THE OFFICIAL JOURNAL OF AIRAH
NOVEMBER 2016 · VOLUME 15.10
RRP $14.95

Ecolibrium

The art of smart

Buildings that think and adapt.

AIRAH

PRINT POST APPROVAL NUMBER PP352532/00001

Modelling the effect of climate change on economiser and night ventilation strategies in Australian cities

P Roach, M.AIRAH, F Bruno, M.AIRAH, M Belusko Barbara Handy Institute: University of South Australia

Corresponding author: Phillip.Roach@postgrads.unisa.edu.au

ABSTRACT

Increasing energy use in commercial buildings from warmer weather due to climate change has been identified as a cause for concern over recent years. Although considerable research has been undertaken into the resulting increase in energy consumptions in both residential and commercial buildings, along with a decrease in comfort levels in unconditioned buildings, little has been done to address the impact to specific operational strategies and the influence this could have on future building design and optimisation.

Simulations were undertaken for 2030 and 2050 for major capital cities in Australia to demonstrate the effect on the day and night-time potential for free cooling. Results showed that while climate change will decrease the benefit gained from natural cooling during the day, the opportunity exists to derive an increased benefit from night-time free cooling for centralised air conditioning systems. With thermal mass being critical to maximising the benefit of night ventilation systems, this provides an indicator of the type of construction that will be more suited to buildings in future years if an increase in energy use due climate change is to be reduced.

Key words: Thermal mass, night cooling, facades, low energy, economiser, climate change, Australia.

INTRODUCTION

In developing countries buildings have been identified to consume more than 40% of global energy, and are responsible for around 30% of global greenhouse gas emissions. These levels are expected to rise by 2.5% per year [1]. Climate change has been demonstrated to have an effect on energy levels globally, with an increase in cooling energy for warm climates [2]. Cooler climates are expected to experience a 30% decrease in heating energy and an increase in cooling energy, with cooling demands still possible from natural options [3].

In Australia, average temperatures have increased by approximately 0.8°C over the past century, with night-time temperatures increasing more than daytime [4] which could affect how passive ventilation strategies operate in future years.

Cooling energy is of primary concern globally and research has demonstrated a rise in the order of 25% due to climate change in California [5]. Sub-alpine regions could experience an increase in cooling demand of 500% and Mediterranean regions 100% [6]. Passive forms of cooling are therefore an important opportunity available to building designers to minimise the use of mechanical cooling systems, and it has been demonstrated that there are opportunities for this in European climates albeit with a decreased climatic cooling potential by the end of the 21st century [7]. It has also been recognised that certain types of buildings will be more sensitive to climate change than others [8]. It is the aim of this paper to identify how economiser and night ventilation strategies specifically can improve a building's resilience to climate change. Research has shown that buildings built to modern standards will see a significant rise in energy but those designed to minimise energy use will be the least affected [9]. Although studies for European climates have investigated, the changing benefit of these free-cooling strategies no such investigation for the varying climates in Australia have been undertaken. Without the swapping effect between heating and cooling experienced in cooler climates [9] Australia stands to experience a significant increase in annual energy use. A recent study on the effect of climate change in five Australian cities has demonstrated an increase in the total design cooling capacity of between 9.1% and 25% over the period 1990 to 2080; however, this study, while investigating a number of building retrofitting options, did not analyse the strategies of night ventilation, economiser cycles or the benefit of thermal mass [10]. Other studies have been undertaken that assess the impact of built form, internal gains and occupant behaviour as part of a parametric analysis with climate change; again these do not specifically investigate the role of economiser or night ventilation strategies [11].

Closer attention with the air conditioning systems design and operation is required if the increase in energy consumption is to be mitigated. It has been noted that a rise in humidity levels due to changes in wet bulb temperature has the potential to limit the cooling effect of direct evaporative coolers [12].

Although this has a greater potential to affect residential buildings in Australia, the change has the potential to limit the use of direct and indirect evaporative technology which is becoming more common for commercial applications [3, 13]. This trend will force a reliance on refrigerated cooling technologies which offer dehumidification as part of the cooling process.

Night-time ventilation has the potential to reduce energy consumption by using the internal thermal mass of a building to cool the night air to dissipate heat absorbed during the day [14]. For this to be of benefit in future years, an assessment of the diurnal temperatures available needs to be undertaken. There are also other factors that impact on the energy use within buildings. In certain climates these may have a more dominant effect in future energy use than climate change [15]. Studies have also demonstrated that for existing buildings in a "hot summer, cold winter" region of China, buildings with improved building envelopes are likely to be more efficient in 2080 than under the current [16] climate with their current envelope.

Studies on European climate change and its impact on night ventilation have demonstrated that the night-time cooling potential will cease to be sufficient to ensure thermal comfort in many central and southern European countries, and in central and northern countries, its benefit reduced by 20–50% [17].

It is recognised that in colder climates such as Stockholm, climate change will result in a decrease in annual heating energy. This has been shown to be in the order of 30% [3]. In California, where a balance of heating and cooling is required throughout the year, the energy required for cooling is likely to increase by 50% in the next 100 years if cooling technology remains at the same level for the Intergovernmental Panel on Climate Change (IPCC)'s worst case scenario, and 25% for the most likely [5].

Free cooling from the use of outside air is a common strategy utilised in heating, ventilation and air conditioning systems (HVAC) systems globally, and differing climatic regions gain differing benefits from each of the strategies. The economiser strategy operates during daytime hours when external ambient temperatures are suitable for free cooling to be of a benefit to the conditioning of the internal spaces of a building. This is generally set within control systems to activate when the external ambient is ≥2°C lower than the internal room set point. The economiser strategy operates on an instantaneous thermal exchange, with heat being removed without a necessity for internal mass for thermal storage. The night ventilation strategy operates in a similar way, but research has demonstrated that increased internal thermal mass increases savings in annual cooling energy [18, 19]. With climate change predicted to result in increased energy use globally, the validity of each of these strategies needs to be questioned to validate current thinking.

In hot humid locations, a decrease in diurnal temperatures is not as pronounced as with hot, dry climates [20] and therefore the benefit of night cooling is reduced. It has also been demonstrated that internal thermal mass is required to maximise the benefit from night-time cooling. If this opportunity is eliminated with climate change, the basis for utilising internal thermal mass is greatly reduced. Daytime economiser cycle use relies on a moderate external ambient temperature, and is therefore exploiting a predominantly instantaneous exploitation of free cooling.

An assessment of climate change on residential buildings in Australia has been undertaken. It shows that energy-efficient buildings are more likely to be affected by increasing ambient temperatures as a percentage of their current energy use. Although this information is not directly transferable to commercial properties it does highlight the effect climate change will have on energy use in Australia. The annual energy use for a property in the mixed-climate region of Sydney is projected to increase up to 120% and 530% for a 7 star rated house when global temperatures rise by 2°C and 5°C, respectively [21].

MODEL AND SIMULATION:

To analyse the effects of climate change on energy consumption, a model building was simulated using Energy Plus, with data interpreted via the Design Builder Software. A standard building footprint of 32x32m, over 10 floors has been recommended by the Australian Building Controls Board (ABCB) as being a common form of existing building for Australian capital cities [22].

Although the basis is this standardisation may be hard to extrapolate to current times, it does provide a basis for the model to be constructed. The intermediate fourth floor was simulated as part of the study, with a glazed opening percentage (GOP) of 60% with single-glazed fenestration. It has been previously demonstrated that GOPs in excess of 60% do not add benefit in terms of lighting energy reduction from increased access to daylight [23]. Although this only offers limited impact for the thermal mass of the façade to influence the energy use within the building, it is more relevant by utilising an appropriate level of glazing, since GOPs less than 60% are not common. It is acknowledged that many modern commercial buildings utilise a predominantly fully glazed façade. But it is believed that the 60% GOP assessment will provide sufficient information for engineers to understand the way HVAC systems will operate with the effects of climate change. The floor simulated included a traditional suspended ceiling and an exposed concrete floor.

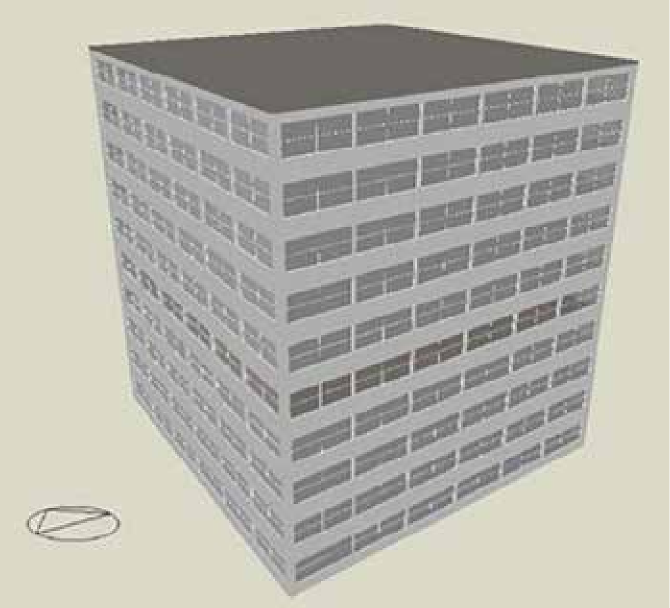

Figure 1: Building model.

A fabric of composite structure was used for the purpose of this investigation, since this has been demonstrated to be the optimum in respect of energy efficiency for a range of climatic regions [19]. Although this structure may not be representative of currently used facades in Australia, this research forms part of a wider investigation into thermal mass in commercial buildings and is included for continuity.

Table 1: Thermal properties of wall structure.

	U	R	M	T	A
	W/m²K	m²K/W	Kg	mm	W/m²K
1-Composite	0.64	1.56	420	250	5.84

U = Thermal transmittance (W/m²K)

R = Thermal resistance (m²K/W)

M = Mass of wall structure (Kg)

T = Thickness of wall structure (mm)

A = Admittance (W/m²K)

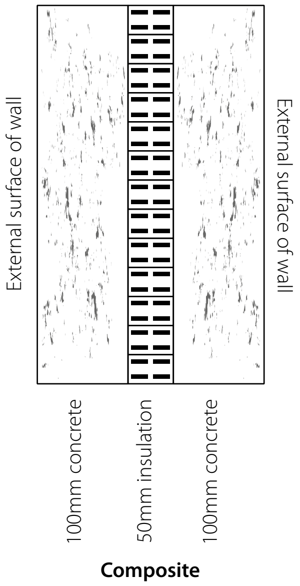

Figure 2: Cross-section of wall structure analysed.

To assess how the installed HVAC systems operate under differing climate change scenarios, the coefficient of performance for the cooling plant is fixed at 1.0, and parasitic energy due to fans and pumps are ignored. Therefore, all annual energy results reported are net building energy input figures. Energy for heating is also eliminated from the assessment, since this is not affected by the operation of economiser and night ventilation systems if control strategies are correctly set. It is not suggested that an efficient night-purge system can be operated without the aid of mechanical fan assistance. But the presentation of energy in its raw state offers engineers the opportunity to clearly identify possible changes in energy use.

The simulations were undertaken for the IPCC's low (B1) and high (A2) climate change scenarios for 2030 and 2060 [24]. The weather data was generated using Meteotest's Meteonorm software using an average of all 18 models from the IPCC report. Meteonorm is a commercially available software suite capable of generating weather data for energy simulations in global locations [25, 26]. The accuracy and limitations of generated as opposed to measured weather data is a separate topic in its own right, and cannot be adequately covered in this paper. Limitations such as location and interpolation of historic data between actual weather stations, the effect of heat islands in CBD locations and the assumptions surrounding future carbon dioxide emissions all need to be considered.

The initial base case for comparison was the International Weather for Energy Calculations from ASHRAE (IWEC) data file for each location, which is intended to represent current building operation. It should be recognised that IWEC files are generated from weather data approximately 10 years ago. More importantly, most simulation software weather files are generated from the measurement of climatic data at remote locations or near airports, but not in the centre of cities where commercial buildings are sited [27]. The urban heat island effect can distort the accuracy of these weather files. But since the same sites have been selected throughout the climate change period, the study is still relevant since a direct comparison can be made between results.

Table 2: Locations investigated.

Location	Building Code of Australia (BCA) zone	ASHRAE zone	Climate classification
Darwin	1	1B	Dry
Brisbane	2	4A	Mixed humid
Alice Springs	3	4B	Mixed dry
Adelaide	5	3C	Warm marine
Perth	5	4A	Mixed humid
Sydney	5	3A	Warm humid
Melbourne	6	3C	Warm marine
Canberra	7	4A	Mixed humid

Combination and operation of systems results:

Simulations were undertaken to calculate the annual cooling energy and peak cooling load with the following free cooling strategies:

1. Air conditioner (A/c) Scheduled and ventilation free cooling off – AsVo
2. A/c Scheduled and ventilation free cooling scheduled from 8am to 6pm (economiser cycle) – AsVs
3. A/c Scheduled and ventilation free cooling constant at 24hrs per day (economiser cycle and free cooling) – AsVc

For each of the options, the base air conditioning system was enabled from 7am to 7pm, with minimum outside air of 10L/s/person available between 8am and 6pm. With occupancy levels fixed at 1person/10m², the rate of supply of outdoor air can be calculated for each option. Outside air is supplied to decentralised units at a fixed rate, calculated on the basis of the density of occupation and the provision of outside air per person according to relevant codes and standards such as the Building Code of Australia [28] or Greenstar Rating systems [29].

HVAC systems in many commercial buildings take the form of two primary types, centralised and decentralised. Each have their benefits in respect of space for reticulation of services, initial capital cost, level of comfort and whole of life costs.

To provide a greater insight into how climate change may affect the decision making of the operational strategies of air conditioning systems, the two primary types of systems were modelled as follows:

1. Central plant air conditioning system – Maximum outside air availability of 12ach/hr and minimum of 10L/s/p, approximately 1ach/hr (figure 3)
2. Decentralised air conditioning system – Fixed outside air availability of 10L/s/p, approximately 1ach/hr (figure 4).

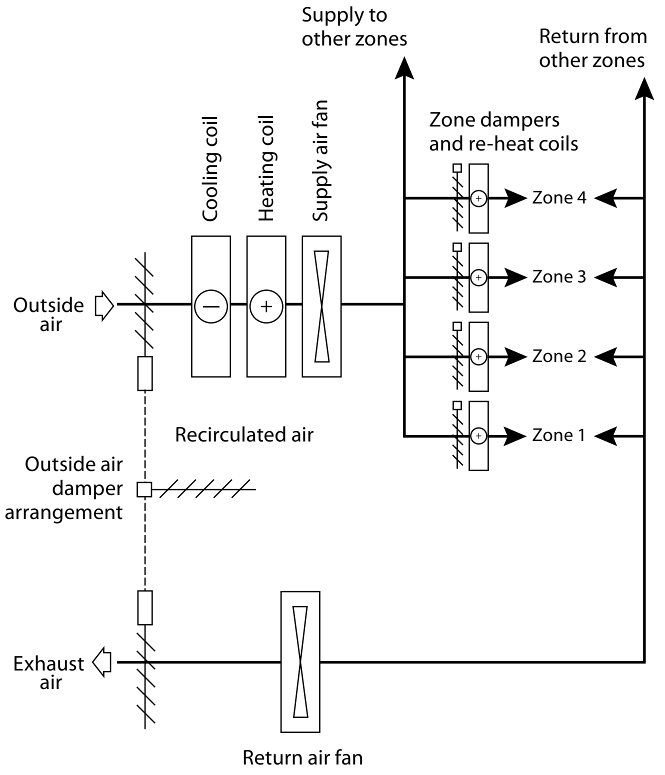

Figure 3: Centralised system schematic.

Centralised systems are common in major buildings and comprise of a central air-handling unit, with ductwork distributed throughout the building. These systems can be either constant or variable-volume flow and terminal reheat batteries are used to provide zone control. For the purpose of this model, a variable air volume system was selected. A central air-handling system has the ability to deliver its full supply volume as outdoor air, and this has great potential for free cooling applications. This economiser operation is a requirement of the Building Control of Australia for systems with a total duty of greater than 120kW in certain climate zones. A decentralised system with say 10 units of 12kW each would be exempt from this requirement, and therefore economiser routines are not often included in the control functionality.

Decentralised systems typically take the form of in ceiling fan-coil units, cassette units or packaged units for single-storey buildings. Unlike the centralised system, the thermal medium for heating and cooling (either water or refrigerant) is reticulated to the zone fan-coil units in pipework.

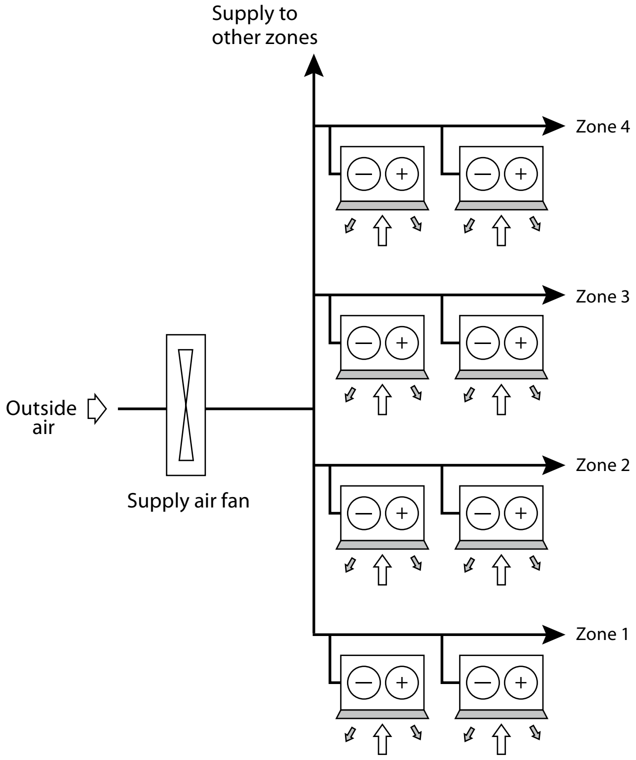

Figure 4: De-centralised system schematic.

Results:

A simple analysis of the results identified the savings delivered from the daytime operation and night-time operation of the outside air systems for both centralised and decentralised models. By separating daytime ventilation operation (AsVs) and from constant ventilation operation (AsVc) night-time savings can be represented. Figures 5 and 6 show that while the effects of climate change will decrease the energy-saving effect of daytime economiser cycle use, its impact, although still negative, will be reduced on night-time free cooling.

Decentralised systems:

For the decentralised systems, it can be seen in both low and high-impact climate change scenarios that there is a decreasing benefit from utilising either day or night-time free cooling strategies as would be expected with temperatures increasing due to climate change.

In Darwin, the minimal positive effect of night ventilation with the current IWEC weather year is even changed to a negative effect in both the low-impact and high-impact scenarios (figures 5 and 6). This is expected, since there is no variable volume control of the outdoor-air volume with these systems, and if average ambient temperatures rise, so will annual energy use.

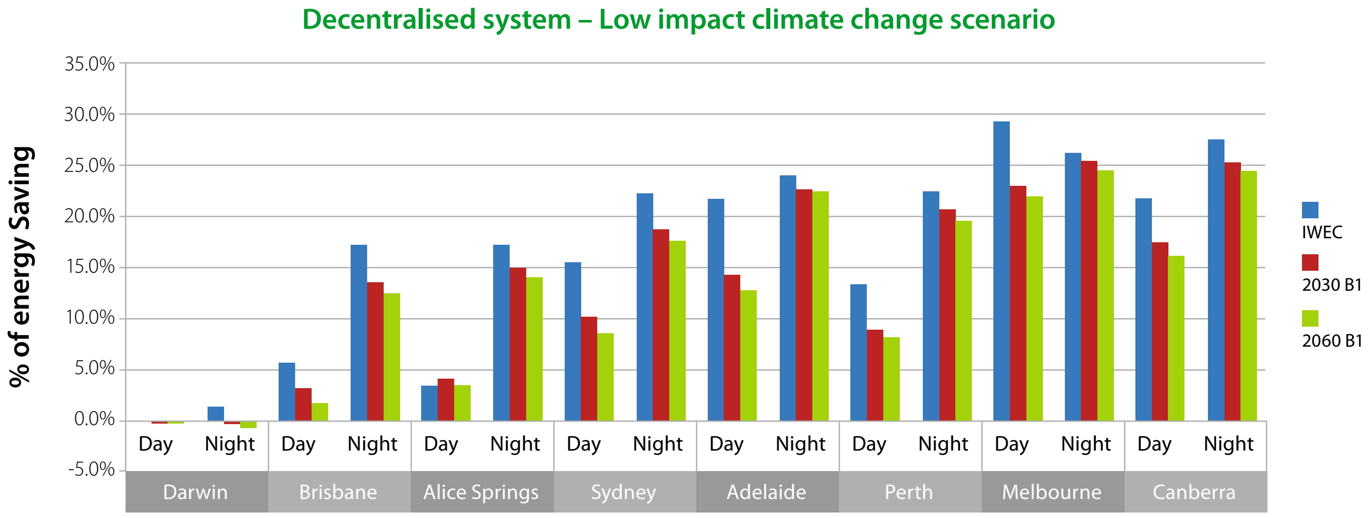

Figure 5: Decentralised system energy analysis – Low-impact climate change scenario.

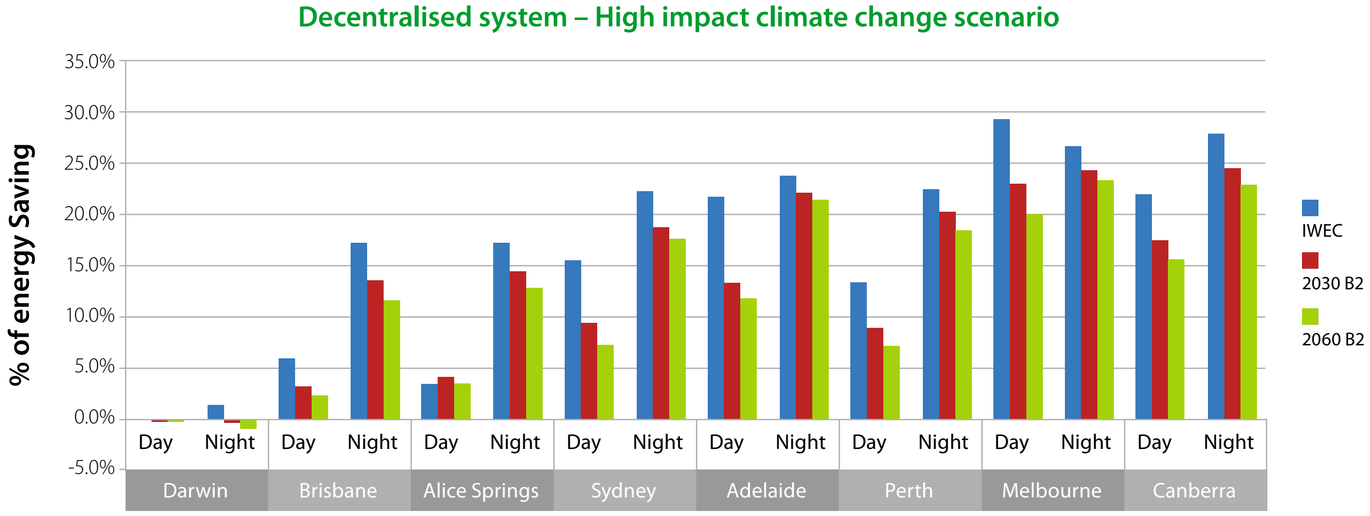

Figure 6: Decentralised system energy analysis – High-impact climate change scenario.

While there is a decrease in the benefit available from night cooling in Brisbane, it still remains a prominent strategy when compared to economiser operation, which decreases in benefit, and by 2060 is close to having a zero impact on energy saving.

Mixed-climate regions such as Adelaide and Sydney experience a significant decrease in the benefit obtained from daytime economiser operation but a relatively sustained benefit from night-time ventilation. With many of these systems not currently exploiting night-time outside-air operation, these results demonstrate that such a control strategy would not only be beneficial in current climate conditions but would be more beneficial in future years.

An understanding of how the building can be cooled during night periods is fundamental. It is accepted that most commercial buildings would utilise the ventilation systems to provide air for night cooling and this as noted earlier attracts parasitic loads. This may not be applicable to all buildings and the degree of fan energy can vary.

Centralised systems:

The analysis of the centralised systems gives a different set of results. It demonstrates that although daytime free-cooling strategies decrease in effectiveness, in mixed climates, the night-time free cooling increases in benefit over the climate change scenarios. Although the percentage increase is moderate, it can be seen in Melbourne that the benefit from night cooling increases with climate change. This is because the benefit from night cooling is represented as a percentage of the total annual energy, which is increasing disproportionally to the energy saved during daytime economiser operation, and improving the benefits from night-time cooling.

With this type of system, a far greater potential exists for the exploitation of free cooling from outside air. There is also an opportunity to reduce the volume flow to a minimum at periods when the ambient conditions are not suitable for free cooling. In Darwin, Brisbane and Alice Springs, both day and night free cooling experience a drop in benefit, but no negative results occur

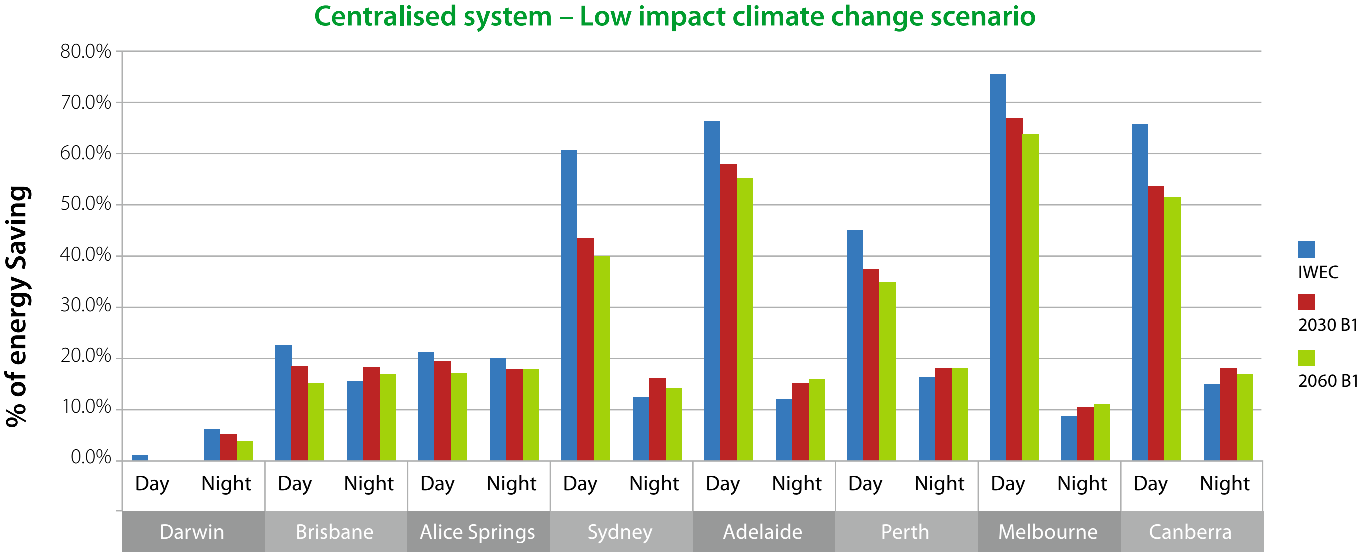

Figure 7: Centralised system energy analysis – Low-impact climate change scenario.

Mixed climates such as Adelaide and Sydney experience an increase in the benefit of night ventilation with climate change whereas savings from daytime operation of economiser cycles reduce to around 50% of their original benefit.

Overall benefit reduces with the effects of climate change but it is clear that a HVAC system that offers the opportunity for night-time free cooling will cope better once the true level of parasitic gains are quantified.

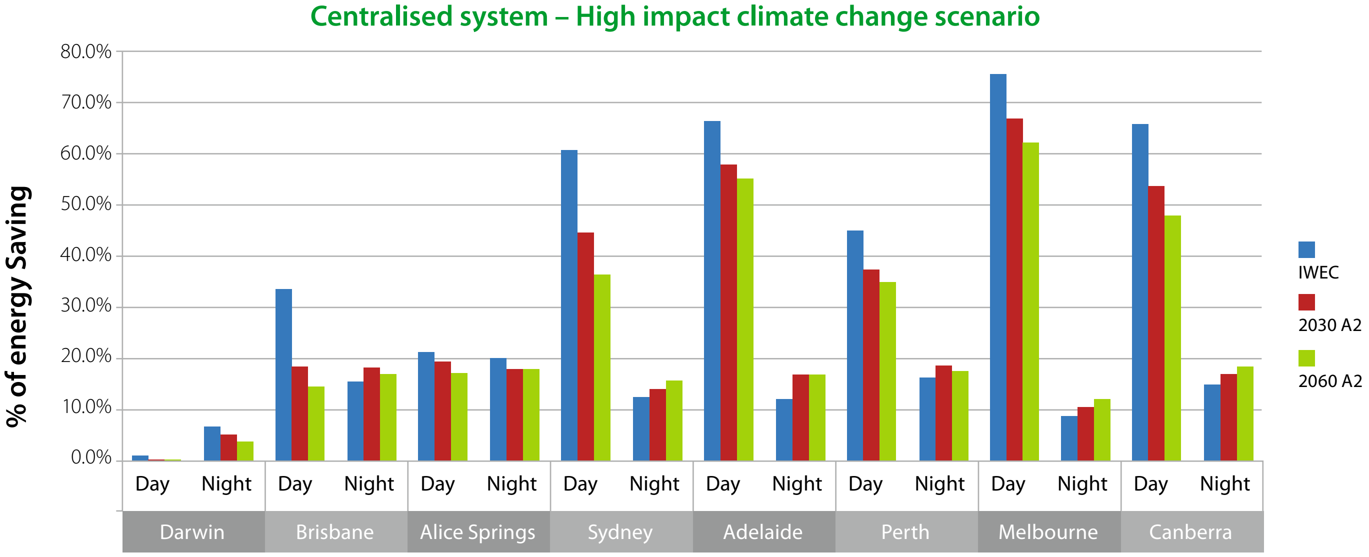

Figure 8: Centralised system energy analysis – High-impact climate change scenario.

as with the decentralised systems. This is because of the additional controls associated with centralised systems to attenuate much of the adverse effect of increased ambient temperatures. These cannot be controlled in decentralised systems with simpler control functions for the outside air volumes. The remaining locations all clearly show a decrease in daytime free cooling but an increase in the benefit achieved from night-time cooling strategies.

Comparison of energy increase against change in cooling degree days:

A comparison of energy use against the 10°C base cooling degree day (10°C CDD) was also calculated for each operation of the outside-air free cooling in a centralised system. This was undertaken for each of the four climate change scenarios against the current IWEC data.

In each of the four climate change scenarios, it can be clearly seen that there is a correlation between the increase in CDD and annual cooling energy for the scheduled air conditioning and "no free cooling" operation system (AsVo).

In Alice Springs and Darwin, there is still a correlation between the increase in CDD and annual energy, whereas in other locations the difference between the increase in CDD and energy use is substantial.

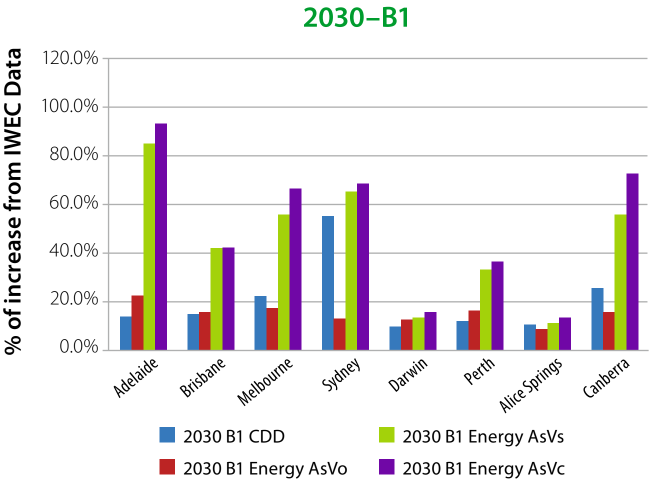

Figure 9: Centralised system – cooling degree days to energy increase, 2030–B1

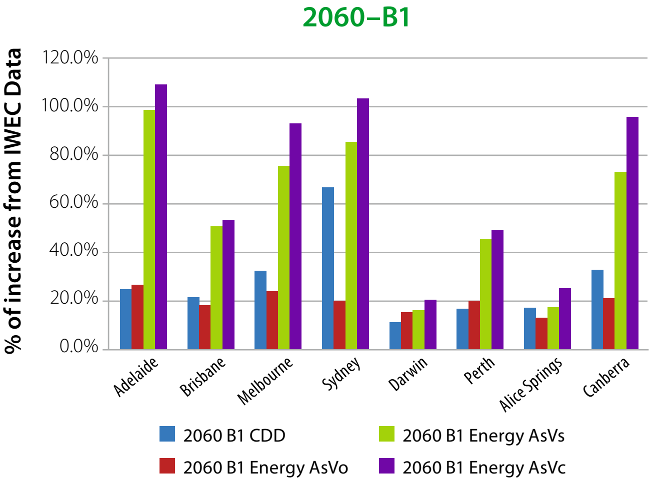

Figure 10: Centralised system – cooling degree days to energy increase, 2060–B1

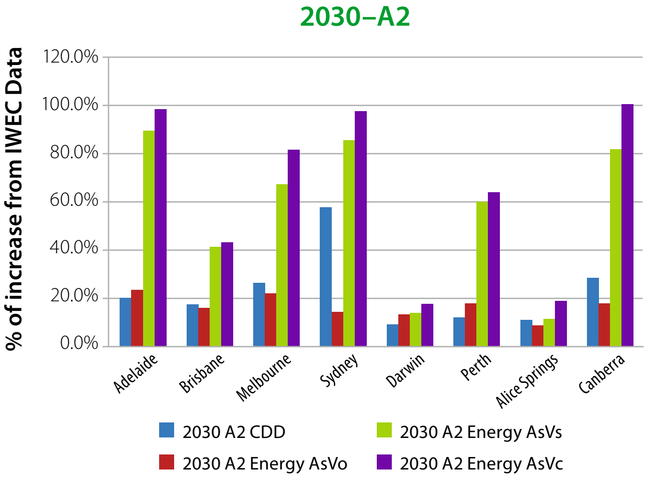

Figure 11: Centralised system – cooling degree days to energy increase, 2030–A2

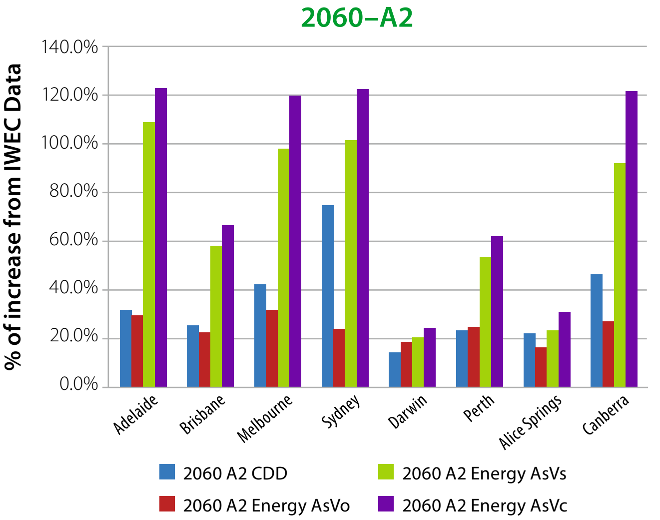

Figure 12: Centralised system – cooling degree days to energy increase, 2060–A2

CONCLUSIONS:

It has been demonstrated that although climate change will decrease the benefit gained from economiser cycle (daytime free cooling) strategies in both centralised and decentralised air conditioning systems, the opportunity exists to derive an increased thermal energy benefit from night-time free cooling for centralised systems.

In mixed climate regions, the benefit from night-time ventilation will be sustained in decentralised systems, and will increase in centralised systems. The benefit from daytime economiser operation will significantly decrease to around 50% of the current benefit.

Thermal mass is critical to maximising the benefit of night ventilation systems. This provides an indicator of the type of construction that will be more suited to buildings in future years if an increase in energy use due to climate change is to be reduced.

It has also been demonstrated that the use of cooling degree days (CDD) to forecast increases in annual cooling energy due to climate change is not appropriate for systems that use either daytime or night-time free cooling. A new approach is therefore required if CDDs are to remain a relevant measure of energy use.

REFERENCES:

1. Roach, P., F. Bruno, and M. Belusko, Modelling the cooling energy of night ventilation and economiser strategies on façade selection of commercial buildings. Energy and Buildings, 2013. 66(0): p.562–570.
2. GBCA, Green star office design V3: technical manual background 1998.
3. Zeng, R., et al., New concepts and approach for developing energy efficient buildings: Ideal specific heat for building internal thermal mass. Energy and Buildings, 2011. 43(5): p.1081–1090.
4. Jenkins, D.P., M. Gul, and S. Patidar, Probabilistic future cooling loads for mechanically cooled offices. Energy and Buildings, 2013. 66(0): p.57–65.

5. Pochee, H., et al. An analysis of the benefits and drawbacks of exposed thermal mass in modern, well-insulated buildings. in Proceedings of the World Renewable Energy Forum, Denver, Colorado. 2012.
6. Al-Sanea, S.A. and M. Zedan, Improving thermal performance of building walls by optimizing insulation layer distribution and thickness for same thermal mass. Applied Energy, 2011. 88(9): p.3113–3124.
7. Artmann, N., H. Manz, and P. Heiselberg. Potential for passive cooling of buildings by night-time ventilation in present and future climates in Europe. 2006.
8. Peng, X. and H. Philip. Case Study of Demand Shifting with Thermal Mass in Two Large Commercial Buildings.
9. Kubota, T., D.T.H. Chyee, and S. Ahmad, The effects of night ventilation technique on indoor thermal environment for residential buildings in hot-humid climate of Malaysia. Energy & Buildings, 2009. 41(8): p.829–839.
10. Karlsson, J., L. Wadsö, and M. Öberg, A conceptual model that simulates the influence of thermal inertia in building structures. Energy and Buildings, 2013. 60(0): p.146–151.
11. Ezzeldin, S. and S.J. Rees, The potential for office buildings with mixed-mode ventilation and low energy cooling systems in arid climates. Energy and Buildings, 2013. 65(0): p.368–381.
12. Al-Sanea, S.A., M.F. Zedan, and S.N. Al-Hussain, Effect of thermal mass on performance of insulated building walls and the concept of energy savings potential. Applied Energy, 2012. 89(1): p.430–442.
13. Mike, S., Indirect/Direct Evaporative Cooling. Heating/Piping/Air Conditioning Engineering : HPAC, 2005. 77(7): p.38.
14. Birtles, A., M. Kolokotroni, and M. Perera, Night cooling and ventilation design for office-type buildings. Renewable Energy, 1996. 8(1-4): p. 259–263.
15. Ma, P. and L.-S. Wang, Effective heat capacity of exterior Planar Thermal Mass (ePTM) subject to periodic heating and cooling. Energy and Buildings, 2012. 47: p.394–401.
16. Steinberg, J.D. and S.D. Hublou, System and method for calculating the thermal mass of a building, 2012, Google Patents.
17. Artmann, N., et al., Impact of climate warming on passive night cooling potential. Building Research & Information, 2008. 36(2): p.111–128.
18. Ogoli, D., Predicting indoor temperatures in closed buildings with high thermal mass. Energy and Buildings, 2003. 35(9): p.851–862.
19. Ma, P. and L.-S. Wang, Effective heat capacity of interior planar thermal mass (iPTM) subject to periodic heating and cooling. Energy and Buildings, 2012. 47: p.44–52.
20. Shaviv, E. and G. Shaviv, Modelling the thermal performance of buildings. Building and Environment, 1978. 13(2): p.95.
21. Williamson, T.J. Assessing the effectiveness for thermal mass in the building envelop. in Proceedings of Building Simulation. 2011.
22. ABCB, DEFINITION OF BASIC FORMS FOR REPRESENTATIVE BUILDINGS. 1991: p.5.
23. Kontoleon, K. and D. Bikas, Modeling the influence of glazed openings percentage and type of glazing on the thermal zone behavior. Energy and Buildings, 2002. 34(4): p.389–399.
24. IPCC, Climate Change 2007 : the physical science basis : contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [electronic resource]2007, Cambridge: Cambridge University Press.
25. Ciobanu, D., E. Eftimie, and C. Jaliu. The Influence of Measured/simulated Weather Data on Evaluating the Energy Need in Buildings. 2014.
26. Remund, J. and S.C. Müller, Solar Radiation and Uncertainty Information of Meteonorm 7. 2011.
27. Wu, L.-X., J.-N. Zhao, and Z.-J. Wang, Night ventilation and active cooling coupled operation for large supermarkets in cold climates. Energy & Buildings, 2006. 38(12): p.1409–1416.
28. ABCB, Building Code of Australia-Volumes One and Two. ABCB, Canberra, Australia, 1996.
29. Chirarattananon, S. and V.D. Hien, Thermal performance and cost effectiveness of massive walls under Thai climate. Energy and Buildings, 2011. 43(7): p.1655–1662.

ABOUT THE AUTHORS

Lead author Phillip Roach, M.AIRAH, is a lecturer in the School of Natural and Built Environments at the University of South Australia. Roach is also engineering services manager at The Bend Motorsport Park.

Dr Frank Bruno, M.AIRAH, is an Associate Professor and leader of the Thermal Energy Storage Group within the Barbara Hardy Institute at the University of South Australia. He has led the group in developing its vision, identifying opportunities and executing a strategic plan.

A researcher in the area of sustainable energy engineering for 18 years, Dr Martin Belusko is a senior research fellow at the Barbara Hardy Institute.