PERCEIVED AND ACTUAL THERMAL CONDITIONS IN GREEN AND CONVENTIONAL OFFICE BUILDINGS

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Abstract. Buildings labelled as ‘green’ often carry high occupant expectations. This can be particularly evident in the commercial office sector where occupants generally anticipate improved comfort conditions, an element which also impacts on their perceived health and productivity levels. This paper reports on a recent post occupancy evaluation of a number of commercial office buildings in Adelaide, South Australia conducted in ‘green’ and ‘non-green’ buildings. Internal environment monitoring and occupant surveys were conducted to assess the perceived and actual thermal, visual and aural comforts, and also health and productivity. This paper focuses on occupants’ satisfaction in response to seasonal temperature conditions with survey results showing that green buildings exhibit equal and in some cases increased occupant satisfaction of internal environmental conditions when compared to non-green buildings. Responses to thermal comfort questions were reviewed against actual temperature measurements logged within both the green and non-green buildings. The study found that altering building temperature set points based on ASHRAE Standard 55-2010 will likely result in improved occupant satisfaction of thermal conditions with the potential to reduce energy consumption.

Keywords. Commercial buildings; thermal comfort; surveys; measurements; perceptions.

1. Introduction

‘Green’ buildings are designed, constructed and operated with the specific objectives of efficient use of resources (Vale and Vale, 1991) and reducing negative impact on human health providing internal environments which re-
sult in high levels of occupant satisfaction and related productivity (Chong, 2007). However, in Australia and internationally, there is limited publicly available post occupancy evaluation information on buildings claiming to be ‘green’. In Germany, Wagner et al (2007) found that buildings that “meet the occupants’ needs for comfort and workspace quality” are conducive to healthier and more productive personnel. Some studies (Leaman and Bordass, 2001; 2007; Turner and Frankel, 2008; Baird et al, 2012) have found conflict between occupants’ level of satisfaction with the internal environments that result from the inclusion of green building characteristics. For example it is expected that the potential for greater use of day lighting will increase occupant satisfaction, however, resulting glare often cause severe discomfort (Leaman and Bordass, 2007). Results from these studies emphasise the importance of undertaking studies that include occupants’ perceptions which are valuable in determining if ‘green’ buildings are meeting expectations. Hillier and Penn (1994) wrote of the necessity of creating “… the virtuous circle…through feedback from user experience” for the progressive improvement in the design of buildings.

This paper presents aspects of a recent post occupancy study of ‘green’ and ‘non-green’ (which will be referred to as conventional) office buildings in the Adelaide CBD, South Australia. The aim of the study was to determine if Adelaide’s ‘green’ commercial office buildings are outperforming conventional construction specifically in energy and water use and in their ability to provide comfortable internal environments with increased occupant satisfaction. ‘Green’ buildings here refer to those whose designs were assessed and rated by a nationally accepted environmental assessment tool, Green Star, (Green Building Council Australia, 2009) which is similar to LEED in the US and BREEAM in the UK. The study included evaluating the energy and water consumption records, building design, as well as internal environment monitoring and surveys that provided data on occupants’ perceived thermal, visual and aural comforts, as well as health and productivity.

This paper, however, only focuses on two aspects of the study; temperature and relative humidity measurements from internal environment monitoring of the buildings and results of the occupant surveys specifically the section related to thermal comfort. The internal environment measurements were compared to recommended comfort zones in the Standard ASHRAE 55-2010 (ASHRAE, 2010) as well as compared to occupant survey responses to thermal conditions questions. Recommendations to changes to thermal conditions are then made which are likely to result in an increase of occupant satisfaction. It has previously been found that occupant’s views on internal environmental conditions greatly affect their sense of overall comfort in a
building which in turn impacts on perceptions of productivity and health (Menadue et al., 2012).

2. Research method

This research involved a comparison of the performance of ‘green’ and conventional buildings in the City of Adelaide. Comparing the data from both building types allows recent buildings to be directly assessed against buildings that were considered ‘typical’ at the time of their construction. Note however, that the conventional buildings in this study were typically older than the ‘green’ buildings as the majority of new commercial building construction in Adelaide is Green Star rated. Also, new construction represents only a small proportion of buildings in Australian cities; only about 2-3 per cent of the building stock is replaced each year (Australian Sustainable Built Environment Council, 2008).

As this paper focuses on the internal thermal environmental measurements and the occupant survey only methods for these aspects will be discussed below.

2.1. BUILDING SELECTION

Buildings were typically recruited for this study through direct contact with management of organisations within the buildings and through subsequent contact with the property managers. The buildings needed to have been occupied for at least 12 months prior to the commencement of the study and have at least 80% of the net lettable area for commercial office activities. There was no restriction on the age of the buildings or their size either in floor area or number of storeys. Ten tenancies/organisations out of more than 30 organisations responded to the invitations to participate in the study. They were divided into two categories; Conventional and Green Star rated buildings. The study included four Conventional buildings (referred to as buildings A to D) and four Green Star rated new or retrofitted buildings (referred to as buildings E to H). All buildings in the study were air-conditioned.

Of the Conventional buildings A, B and D are owner occupied while building C is multi-tenanted. The buildings range in size from 7000 to 24000m² of net lettable area, have 10 to 17 floor levels and house between 450 and 1400 occupants. Buildings A and B were constructed in the 1970s and have concrete facades with small windows evenly distributed, building D was constructed in the 1980s and has fully glazed facades, while building C, constructed in the late 1990s has approximately 50% glazing to its concrete facades. The HVAC systems in the Conventional buildings were de-
scribed as ‘aging’ by their facilities managers (they were Constant Volume HVAC systems); however all were running economy cycle when outside conditions permitted. Building A was trialling active chilled beams on 2 floor levels.

All of the Green Star buildings are multi-tenant, ranging in size from 8 to 21 floor levels with net lettable areas between 6000 and 31000m$^2$ and housing 350 to 2000 occupants. Buildings E and F are certified as 5 Star under the ‘Office as Built’ Green Star assessment while buildings G and H are 4 Star certified under the ‘Office Design’ assessment (building H is a retrofitted building). All of the Green Star Buildings received multiple credits in the Internal Environment Quality section of their assessments (Green Building Council Australia, 2013a). Construction for all buildings was completed between 2007 and 2009. Buildings E, F and G have high performance fully glazed facades to the north and in at least one other direction, while building H has concrete facades with high performance glazing to existing openings which cover approximately 50% of the external walls. Buildings E, F and G incorporate mixed-mode ventilation systems while E and F also provide 100% fresh air with no recirculation and passive chilled beams for cooling. Building E also has a 5 storey atrium with automated louvers for additional ventilation.

2.2. INTERNAL ENVIRONMENT MONITORING

A number of small and unobtrusive temperature and relative humidity data loggers were installed in the buildings to monitor the internal environment. The loggers took half hourly readings for a total of 12 months, from Autumn 2010 to Autumn 2011. The loggers were installed at approximately 1.2m above floor level (head height of a seated person) and were typically located on partitions between individual work spaces.

2.3. OCCUPANT SATISFACTION SURVEY

The Building Use Studies (BUS) survey which has been used extensively in other research such as the Probe studies in the UK (Leaman and Bordass, 2001; Leaman, 2007 and more recently by Baird (2010) was used under license in this study (with some modifications from the original format). The online occupant satisfaction survey which was predominately in the form of yes/no and seven point Likert scale questions with comment boxes for additional feedback, collected occupant responses to the internal thermal, light and aural conditions and the workplace environment as well as gathered their understanding of how the building operates, particularly in relation to providing thermal comfort. Building representatives were asked to distribute
the survey via organisation email circulation lists in the spring of 2010. A follow up email was distributed two weeks later. Although all participating organisations initially agreed to partake in the occupant survey, ultimately only 8 organisations completed this stage of the study with over 600 responses received in total.

2.4. ANALYSIS

As this study dealt with commercial office buildings operating during business hours the readings from all the loggers installed in the study buildings were filtered to isolate measurements taken between 8am and 6pm Monday to Friday; the time period of occupation. Public holidays were also removed as the buildings were not occupied on these days. The measured temperature and relative humidity readings from the buildings were compared against the recommended winter and summer comfort zones from ASHRAE Standard 55. Each logger was assessed individually for measurements taken in the winter of 2010 and summer of 2010/11 with the percentage of readings outside of the comfort zones for each of the scenarios also calculated.

For the thermal comfort questions in the occupant satisfaction survey a mean score was calculated from the individual responses in each of the building sets.

3. Results

3.1. CONVENTIONAL BUILDINGS

Coincident temperature and relative humidity measurements were plotted onto a psychrometric chart and compared to the recommended Standard winter and summer comfort zones. For the Conventional buildings Table 1 shows the percentage of readings outside the winter and summer comfort zones. During winter the majority of measurements were within the recommended comfort zone; however, during summer the majority of readings were outside of the comfort zone with measurements found in the cooler region. An example of this is shown in Figure 1.

Table 2 provides a summary of the Conventional buildings’ occupant responses to the thermal comfort survey questions. Overall both the winter and summer conditions were rated as neutral and considered neither satisfactory nor unsatisfactory. In winter factors such as the temperature level and air movement both rated close to optimum with the temperature level rating on the cool side of the scale. In summer air movement rated close to optimum, while the temperature level was rated as ‘cold’ by the survey respondents.
Table 1. Conventional Buildings – comfort zone psychrometric measurements

<table>
<thead>
<tr>
<th>Building No.</th>
<th>Mean percentage of readings outside of comfort zones</th>
<th>winter</th>
<th>summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3%</td>
<td>81%</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>3%</td>
<td>90%</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>0%</td>
<td>95%</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>5%</td>
<td>80%</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1. Conventional Buildings – summer conditions generally cooler than recommended

Although in winter an increase in the temperature set point in the order of 0.5°C would provide temperatures still within the recommended level and possibly increase occupant comfort, it is actually considered more important to eliminate the high level of temperature variability experienced by the occupants. During site visits to the buildings occupants reported that on cold mornings personal heaters were often used to warm individual work areas. The low morning temperatures were also evident in the monitored data.

It was also noted that building management and individual tenancies gave different responses to the issue of occupancy hours, with tenants typically occupying the building for longer hours than allowed for by management. This resulted in occupants commencing work in the mornings as buildings systems were just becoming operational for the day or in some cases before
operation had commenced meaning work spaces were still cold. This situation was also seen to an extent at the end of the day with building systems shutting down before some occupants had finished work. It is therefore suggested that to improve occupant satisfaction in the Conventional buildings during winter, rather than making changes to temperature set points, the operating hours of the HVAC systems should be reviewed and extended particularly by starting up earlier in the morning.

Table 2. Conventional Buildings – occupant mean responses to thermal comfort

<table>
<thead>
<tr>
<th>Thermal issue</th>
<th>optimum score</th>
<th>winter</th>
<th>conclusion</th>
<th>summer</th>
<th>conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>7</td>
<td>3.94</td>
<td>Neutral – on uncomfortable side of scale</td>
<td>3.91</td>
<td>Neutral – on uncomfortable side of scale</td>
</tr>
<tr>
<td>Temperature Level</td>
<td>4</td>
<td>4.31</td>
<td>Close to optimum – on cold side of scale</td>
<td>4.53</td>
<td>Slightly too cold</td>
</tr>
<tr>
<td>Temperature Stability</td>
<td>1</td>
<td>5.41</td>
<td>High variability</td>
<td>5.33</td>
<td>High variability</td>
</tr>
<tr>
<td>Air Movement</td>
<td>4</td>
<td>3.62</td>
<td>Close to optimum – on still side of scale</td>
<td>3.57</td>
<td>Close to optimum – on still side of scale</td>
</tr>
<tr>
<td>Air Moisture</td>
<td>4</td>
<td>3.24</td>
<td>Slightly dry</td>
<td>3.46</td>
<td>Slightly dry</td>
</tr>
<tr>
<td>Conditions</td>
<td>7</td>
<td>3.78</td>
<td>Neutral – on unsatisfactory side of scale</td>
<td>3.91</td>
<td>Neutral – on unsatisfactory side of scale</td>
</tr>
<tr>
<td>Overall</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In summer an increase in the temperature set point in the order of 1 to 2°C would move temperatures to within the recommended ASHRAE 55 comfort zone and would expectantly increase occupant comfort. An increase in the summer temperature set point could also reduce the ‘cyclic’ on and off of the HVAC system throughout the day which in turn may assist in eliminating the high level of temperature variability experienced by the occupants during this season. An increase in summer temperature set points would result in reduced energy usage.

3.2. GREEN STAR BUILDINGS

Results from the ‘green’ buildings show similarities to those from the conventional buildings, with the majority of the winter indoor environment being within the recommended comfort zone and the majority of summer measurements being outside of the comfort zone, in the cooler region. Table
3 shows the mean percentage of combined temperature and relative humidity measurements outside of the recommended winter and summer comfort zones.

Table 3. Green Star Buildings – comfort zone psychrometric measurements

<table>
<thead>
<tr>
<th>Building No.</th>
<th>Mean percentage of readings outside of comfort zones</th>
<th>winter</th>
<th>summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>3%</td>
<td>77%</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>6%</td>
<td>72%</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>8%</td>
<td>79%</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>3%</td>
<td>76%</td>
<td></td>
</tr>
</tbody>
</table>

Occupant survey results from the Green Star buildings are quite similar to those seen in the Conventional buildings (Table 4) with the overall winter and summer conditions both rated as neutral, while in winter factors such as air movement and air moisture both rated close to optimum. The temperature level rated on the ‘too cold’ side of the scale. In summer only air moisture rated close to optimum, while the temperature level again rated as slightly ‘too cold’.

As discussed in the Conventional buildings it is considered important to eliminate the high level of temperature variability experienced by the occupants in the Green Star buildings. As was seen in the Conventional buildings, low morning temperatures were evident in the recorded data and again a discrepancy was found between building management and individual tenancies occupancy hours with the tenancies typically occupying the buildings for longer hours than allowed for by management. It is therefore suggested that to improve occupant satisfaction in the Green Star buildings during winter, the temperature set point be increased in the order of 0.5 to 1.0 °C with the operating hours of the HVAC systems reviewed and extended particularly by starting up earlier in the morning.

In summer increasing the temperature set point in the order of 1 to 2°C would move temperatures to within the recommended level and is likely to increase occupant comfort, similar to the situation in the Conventional buildings. An increase in winter temperature set points and/or in operating hours would likely result in an increase in energy use in the Green Star buildings, however this would be offset by an increase in the summer temperature set point.
Table 4. Green Star Buildings – occupant mean responses to thermal comfort

<table>
<thead>
<tr>
<th>Thermal issue</th>
<th>optimum score</th>
<th>winter</th>
<th>conclusion</th>
<th>summer</th>
<th>conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>7</td>
<td>4.33</td>
<td>Neutral – on comfortable side of scale</td>
<td>4.10</td>
<td>Neutral – on comfortable side of scale</td>
</tr>
<tr>
<td>Temperature Level</td>
<td>4</td>
<td>4.96</td>
<td>Slightly too cold</td>
<td>4.61</td>
<td>Slightly too cold</td>
</tr>
<tr>
<td>Temperature Stability</td>
<td>1</td>
<td>5.36</td>
<td>High variability</td>
<td>5.19</td>
<td>High variability</td>
</tr>
<tr>
<td>Air Movement</td>
<td>4</td>
<td>3.70</td>
<td>Close to optimum – on still side of scale</td>
<td>3.40</td>
<td>Slightly too still</td>
</tr>
<tr>
<td>Air Moisture</td>
<td>4</td>
<td>3.73</td>
<td>Close to optimum - on dry side of scale</td>
<td>3.84</td>
<td>Close to optimum - on dry side of scale</td>
</tr>
<tr>
<td>Conditions Overall</td>
<td>7</td>
<td>4.29</td>
<td>Neutral – on satisfactory side of scale</td>
<td>4.14</td>
<td>Neutral – on satisfactory side of scale</td>
</tr>
</tbody>
</table>

4. Conclusion

The results of this post occupancy study show that measured thermal conditions and also occupant perceptions are similar within the Conventional and Green Star buildings. Statistical analysis of the difference between the mean responses to the thermal issues shows there is no statistical difference between the two building sets in summer except for the issue of ‘air moisture’ (p<0.05) with the Green Star buildings’ occupants expressing greater satisfaction. In the winter season however, there was a significant difference (p<0.01) between responses to ‘temperature level’ which scored higher in the Conventional buildings and ‘air moisture’ and ‘conditions overall’ which scored higher in the Green Star buildings (Menadue et al, 2012). These results conflict with the general assertion that ‘green’ buildings provide more comfortable thermal conditions (Green Building Council, 2013b).

Important implications drawn from this study and relative to office buildings in temperate climates in Australia are that altering internal environmental conditions between seasons is likely to reduce energy costs and increase occupants’ satisfaction. Also, given the low level of occupant satisfaction with winter conditions despite measurements being within the recommended range, the issue of occupant education should be addressed in all buildings. In the words of Leaman and Bordass:

If people understand how things are supposed to work and what they are for...they tend to be more tolerant if things do not turn out quite as they should (Leaman and Bordass, 2007)
5. References


