The Potential Energy Savings through the use of adaptive comfort cooling setpoints in fully air conditioned Australian office buildings, a simulation study

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ABSTRACT

The adaptive comfort model, in which indoor comfort temperature changes with outdoor air temperature, was developed by de Dear et al [4]. The energy savings that can be delivered by use of an adaptive setpoint have been investigated in a number of studies of mixed-mode buildings with openable windows. In a fully air conditioned building, occupants are not able to adapt to outdoor temperature as much as they could in a building with openable windows and access to natural ventilation. The range of temperatures at which occupants of fully air conditioned buildings feel comfortable is more narrowed than in naturally ventilated building but the comfort temperature still varies in response to outdoor temperature.

This paper discusses a simulation study of six fully air conditioned office buildings using variable cooling setpoints matched to the adaptive comfort criteria. Three of the modelled buildings are real office buildings recently built in Canberra. The other three models are the San Francisco versions of benchmark offices developed by the US Department of Energy for use with EnergyPlus [5]. These benchmark offices are fairly simplistic models similar to those used by the Australian Building Codes Board for benchmarking.

All six buildings were modelled using EnergyPlus, the US Department of Energy's building simulation package. The modelling was done in accordance with NABERS Energy Guide to Building Energy Estimation [10], providing default values for occupancy (notionally 50 hours per week), lighting, equipment and air conditioning operation.

EnergyPlus, like most simulation packages, does not allow modelling of detailed control algorithms. These control functions were mimicked by creating daily cooling setpoints based on the weather data file.

The simulation outcomes showed that even with the narrow variation of comfort temperatures in a fully air conditioned building, energy savings were achieved with the use of variable setpoints. The size of the energy savings varied between climates and buildings, providing evidence of the advantage of being able to model these control strategies.

1. INTRODUCTION

The adaptive comfort model of de Dear et al [4] correlates the indoor comfort temperature reported by building occupants with outdoor temperature. This correlation differs substantially between naturally ventilated and fully air conditioned buildings. The use of adaptive comfort cooling setpoints with naturally ventilated and mixed-mode buildings as described by de Dear and Brager [2, 3, 4] has been incorporated into ASHRAE Standard 55 [1]. This model is based on a mean effective monthly temperature (being the arithmetic average of the 6.00am and 3.00pm temperatures over a calendar month).

Figure 1 summarises the adaptive comfort model generated by de Dear et al [4] for fully air conditioned buildings with non-opening windows. Unlike the data in ASHRAE Standard 55 [1], this data is based on the daily effective outdoor temperature. De Dear compiled approximately 21,000 sets of raw data on comfort from locations throughout the world. This data included consideration of parameters such as clothing, metabolic estimates, indoor and outdoor climate measures and responses to a thermal comfort questionnaire.

![Figure 1: Adaptive comfort model for buildings with centralised HVAC and non-opening windows adapted from de Dear et all [4].](image)

Studies in Hong Kong of a variety of offices [9], including those with full and mixed-mode air conditioning found total building energy consumption could be reduced by approximately...
7% solely through the use of adaptive comfort setpoints. Other papers describe energy savings of 40–45% that can be achieved with the use of adaptive comfort setpoints in mixed-mode buildings [3, 8]. This simulation study considers only fully air conditioned buildings where there is no opportunity for occupants to access natural ventilation.

The use of thermal mass to complement the use of adaptive comfort setpoints is also considered to be beyond the scope of the current study, as the building would be assumed to have no opportunity to vary thermal mass and also have no natural ventilation to maximise the benefits of it. The use of thermal mass with natural ventilation and adaptive comfort has been explored in Germany [6], where a reduction in cooling load of 14–17% was calculated with a reduction of whole building energy consumption of 6–7%.

The adaptive comfort setpoint for this study was set on a daily basis as described in the methodology section below, consistent with the daily effective temperature used by de Dear [4]. More sophisticated methods of grey prediction have been investigated [7, 8, 11] but are beyond the scope of this study.

2. METHODOLOGY

In the simulations described in this study, the cooling setpoint for the standard buildings without adaptive comfort variation was 23°C during occupied hours. These buildings will be referred to as “standard buildings” throughout this paper.

In simulating the buildings with adaptive comfort cooling setpoints, the cooling setpoint was adjusted at the start of each working day in accordance with Figure 1 based on the temperatures of the previous day and de Dear et al’s [4] definition of daily effective temperature (being the average of the last 6am and 3pm temperatures before building start-up based on the weather data file). This daily adjustment of setpoint would allow occupants the opportunity to adjust clothing. This adjustment was only made if the setpoint would rise above 23°C. It is important to note that each increase in cooling setpoint in these simulations would have resulted in increased occupant comfort. The buildings using the adaptive comfort setpoint will be referred to as “adaptive buildings” throughout this paper.

The modelling was performed for the climates of Darwin, Melbourne and Sydney.

Figure 2 summarises the proportion of occupied hours for which the temperature setpoint is within 0.1°C range in the simulation of each location. As would be expected, the average temperature setpoint in Darwin is the highest at 23.7°C, with a small standard deviation of 0.1°C. The Sydney average of 23.3°C was only slightly higher than the Melbourne average of 23.2°C, and both locations have standard deviations in the setpoints of 0.2°C.

Figures 3 to 8 show the models of the six buildings simulated in this study. Buildings One, Two and Three are recently built Canberra office buildings that have been designed to achieve a NABERS Energy of approximately 4 stars. Buildings One and Three had substantial shading from nearby buildings and all Canberra buildings had non-uniform shapes typical of real buildings.

<table>
<thead>
<tr>
<th>Building</th>
<th>Covered area (m²)</th>
<th>Net Lettable area (m²)</th>
<th>No of floors</th>
<th>Type of HVAC installed</th>
<th>Glazing</th>
<th>Insulation</th>
</tr>
</thead>
</table>
| One      | 21,360            | 16,500                 | 15           | VAV with perimeter 
CV heating | DG 6/12/6 Evergreen Low-e | R4 roof | R2 wall |
| Two      | 2,960             | 2,610                  | 1            | VRF with heat recovery | SG Solar E | R3.5 roof | R1.75 wall |
| Three    | 18,450            | 12,380                 | 6 + basement | VAV | DG Argon filled reflective outer pane | R6 roof | R2.5 wall |
| Four     | 510               | —                      | 1            | DX with gas heating 
coil | SG SHGC 0.34 | R4.5 wall | R1.3 wall |
| Five     | 4,982             | —                      | 3            | DX with gas heating 
coil | SG SHGC 0.34 | R1.2 wall | R2.5 roof |
| Six      | 42,757            | —                      | 12 + basement | VAV with gas reheat | SG SHGC 0.34 | R1.2 wall | R2.5 roof |

Table 1: Characteristics of the modelled buildings.
3. RESULTS AND DISCUSSION

The base building energy, i.e. all energy used in the building excluding tenant light and power, for each of the standard building models is summarised in Table 2 below. The range of performance shown here is approximately between a 2.5 and 5 stars NABERS Energy rating.

Figure 9 below shows the base building energy consumption of the adaptive buildings as a percentage of the equivalent standard building in the three climates for which the modeling was performed. In the Darwin modeling, the reduction in base building energy ranged from 3.5% to 7.4%. In the Melbourne modeling the percentage reductions ranged from 0.8% to 7.0%. The Sydney modeling generated the largest percentage reductions in base building energy consumption through use of the adaptive comfort with the percentage reductions ranging from 3.0% to 8.8%.

The difference between the base building electricity consumption in the standard building and that of the adaptive building is shown in Figure 10 below. The results vary significantly between buildings and climates, particularly for the real buildings with more complex geometry and irregular exterior shading.

In all climates and with all buildings, some base building energy was saved through the use of the narrow range of adaptive comfort setpoints applicable to fully air conditioned

<table>
<thead>
<tr>
<th>Building</th>
<th>Base building energy consumption (MJ/m²)</th>
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<tbody>
<tr>
<td></td>
<td>Darwin</td>
</tr>
<tr>
<td>One</td>
<td>208</td>
</tr>
<tr>
<td>Two</td>
<td>203</td>
</tr>
<tr>
<td>Three</td>
<td>639</td>
</tr>
<tr>
<td>Four</td>
<td>408</td>
</tr>
<tr>
<td>Five</td>
<td>572</td>
</tr>
<tr>
<td>Six</td>
<td>451</td>
</tr>
</tbody>
</table>

Table 2: Base building energy consumption for each building with fixed 23°C cooling setpoint during occupied hours.
buildings; there was no occurrence of a poorer energy performance from the use of the adaptive comfort setpoints. As shown in Figure 10, the savings ranged from 0.8 MJ/m² for Building One in Melbourne climate to 34.6MJ/m² for Building Six in the Sydney climate.

The absence of a “pattern” and the wide range of these results provide strong evidence of the value of being able to simulate these control strategies accurately.

4. CONCLUSION

The use of adaptive comfort setpoints can provide significant energy savings in fully air conditioned Australian office buildings when natural ventilation is not available. Importantly these energy savings are achieved while increasing occupant comfort. Both increased comfort and energy savings can be provided at the small expense of implementing a control strategy.

This study shows how the impact of a single control strategy varies considerably between buildings and climates. To accurately quantify the impact of a control strategy such as an adaptive comfort setpoint, detailed control functions need to be developed for building simulation software. Accurately quantifying the benefits of control strategies in the design stage would lead to greater recognition and implementation of these inexpensive and effective energy saving methods.

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REFERENCES


About the author

Annie Egan is a research student at the Australian National University. She is a mechanical engineer and also has degrees in psychology, renewable energy and construction management. Having worked for several years as an energy consultant, Annie is focusing on improving techniques for predicting the energy efficiency of office buildings. Her supervisors are Mike Dennis, Paul Bannister, M.AIRAH, Keith Lovegrove and Keith Barzoli.