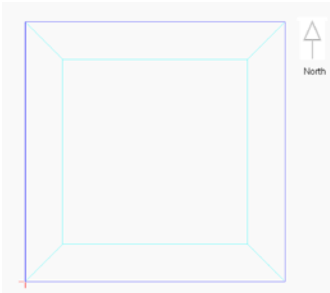

Figure 2: Floor plate showing zones

The total NLA is 5,000 m .

Building Construction

The following constructions were used:

- Glazing

Double glazing with the characteristics shown in Table 1 was used in the simulation.

Table 1: Glazing characteristics for the best practice model

Type	Construction (From outside to inside)	U value ($W/m^2.K$)	Shading coefficient	% Light transmittance
External glazing	6mm Pilkington Optifloat Green	2.8	0.53	76
	Air cavity			
	6mm Clear float			

- Opaque construction

The following opaque constructions were used in the simulation:

Table 2: Opaque construction details for the best practice model

Construction description	Material (From outside to inside)	Thickness (mm)	Total R-Value (m ·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.

Building Loads

The building loads are as follows:

- Occupancy. 10 m per occupant. Sensible load of 75 W/m and 55 W/m latent load.
- Equipment. 15W/m
- Lighting power density. The lighting power density of 10 W/m distributed equally between plenum and zone.

Ventilation and infiltration

The ventilation rate during occupied hours was set at 7.5 l/s/person.

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 $l/(s \cdot m \cdot P_a^{0.6})$ was selected to represent the average leakage through the windows. The crack length is equal to the window perimeter.

Weather file

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

Modelling software

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.

Schedules of operation

The Australian NABERS schedules were used as shown in Appendix 1:

HVAC

- Zone temperature control

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

- AHU configuration

Separate AHUs were provided for each facade and for the centre zone. All AHUs were configured with an 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.

- Heating

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

- Cooling

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.

SCENARIOS

In order to examine the impact of the control failure and improvement, the scenarios listed below are modelled. The description for each scenario is the changes to the base case.

Zone control scenarios

- Scenario 01 – zone temperature deadband from 22°C to 23°C with 1°C proportional bands either side of this.
- Scenario 02 – zone temperature deadband from 22°C to 23°C with 0.5°C proportional bands either side of this.
- Scenario 03 – zone temperature deadband from 22.25°C to 22.75°C with 0.5°C proportional bands either side of this.
- Scenario 04 – zone temperature deadband from 21°C to 24°C, ON/OFF control for heating and cooling at 21°C and 24°C.

Fan control scenarios

- Scenario 05 – x2 fan turndown (representing constant pressure control)
- Scenario 06 – linear fan turndown (representing constant fan)

Supply temperature control scenarios

- Scenario 07 – Supply air temperature reset from 12°C to 24°C when the zone temperature drops from 24°C to 23.5°C.
- Scenario 08 – Supply air temperature reset from 12°C to 24°C when the zone temperature drops from 24.5°C to 24°C.
- Scenario 09 – Supply air temperature reset from 12°C to 20°C when the zone temperature drops from 23.5°C to 21.5°C.

Economy cycle control scenarios

- Scenario 10 – Enthalpy economy cycle with a drybulb lockout at 19°C. The AHU will use outside air as free cooling when the outside air enthalpy is less than the return air enthalpy.
- Scenario 11 – Temperature economy cycle with a drybulb lockout at 19°C and a RH lockout at 70%. The AHU will use outside air as free cooling when the outside air drybulb temperature is less than that of the return air.
- Scenario 12 –Temperature economy cycle with a drybulb lockout at 19°C

Minimum outside air control scenarios

- Scenario 13 – Outside air controlled by the indoor CO2 concentration between 600 ppm to 800 ppm.
- Scenario 14 – Minimum outside air set to 10 l/s/person
- Scenario 15 – Minimum outside air set to 11.25 l/s/person

Chiller control scenario

- Scenario 16 – Chiller configuration changed from fixed chilled water temperature to variable temperature

Combination scenarios

- Scenario 17 – a “good control” scenario which is the combination of scenario 04 and 16.
- Scenario 18 – a “bad control” scenario which is the combination of scenario 03, 06, 08, 11 and 13.

RESULTS

The base case and the scenario 1 to 18 were modelled respectively. The simulations were carried out in four Australian capital cities - Sydney, Melbourne, Brisbane and Canberra. The results are shown in Table 6 to Table 9 in Appendix 2. The item “difference” in the tables is the percentage of each scenario’s increase or reduction compared to the base case.

ANALYSIS

Zone temperature control

In Figure 3, the impact of increasing the proportional band at fixed deadband can be seen. SC01 and SC02 both have 1°C deadband but the proportional band is 1°C in SC01 and 0.5°C in SC02. It is clear from the figure that in all cases the narrower proportional band increases energy consumption, reflecting the genrally tighter control range that results. The effect is strongest in cooler climate centres.

In Figure 4, the impact of deadband is demonstrated. It can be seen that the narrowness of the deadband significantly increases the energy consumption. By contrast, scenario 4, which has the widest deadband and uses PID control to maintain temperature within the control band limits, provides an improved energy efficiency relative to the base case in all centres. Dead band effects are also greatest for cooler climates, reflecting the increased possibility of heating/cooling conflict in these climates.

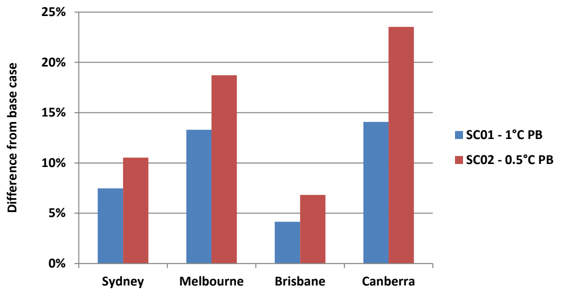

Figure 3 SC01 and 02 – effect of proportional band

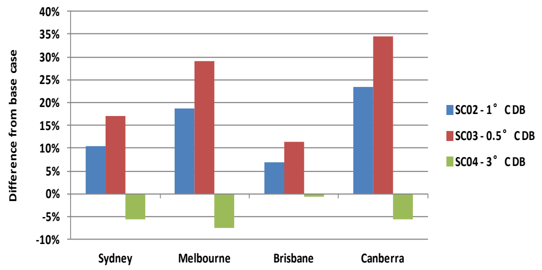

Figure 4 SC02, 03 and 04 – effect of deadband band

Of course, in modulating the zone temperature control, it is arguable that one is impacting on occupant comfort. To test this the area weighted PMV values have been calculated and the results are shown in Table 3. Note that the Clothing level is set to 0.95 for calculating PMV<-0.5 and 0.6 for calculating PMV>0.5, the activity level is set as sedentary work and air velocity 0.15 m/s. The results in Table 3 shows that except SC04 the percentages of area weighted PMV in different scenarios but in the same city are very close, indicating that the comfort impacts are minimal.

Table 3: Percentages of area weighted PMV

PMV between -0.5 and +0.5	Base case	SC01	SC02	SC03	SC04
Sydney	99.8%	99.9%	99.9%	100.0%	96.5%
Melbourne	99.1%	99.3%	99.4%	99.5%	96.4%
Brisbane	99.6%	99.7%	99.8%	99.8%	95.5%
Canberra	97.1%	97.5%	97.7%	97.9%	95.3%

Fan control

Figure 5 provides clear evidence of the impact of fan control on energy use, with differences in excess of 35% relative to base case for linear fan turn down in the cooler climates. It can be seen that warmer climates are less impacted by fan energy, although this is largely due to the predominance of chiller energy in these locations, as the absolute increase in fan energy is comparable.

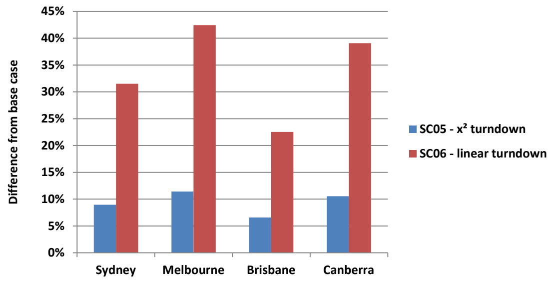

Figure 5 SC05 and 06 – linear and x2 fan turndown

Supply air temperature reset

The control of supply air temperature sets a critical balance between fan energy and chiller energy for a VAV system as tested in Scenarios 7 and 8, which progressively move from the low temperature/low flow bias of the base case to a high temperature/high flow bias.

It can be seen from Figure 6 that the impacts of strong bias to high flow/high temperature operation (Scenario 8) are considerable in all centres, while those associated with a mild bias (Scenario 7) are somewhat more equivocal, especially in the cooler climates. This is expected to reflect the increased use of chillers in winter ahead of economy cycle operation in these cases. A combination of base case operation and scenario 7 with seasonal adjustments to maximise economy cycle operation may achieve improved overall results in this case, but is difficult to test.

Scenario 9 tests the impact of a lowered maximum supply temperature, which should be expected to increase the use of chillers and terminal heating. However in all cases the impact is minor.

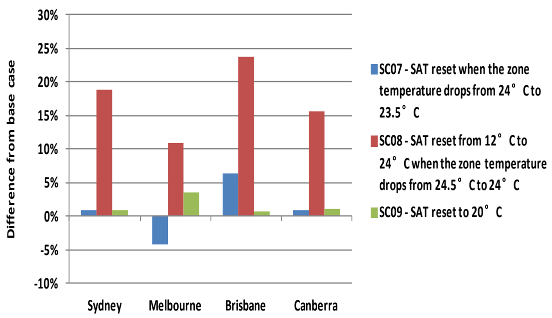

Figure 6 SC07, 08 and 09 – AHU supply air temperature reset

Economy cycle

In the base case, the economy cycle is the temperature economy cycle with drybulb lockout at 24°C and dewpoint lockout at 14°C. Three other scenarios – enthalpy economy cycle with drybulb lockout at 19°C (SC10), temperature economy cycle with drybulb lockout at 19°C and RH lockout at 70% (SC11) and temperature economy cycle only with drybulb lockout at 19°C (SC12) are modelled to analyse the energy impact. These three scenarios consume slightly more energy than the base case. Maximally SC11 served by the standard VAV system in Canberra use about 5% than the base case. Other scenarios only have energy increases between 1% to 2.5%.

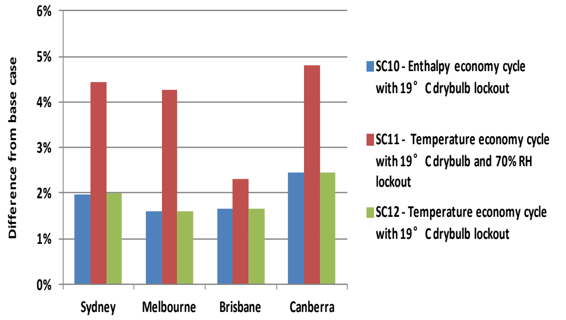

Figure 7 SC10, 11 and 12 – control of economy cycle

Minimum outside air

The minimum outside air is 10 l/s/person for SC14 and 11.25 l/s/person for SC15 compared with 7.5 l/s/person for the base case. In SC12, CO2 control is used to adjust minimum outside air to maintain the room CO2 concentration between 600 ppm to 800 ppm, which is generally equivalent to a higher level of outside vair ventilation basis than either of the other scenarios.

Generally the impact of outside air is very limited in Sydney, Melbourne and Brisbane. But it does have substantial impact in Canberra because Canberra buildings need more heating and excess outside air significantly increases the heating load.

The relatively high energy use of scenario 13 demonstrates that the value of CO2 control lies largely in the selected control figure than the presence or otherwise of the control; clearly, selecting the wrong control band for CO2 control can have a significantly negative impact on efficiency.

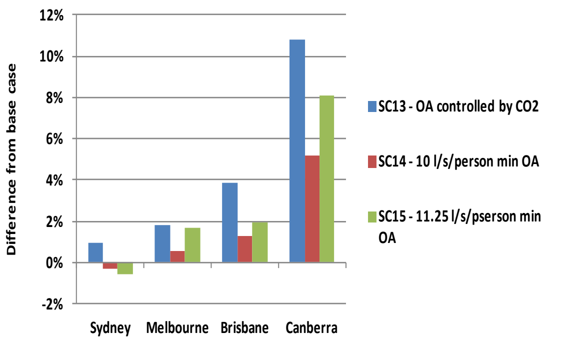

Figure 8 SC13, 14 and 15 – minimum outside air control

Variable chilled water temperature control

Variable chilled water temperature control is modelled in SC16. As the ambient air temp goes from 28ºC to 16ºC the chilled water is reset from 5ºC to 10ºC. Part load performance data at a range of condenser water temperatures (14 to 26ºC) and chilled water temperatures (5 to 10 ºC) were used to look up the Coefficient of Performance (COP) over a range of operating conditions. Figure 9 shows this chiller control strategy saves energy but the saving is limited.

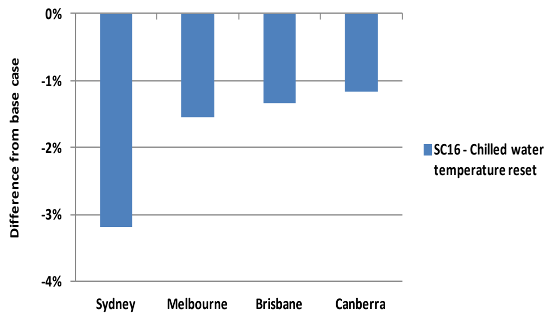

Figure 9 SC16 – variable chilled water control

Combined scenario testing

In real buildings, control failures tend to occur in groups rather than individually. As a result, it is worthwhile to examine the impact of combined control scenarios to understand the potential overall impact of good control versus bad control.

The "good control" scenario has been set based on the combination of the base case with the generally positive impacts of the zone temperature control from scenario 4 and 16.

The "bad control" scenario has been set based on the combination of the base case with the worst case scenarios 3, 6, 8, 11 and 13.

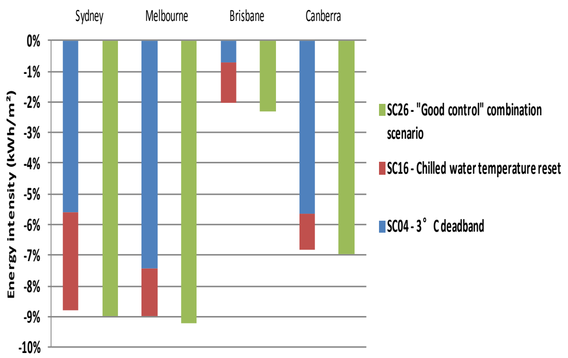

Figure 10 SC17 – the "good control" combination scenario compared to SC04 and 16

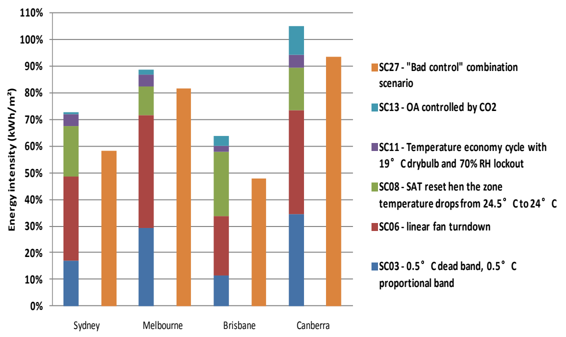

Figure 11 SC18 – the "bad control" combination scenario compared to SC03, 06, 08, 11 and 13

The effect of the "good control" combination scenario is approximately equal to the sum of the individual scenario 04 and 16. However the effect of the "bad control" combination scenario is less than the sum of the individual scenarios. That means the combination of good control strategies or the control failures will not give additive effects on the energy consumption.

CONCLUSION

The HVAC controls play a significant role in the determination of energy efficiency in Australian office buildings. A simulation model is a valuable tool in assessing the effectiveness of controls. From the above analysis, we draw the following conclusions:

- The fan turndown is the most important impacting factor. The linear fan turndown wastes up to 40% more energy than the x2.7 turndown which represents the variable pressure fan control.
- Zone temperature control is a simple and effective way to change the building efficiency. Over tightening the zone deadband and proportional band will not obviously improve the thermal comfort but will use a lot more energy.
- For a VAV building, the cooling supply air temperature is also important. The control that starts to lower the supply air temperature after the VAV flow reaches maximum should be avoided.
- Economy cycle, minimum outside air and chilled water temperature reset have a less impact (<10%) on energy consumption.
- Combined failure scenarios show that the difference between best practice and poor control can range as high as 50% to 90%, demonstrating the fundamental importance of control.
- Sensitivity to control is considerably greater in milder climates.

REFERENCES

NSW office of environment and heritage. 2011. NABERS Energy Guide to Building Energy Estimation.

Integrated Environmental Solutions Limited. 2012. IES<VE> User Guide.

APPENDICES

Appendix 1 - Australian NABERS schedule

Table 4: Australian NABERS schedule for Weekdays

Time Period	Occupancy	Lighting (limited control)	Equipment	HVAC Operation
0000-0100	0%	15%	50%	off
0100-0200	0%	15%	50%	off
0200-0300	0%	15%	50%	off
0300-0400	0%	15%	50%	off
0400-0500	0%	15%	50%	off
0500-0600	0%	15%	50%	off
0600-0700	0%	15%	50%	off
0700-0800	15%	40%	65%	on
0800-0900	60%	90%	80%	on
0900-1000	100%	100%	100%	on
1000-1100	100%	100%	100%	on
1100-1200	100%	100%	100%	on
1200-1300	100%	100%	100%	on
1300-1400	100%	100%	100%	on
1400-1500	100%	100%	100%	on
1500-1600	100%	100%	100%	on
1600-1700	100%	100%	100%	on
1700-1800	50%	80%	80%	on
1800-1900	15%	60%	65%	off
1900-2000	5%	60%	55%	off
2000-2100	5%	50%	55%	off
2100-2200	0%	15%	50%	off
2200-2300	0%	15%	50%	off
2300-2400	0%	15%	50%	off

Table 5: Australian NABERS schedule for weekends and holidays

Time Period	Occupancy	Lighting (limited control)	Equipment	HVAC Operation
0000-0100	0%	15%	50%	off
0100-0200	0%	15%	50%	off
0200-0300	0%	15%	50%	off
0300-0400	0%	15%	50%	off
0400-0500	0%	15%	50%	off
0500-0600	0%	15%	50%	off
0600-0700	0%	15%	50%	off
0700-0800	0%	15%	50%	off
0800-0900	5%	25%	55%	off
0900-1000	5%	25%	55%	off
1000-1100	5%	25%	55%	off
1100-1200	5%	25%	55%	off
1200-1300	5%	25%	55%	off
1300-1400	5%	25%	55%	off
1400-1500	5%	25%	55%	off
1500-1600	5%	25%	55%	off
1600-1700	5%	25%	55%	off
1700-1800	0%	15%	50%	off
1800-1900	0%	15%	50%	off
1900-2000	0%	15%	50%	off
2000-2100	0%	15%	50%	off
2100-2200	0%	15%	50%	off
2200-2300	0%	15%	50%	off
2300-2400	0%	15%	50%	off

The schedules above are effectively for a building operating with comfort conditions from 08:00 to 18:00 hours with an hour's warm up of the HVAC system. This is 50 hours per week

Appendix 2 – Simulation results

Table 6: Results of Sydney standard VAV models

Sydney-Standard VAV	Base case	SC01	SC02	SC03	SC04	SC05	SC06	SC07	SC08	SC09	SC10	SC11	SC12	SC13	SC14	SC15	SC16	SC17	SC18
Category	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh
Chiller	73,291	78,807	78,890	81,585	67,390	74,375	76,962	60,285	56,666	73,859	75,606	78,448	75,622	73,882	72,842	72,555	70,081	63,918	70,632
Chiller pump	15,535	16,313	16,331	16,766	13,416	15,690	16,160	11,833	10,810	15,670	16,187	16,666	16,188	15,489	15,348	15,214	15,535	13,416	14,319
Cooling tower	4,859	5,241	5,260	5,465	4,458	4,934	5,121	3,905	3,610	4,899	5,036	5,229	5,037	4,941	4,834	4,822	4,212	3,861	4,734
Reheat	1,808	3,068	5,104	8,053	1,447	1,804	1,778	592	494	2,281	1,805	1,741	1,818	1,824	1,836	1,877	1,808	1,447	3,778
AHU fan	25,626	26,753	28,285	29,950	27,617	35,162	59,260	45,554	72,315	25,539	24,859	24,422	24,873	26,100	25,859	25,976	25,626	27,617	98,048
HVAC Total	121,118	130,182	133,870	141,820	114,328	131,964	159,281	122,170	143,895	122,248	123,494	126,506	123,537	122,236	120,718	120,444	117,262	110,258	191,511
Difference	N/A	7%	11%	17%	-6%	9%	32%	1%	19%	1%	2%	4%	2%	1%	0%	-1%	-3%	-9%	58%
Energy intensity (kWh/m)	24.2	26.0	26.8	28.4	22.9	26.4	31.9	24.4	28.8	24.4	24.7	25.3	24.7	24.4	24.1	24.1	23.5	22.1	38.3

Table 7: Results of Melbourne standard VAV models

Melbourne-Standard VAV	Base case	SC01	SC02	SC03	SC04	SC05	SC06	SC07	SC08	SC09	SC10	SC11	SC12	SC13	SC14	SC15	SC16	SC17	SC18
Category	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh
Chiller	39,664	44,420	44,217	46,500	34,310	40,471	42,621	30,135	28,037	40,378	40,910	42,998	40,891	38,710	38,440	37,987	38,761	33,162	36,576
Chiller pump	9,408	10,408	10,275	10,712	7,367	9,579	10,125	6,294	5,692	9,664	9,758	10,213	9,769	8,902	8,887	8,666	9,408	7,367	7,747
Cooling tower	2,850	3,179	3,175	3,345	2,389	2,911	3,074	2,052	1,869	2,925	2,942	3,087	2,941	2,768	2,749	2,707	2,477	2,074	2,552
Reheat	9,764	14,121	17,982	22,742	10,303	9,503	8,567	7,121	7,007	11,634	9,773	9,574	9,776	12,347	11,797	13,302	9,764	10,303	22,657
AHU fan	20,540	21,036	21,975	22,928	21,755	29,145	52,729	33,098	48,541	20,483	20,158	19,856	20,170	20,987	20,807	20,936	20,540	21,755	79,665
HVAC Total	82,226	93,164	97,623	106,226	76,123	91,609	117,116	78,700	91,147	85,085	83,542	85,728	83,547	83,714	82,679	83,599	80,950	74,661	149,196
Difference	N/A	13%	19%	29%	-7%	11%	42%	-4%	11%	3%	2%	4%	2%	2%	1%	2%	-2%	-9%	81%
Energy intensity (kWh/m)	16.4	18.6	19.5	21.2	15.2	18.3	23.4	15.7	18.2	17.0	16.7	17.1	16.7	16.7	16.5	16.7	16.2	14.9	29.8

Table 8: Results of Brisbane standard VAV models

Brisbane-Standard VAV	Base case	SC01	SC02	SC03	SC04	SC05	SC06	SC07	SC08	SC09	SC10	SC11	SC12	SC13	SC14	SC15	SC16	SC17	SC18
Category	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh
Chiller	109,155	113,208	114,017	116,452	107,027	110,212	112,721	100,195	96,661	109,684	111,825	112,834	111,828	113,166	110,671	111,339	107,832	105,229	112,380
Chiller pump	19,813	20,343	20,554	21,035	18,984	19,996	20,394	17,856	17,086	19,996	20,475	20,674	20,473	21,110	20,032	20,206	19,813	18,984	20,864
Cooling tower	6,769	7,051	7,132	7,321	6,641	6,848	7,032	6,164	5,892	6,801	6,956	7,019	6,956	7,200	6,907	6,976	5,890	5,775	7,190
Reheat	711	1,249	2,696	5,021	624	696	676	338	262	1,051	710	677	710	705	717	723	711	624	2,517
AHU fan	28,755	30,207	32,093	34,096	30,787	38,343	61,600	51,042	84,658	28,682	27,976	27,813	27,980	29,366	29,033	29,171	28,755	30,787	101,247
HVAC Total	165,203	172,059	176,493	183,925	164,063	176,095	202,422	175,595	204,559	166,214	167,942	169,016	167,946	171,547	167,360	168,416	163,001	161,399	244,198
Difference	N/A	4%	7%	11%	-1%	7%	23%	6%	24%	1%	2%	2%	2%	4%	1%	2%	-1%	-2%	48%
Energy intensity (kWh/m)	33	34.4	35.3	36.8	32.8	35.2	40.5	35.1	40.9	33.2	33.6	33.8	33.6	34.3	33.5	33.7	32.6	32.3	48.8

Table 9: Results of Canberra standard VAV models

Canberra-Standard VAV	Base case	SC01	SC02	SC03	SC04	SC05	SC06	SC07	SC08	SC09	SC10	SC11	SC12	SC13	SC14	SC15	SC16	SC17	SC18
Category	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh	KWh
Chiller	33,766	38,351	38,719	40,872	29,988	34,365	36,059	26,572	24,029	34,023	35,812	37,823	35,803	33,379	32,936	32,651	33,103	29,178	33,461
Chiller pump	8,373	9,346	9,472	9,902	7,028	8,513	8,900	6,252	5,521	8,436	8,956	9,394	8,955	8,145	8,063	7,958	8,373	7,028	7,773
Cooling tower	2,534	2,879	2,919	3,085	2,232	2,587	2,725	1,976	1,750	2,578	2,700	2,858	2,700	2,486	2,459	2,430	2,204	1,940	2,513
Reheat	18,927	24,481	31,028	36,607	18,291	18,207	16,213	17,045	16,863	19,548	18,937	18,618	18,936	28,372	24,334	27,072	18,927	18,291	42,938
AHU fan	21,413	21,922	22,868	23,872	22,655	30,314	54,339	33,888	50,143	21,370	20,705	20,407	20,711	21,805	21,644	21,762	21,413	22,655	77,900
HVAC Total	85,013	96,980	105,006	114,338	80,194	93,986	118,235	85,734	98,307	85,956	87,109	89,100	87,105	94,188	89,436	91,873	84,020	79,092	164,585
Difference	N/A	14%	24%	34%	-6%	11%	39%	1%	16%	1%	2%	5%	2%	11%	5%	8%	-1%	-7%	94%
Energy intensity (kWh/m)	17	19.4	21.0	22.9	16.0	18.8	23.6	17.1	19.7	17.2	17.4	17.8	17.4	18.8	17.9	18.4	16.8	15.8	32.9