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UNFORGIVABLE

Exploring thermal comfort, adaptation, and forgiveness in a problem green office building

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Abstract. Adaptive and green buildings have been positively correlated with thermal comfort and occupant satisfaction. Similarly, occupants with pro-environmental attitudes have been observed to exert a greater willingness to overlook suboptimal indoor conditions. It may therefore be expected that a building which is green both in its design and in the profile of its occupants is set up to succeed. This paper explores the results of a field study of a mixed-mode office building which is of an adaptive and bioclimatic design, and accommodates occupants of a strongly pro-environmental profession, but which is performing poorly. The study comprised a thermal comfort field study and post-occupancy evaluation, alongside qualitative interviews. The paper discusses the influence of 'forgiveness' in defining the relationship between a building and its occupants, and looks at the impact of design and reliability problems on forgiveness. The forgiveness index as a quantitative measure in the assessment of a building is discussed. The study prompts questions around building design, the importance of a functional adaptive feedback loop, and consideration of forgiveness in adaptive buildings.

Keywords. Adaptive thermal comfort; bioclimatic design; post-occupancy evaluation; offices; forgiveness factor.

1. Introduction

An adaptive building is one in which the occupants are able to react to and rectify discomfort using their adaptive opportunity, which refers to the degree to which they are able to make interventions which restore their comfort (Baker and Standeven, 1994). An example of a highly adaptive building is one with single-occupant rooms, user-operated environmental control, and freedom in terms of clothing, activity, and spatial and temporal working arrangements (Brager and de Dear, 1998).

Adaptive buildings are of interest because there is a well-understood need to lower energy consumption in buildings, and one pathway for achieving this is to reduce the use of air conditioning by cutting plant running time or adopting wider temperature set points. Additionally, increased adaptive opportunity in the form of personal environmental control is positively correlated with occupant comfort and productivity (Leaman and Bordass, 1999), and therefore can provide a superior indoor environment. 'Green' buildings are those which have adopted design strategies intended to lower their environmental impact and provide a healthier indoor environment for occupants. Adaptive buildings can be considered a subset of green buildings.

The success of a building in providing comfort is influenced by the expectations of the occupants, including their willingness to tolerate or forgive suboptimal indoor conditions. The 'forgiveness factor', coined by Leaman and Bordass (2007), refers to this willingness to make allowances in judging how comfortable the building is. Leaman and Bordass quantify this as a 'forgiveness index' calculated from comfort scores in the Building Use Studies (BUS) post-occupancy evaluation survey. Leaman and Bordass found, tentatively, that occupants are more forgiving of green buildings (those briefed with environmental goals) than they are of conventional buildings. Deuble and de Dear (2012) explored the impact of occupant attitudes on willingness to forgive, and found that occupants with pro-environmental beliefs were more forgiving of suboptimal conditions than their non-green counterparts, and that this was more so for occupants of green buildings.

These findings are supportive of a user-centric perspective of the built environment, which is one that focuses on the user-environment relationship and considers the social context of the occupant experience as well as the features of the physical environment (Vischer, 2008). From this point of view, both the building and its occupants are equally important to thermal comfort and forgiveness.

In simple terms, given that both green buildings and green occupants are associated with higher comfort, satisfaction and willingness to forgive, it is expected that a building encompassing both is set up to succeed in its goal of providing a comfortable, productive, and satisfactory work environment. The converse of this supposition is the topic of this paper: what does it take for a green building with green occupants to fail – to be unforgivable?

2. Method

The building was a commercial office with 448m2 of office space over two floors, and was first occupied in 2009. It was located in Brisbane, in the warm humid climate region on the east coast of Australia, characterised by warm, humid summers and winters with cool overnight temperatures and sunny days. It received a five star Green Star rating and included a range of design measures intended to promote indoor environment quality and thermal comfort such as high fresh air ventilation rates and good air change effectiveness.

Thirty-six workstations were located in the upper open plan office area with fully operable louvred facades to the north and south, forming a ventilation path of 18 metres. There were shaded operable casement windows extending part way along the west-facing facade. Twelve workstations in the open plan space are immediately adjacent to operable windows. The occupants have full control over the opening of windows and louvres, which are not interlocked with the air conditioning system. In addition, there are three private offices on the upper floor and a four-person office on the lower floor. Out of a total of 43 workstations, 38 were occupied at the time of the study, with all five of the empty desks within the large open plan area.

Air conditioning is provided via floor-mounted constant volume fan coils serving the open plan area and wall-mounted units serving the private offices. An additional wall-mounted unit provides cooling boost to the open plan. The air conditioning is controlled by a building management system, but occupants have the ability to turn the air conditioning on, off, or fan only via a control panel located in the open plan area. The open plan, boardroom, and four-person office air conditioning are operated as a single zone. Occupants in private offices have full control of single-zone air conditioning units. A task ventilation system supplies fresh air at 20°C via a plenum serving groups of between four and eight desks, with two diffusers per desk. Occupants are able to control the direction and flow rate of the task air. The task air system is able to be turned on or off via the control panel.

The building has been subject to frequent mechanical breakdowns during which the air conditioning cannot be operated. This occurs most often in summer. Other design issues alternatively constrain and compel the use of air conditioning. For example, the air conditioning is sometimes turned off due the floor-mounted supply air causing localised cold discomfort. However, the air conditioning must be turned on while the boardroom is occupied due to the lack of an alternative ventilation method for that room.

The building was purpose built for the tenant and is leased over the long term. The tenant organisation’s primary function is environmental management, recreation, and conservation, and on an organisational scale embraces environmental stewardship as a core value. The occupant group is comprised of management, administrative, technical, and field staff, some of whom are wholly office-based and others spending a proportion of time in field-based work. The occupants follow a dress code which offers a wide range of clothing choices for both winter and summer.

The study adopted a mixed-methods approach comprising three phases. Participants completed an ASHRAE-style thermal comfort, acceptability and preference questionnaire while air temperature, globe temperature, air velocity and humidity were measured and state conditions recorded for the air conditioning and adaptive devices. 16 occupants participated in this phase, all of whom worked within the large open plan area, representing 52% of the occupants of this area. The measurement and questionnaire was completed over a winter day in June 2012.

A post-occupancy evaluation was carried out in May 2012 and achieved a return rate of 22 out of 38 occupants, 20 of whom worked in the open plan area. The survey covered user issues including thermal comfort, noise, lighting, ventilation, storage, impressions to visitors, and commuter transport, and allowed for both Likert scale scoring and open-ended responses. The results were benchmarked against the 50 most recently surveyed buildings in the BUS Australian database, and categorised as either significantly better than the database ('good'), not significantly different from the database ('OK'), or significantly worse than the database ('poor'). Significance is determined in relation to a critical region, defined by both the results within the benchmark database and the upper and lower limits of the scale midpoint.

Semi-structured interviews with 11 occupants from the open plan were held in April 2012. The interviews were conducted individually and covered likes and dislikes of the occupants' work areas, experiences of comfort and adaptation, adaptive habits, preferences and disposition, and opinions of green buildings and energy efficiency. The interviewees were given the opportunity to raise any other issues.

3. Results

3.1. COMFORT AND ADAPTATION.

The measurement and questionnaire phase was carried out over a day in winter on which the 80% adaptive comfort zone was predicted as between 19.2 and 26.2°C based on a seven-day running mean temperature (Nicol and Humphreys, 2010) (Figure 1). The outdoor conditions on the day of the study ranged from 7.5°C at 6am to 21°C at 1pm. These measurements were obtained from the Bureau of Meteorology Brisbane Aero automatic weather station, located 10km away in a geographically similar location. On-site outdoor measurements were not available.

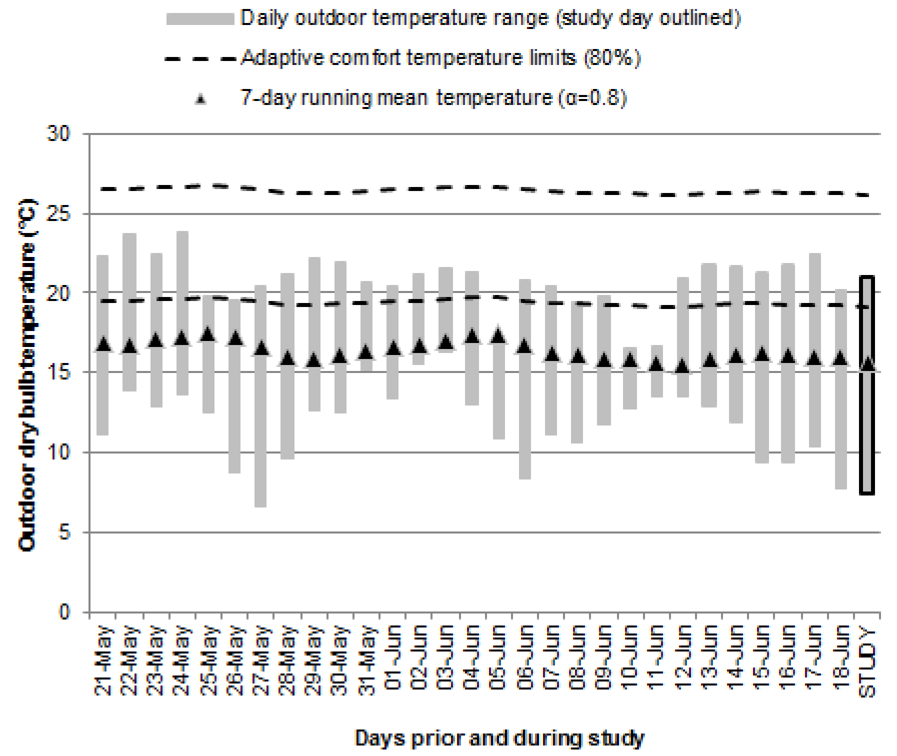

Figure 1. Prevailing outdoor temperature and adaptive comfort limits.

During the thermal comfort study phase the building was in natural ventilation mode, the windows were closed, and the task air was not being used. The indoor temperature ranged between 19.2 and 22.4°C, hence within the 80% adaptive comfort zone, and relative humidity was around 50%.

Seven out of the 16 participants reported being cool (-2 on the ASHRAE scale) or cold (-3). Nine participants found their thermal environment unacceptable, most of whom wanted it warmer. This appeared to be a typical situation in winter according to the BUS results, which rated the temperature in winter as generally too cold and variable. In the interviews, occupants noted that the air conditioning was too cold for winter due to the supply air location and hence was often turned off. Occupants relied on their ability to increasing clothing insulation, which ranged between 0.6 and 1.3 clo, with a mean of 0.9 clo. The most commonly used adaptive devices were the windows, blinds, air conditioning, and task air. The task air devices were a matter of taste for occupants; some of whom used them heavily, and others finding the constant stream of air uncomfortable.

The design and layout of the building meant that the perimeter zones adjacent to the louvres were subject to excessive glare, direct solar radiation, and air movement, while the internal zones received little cross-ventilation, producing a different set of undesirable indoor conditions in each zone.

The building scored poorly in the BUS survey for aspects of comfort, storage space, and self-assessed productivity of occupants. The BUS survey does not define productivity; instead it asks occupants to assess how the building increases or decreases their productivity as a percentage, thereby leaving both the definition and measurement of productivity in the hands of the respondent. This approach takes the view that only the individual can measure their own productivity, and is therefore not a proxy measurement, and has the advantage of not forcing a potentially inappropriate measure of productivity (such as unit output), but makes the results difficult to interpret. The measure should therefore be viewed as a direct measurement taken with an uncalibrated instrument. The building placed in the bottom 20% of the database for self-assessed productivity. Interpretation notwithstanding, this is indicative of a particularly poor building.

All interviewees felt that it was important that their organisation be based in a green building in order to "set an example", or "show the general public we have a conscience when it comes to sustainability". However, most felt that the building did not fulfil this role successfully.

3.2. FORGIVENESS INDEX

The BUS forgiveness index is a composite score which relates the score for comfort overall with the average of the comfort scores given for air in winter, air in summer, temperature in winter, temperature in summer, light, and noise (Equation 1). A building is considered more forgivable than not when the forgiveness index is greater than one. The forgiveness index is hence not a measure of whether a building is good or bad, but compares how the occupants score the whole against the sum of its parts, comfort-wise.

$$\text{FI} = \text{Comfover} / ((\text{AirW} + \text{AirS} + \text{Twover} + \text{Tsover} + \text{Ltover} + \text{Nseover}) / 6) \quad (1)$$

The building achieved a forgiveness index of 1.06, indicating that the occupants afforded some forgiveness. This result places the building in the 62nd percentile of the database; ranking it higher than 62% of other buildings. Examined separately (Figure 2), each of the constituent comfort scores were within the benchmark range, defined by the database mean and standard deviation and the scale midpoint, except for the air in summer, which is significantly poorer than the benchmark. The resulting forgiveness index was due to comfort overall scoring higher on the Likert scale for all except lighting. All of the forgiveness index constituent scores ranked below the 50th percentile, with the best-performing being noise (42), and the poorest being air in summer (26) and lighting (26).

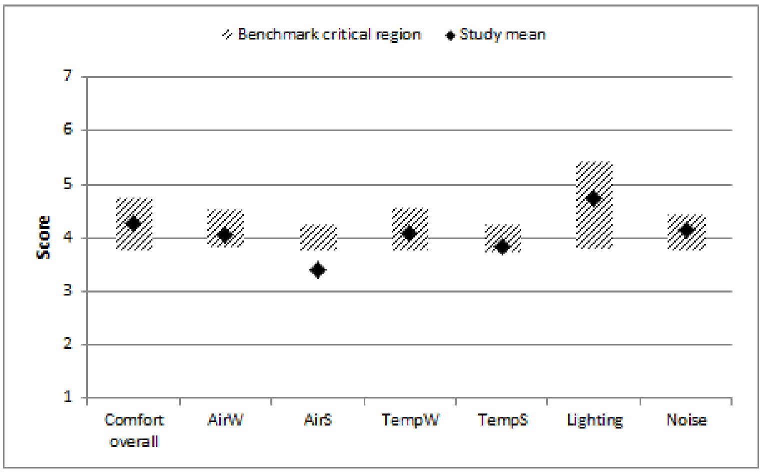

Figure 2. Study mean scores for forgiveness index constituents. Scores above the critical region are good; below the critical region are poor.

In contrast to the survey, the interviews did not suggest a sense of forgiveness. Most felt that problems including breakdowns, insufficient zoning, and air delivery, as well as poor ventilation design, precluded comfortable operation of the building for much of the year. Comfort adaptations were made on a 'least worst' basis and did not alleviate discomfort.

> I think this building, if the air conditioning worked effectively, would be a really nice place to work. [..] All of those other factors mean nothing because we're never comfortable inside the building…

> We don't ever seem to be able to have a happy medium. It very rarely where everyone's happy.

> Usually we only open up the windows because the air conditioning's not working. It's never, "let's open up the windows today," it's, "oh the air conditioning's not working so we'll open up the windows".

This result was not tempered by the building's green status. Some occupants were left with a poor impression of green buildings in general, believing that they necessarily involved a trade-off in indoor environment quality.

> I totally agree that we need to look after the environment, but designing buildings like this is not the answer.

A more detailed examination of the survey results showed a difference in how the occupants rated comfort overall compared with more specific aspects. For example, the temperature in winter overall was not significantly worse than the database, but the occupants considered it too cold and variable (Table 1). Likewise, the temperature in summer overall was not worse than the database, but the temperature variability scored very poorly.

Table 1. Overall and specific aspects of forgiveness index constituents and results in relation to BUS database (*results judged 'good' by BUS survey but outside database target range).

Overall	Result	Specifics	Result (why)
Air in winter	OK	Dry/humid	Poor (dry)
		Fresh/stuffy	Good (fresh)
		Odourless/smelly	OK
		Still/draughty	Poor (still)
Air in summer	Poor	Dry/humid	Poor (too humid)
		Fresh/stuffy	OK
		Odourless/smelly	OK
		Still/draughty	OK
Temperature in winter	OK	Hot/cold	Poor (too cold)
		Stable/varies	Poor (varies)
Temperature in summer	OK	Hot/cold	Good* (too cold)
		Stable/varies	Poor (varies)
Light	OK	Artificial light	Good* (too little)
		Glare from lights	OK
		Glare from sun/sky	OK
		Natural light	Poor (too little)
Noise	OK	Noise from colleagues	Poor (too much)
		Noise from outside	Poor (too little)
		Other noise from inside	OK
		Unwanted interruptions	Poor (very frequent)

4. Discussion

The results showed that the occupants scored the building poorly in terms of comfort, and that, while the survey suggests they were more forgiving when assessing comfort in the building as a whole, the qualitative results demonstrated a level of frustration owing to design and reliability problems.

The thermal comfort phase of the study indicated that the adaptive comfort model was not necessarily a good predictor of comfort levels within the open plan area of the building. In general, people were colder than predicted, despite having the freedom to increase clothing levels.

In a previous field study, Cena and de Dear (2001, p 413) noted that some occupants tended to ignore the impact of adaptive actions such as clothing when casting comfort votes, as if to say, “because I had to put on a pullover to stay comfortable, I must be cooler than neutral”. This may have been the case in this study, indicating frustration with the comfort conditions inside the building. As an adaptive building, this can be interpreted as not just a problem of the indoor conditions, but an inadequacy in the adaptive opportunity available to occupants.

The main impedances to the functionality of the adaptive feedback loop were the problems with the air conditioning and deficiencies in the building’s bioclimatic design. The air conditioning was often turned off because it caused cold discomfort, or at other times kept on when not wanted due to zoning problems. Additionally, the air conditioning was often unavailable due to frequent breakdowns. Discussion of the mechanical failures dominated the occupant interviews. These issues hence would have had a negative impact on the results of the post-occupancy evaluation, particularly in terms of thermal comfort and productivity.

Adaptive comfort relies to an extent on tolerance of suboptimal conditions by the occupants, driven by an understanding that an indoor environment more closely linked to outdoor conditions will more closely resemble outdoor conditions. There is then an onus on the building designer to ensure that the building capitalises on the pleasant aspects of the climate and is capable of excluding or at least tempering the unpleasant. In the study building, comfort problems were directly caused by both the air conditioning system and aspects of the building layout, actively introducing discomfort and running counter to the principles of good adaptive design. The result was the opposite of that which other studies have identified, which was a tendency for the occupants to regard the building with frustration, rather than forgiveness. In addition, the building did not fulfil the implied promise of green buildings that the unconventional design and/or additional cost outlay will be ultimately justified by improved comfort, reduced environmental impact, and lower operating costs. The occupants were acutely aware of this.

The BUS survey results did demonstrate the poor comfort outcomes; however, the occupants’ views were not necessarily borne out in the forgiveness index. The constituent parts of the forgiveness index did not reflect the various dysfunction present in the building and the corresponding impact on occupant frustration and discomfort and hence forgiveness. This reinforces the view that surveys should be accompanied by qualitative methods in order to obtain a user-centric assessment of a building. Further consideration of forgiveness, including the quantification of forgiveness, is warranted.

5. Conclusion

The study highlighted issues of good design of adaptive buildings and the importance of a functioning adaptive feedback loop. Without a successful adaptive design, both in terms of the bioclimatic fundamentals and the building services, the comfort and satisfaction outcomes expected from adaptive buildings with green occupants are unlikely to be realised.

The qualitative results provided insight into the BUS survey results, particularly in terms of the interpretation of the forgiveness index. Further study of the concept of forgiveness within buildings should take a user-centric approach which considers context alongside quantification.

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