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Green Occupants for Green Buildings: The Missing Link?

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Summary
This paper follows the results of recent post-occupancy evaluation surveys within two office buildings at Macquarie University, Sydney Australia. Supplemented with an environmental attitudes questionnaire, based upon the New Ecological Paradigm (Dunlap et al. 2000), it was found that occupant satisfaction levels are positively associated with environmental beliefs. Occupants with higher levels of environmental concern were more tolerant of their building, particularly those featuring aspects of green design, such as naturally-ventilated façades and operable windows. Despite their criticisms of the building's indoor environmental quality, the 'green' occupants were prepared to overlook and forgive less-than-ideal conditions more so than their 'brown' (non-green) counterparts. Drawing upon these results, statistical analyses of the association between environmental beliefs and occupant satisfaction in this paper support the hypothesis that broad environmental attitudes are closely associated with the stronger 'forgiveness factor' often observed in green-intent buildings.

Keywords
Green buildings, Post-occupancy evaluation (POE), Forgiveness factor, New Ecological Paradigm (NEP)

Introduction

Many adaptive comfort studies (Humphreys and Nicol 1998; Nicol and Humphreys 2002) have called for greater indoor environmental variability, either via user adjustments to operable windows, shade devices, etc or automated controls shifting heating, ventilation and air-conditioning (HVAC) set-points in sync with weather and seasonal variations outdoors. This shift towards greater indoor climatic variability is integral to many sustainable building designs. Buildings featuring natural ventilation capabilities are typically defined nowadays as green-intent buildings. Many studies (Abbaszadeh et al. 2006; Leaman and Bordass 2007; Brager and Baker 2009) have found occupants are more favourably disposed to green buildings than their conventional energy-intensive predecessors. It is now widely accepted that occupants prefer more adaptive opportunities inside their buildings than the sealed façade, air-conditioned (AC) designs of last century (Baker and Standeven 1996). Leaman and Bordass (2007) observed in their extensive database of post-occupancy evaluation (POE) studies that occupant satisfaction scores for green-intent buildings tend to be higher than those in conventional AC buildings. Despite occupants preferring greater adaptive opportunities, they do not necessarily *expect* the thermal excursions that sometimes occur in naturally-ventilated (NV) buildings, especially in hot weather. Recent POE studies suggest that, notwithstanding occasional discomforts, occupants of green buildings tend to forgive these shortcomings provided they can exercise a modicum of indoor environmental control (Leaman and Bordass 2007). Coined as the ‘forgiveness factor’, derived by dividing ‘comfort overall’ scores by the average of the variables for temperature in summer and winter, ventilation/air in summer and winter, noise and lighting, this variable describes how people extend their comfort zone by overlooking and allowing for inadequacies of their thermal environment (Leaman et al. 2007). Although many green buildings tend to be hotter in summer, colder in winter and contain more glare from the sun and sky than their conventional AC alternatives, the occupants tend to be more forgiving. This toleration of moderate discomfort suggests that people may have an understanding of and a connection to the outdoor climate by virtue of the buildings design. Leaman and Bordass (2007) suggest increased knowledge of the adaptive opportunities in buildings yields a greater likelihood of reduced discomfort.

Environmental Attitudes, Behaviours and The New Ecological Paradigm (NEP)

In recent decades, there has been a growing awareness of the problematic relationship between modern industrialised societies and the physical environments on which they depend (Dunlap 2008). With the emergence of pervasive environmental problems such as climate change, researchers have started exploring how to quantify public sentiment on these issues. The New Ecological Paradigm (NEP) scale, a revision of the New Environmental Paradigm, is a 15-item questionnaire consisting of 8 pro-NEP and 7 anti-NEP items. It measures strength of endorsement (from low to high) of an ecological worldview (Dunlap et al. 2000). After extensive application across diverse studies, a broad consensus is emerging in the environmental psychology literature that the NEP represents a valid and reliable scale for measuring levels of ecological beliefs and behaviours (Cordano et al. 2003). To date, however, the NEP scale has not been used in building occupant studies.

Methods

Sydney’s Climate

The Sydney metropolitan region is located on the eastern coast of Australia (34°S, 151°E) and is characterised by a moderately temperate climate. Influenced from complex elevated topography surrounding the region to the north, west and south and due to close proximity to the Tasman Sea to the east, Sydney avoids the high temperatures commonly associated with more inland regions as well as the high humidity of tropical coastal areas (BoM 1991). The summer months of December to February can be described as warm-to-hot with moderate-to-high humidity peaking in February to March. Between June and August, Sydney experiences cool-to-cold winters. Macquarie University (MQ) is located in Sydney’s North Ryde, 16km north-west of Sydney’s CBD (33° 46’ S, 151° 6’ E). Seasonal variations are fairly consistent with the greater metropolitan region with a mean summer daily maximum temperature of 26-28°C, a mean winter daily maximum of 17°C and an annual mean daily maximum of 22-23°C. Mean minimum daily temperatures range from 5-8°C in winter, to 17-18°C over the summer months, with an annual daily minimum temperature of 11-13°C (BoM 2007). Given the city’s yearly seasonal variations, Sydney’s climate is well suited to mixed-mode (MM) buildings.

Case Study Buildings

Two academic staff buildings from MQ were selected for this study, both having North-South orientations, with North facades directly irradiated from the Sun, creating warmer internal temperatures than the South-facing perimeter zones. The sample buildings consisted of a MM building (see Photo 1) commissioned in 2006, and a NV building (see Photo 2) built in the late 1960s.

The MM building features operable windows on all perimeter cellular offices along North and South facades separated by an AC central open-plan office zone. Indoor temperature and outdoor weather sensors drive the Building Management System (BMS) to switch to AC mode when average indoor temperatures increase above 25°C. Occupants are mainly academics and administrative staff from economics and finance departments. The NV building features occupant-operated windows and a narrow floor-plate traversed by a central corridor with single- and dual-occupant cellular offices on either side. Academic staff, administrative staff and post-graduate students from a variety of environment-related disciplines occupy this NV building.

Photo 1: MQ, MM building (North façade) featuring operable windows with external solar shading devices on north-facing windows

Photo 2: MQ, NV building (North façade) featuring occupant-operated windows with some individual air-conditioner units

Measurements

Throughout the study, dataloggers have been randomly located within each building to record air temperatures, globe temperatures and relative humidity at 5 minute intervals. These were placed within 1 metre of the occupants' workstation to characterise the immediate thermal environment experienced by the occupant whilst working. In addition to indoor climate measurements, outdoor air temperature was also recorded over the same period at a nearby automatic weather station. Concurrent BMS data from the survey period was collected from the University's Office of Facilities Management (OFM).

Questionnaires

Between March and April 2009 (the Austral autumn), two questionnaires were distributed to all staff in both buildings:

1. The three-page Building Use Studies (BUS 2009) POE uses 7-point Likert scales with space for commentary, covering variables relating to occupant satisfaction, e.g. thermal, visual and acoustic comfort, indoor air quality, perceived health and productivity, and general acceptance of the workplace. BUS (2009) further details the BUS methodology. Combinations of these scores enable the calculation of BUS comfort and satisfaction indices, as well as the forgiveness factor (defined earlier).
2. The Environmental Attitudes questionnaire is a 15-item version of the NEP Scale (Dunlap et al. 2000), using 5-point response scales ranging from *Strongly Disagree* to *Strongly Agree*, with higher scores on the scale from 1 (low) to 5 (high) indicating greater levels of environmental concern. All scales were converted to a NEP score by summing each item response and dividing by the total number of items in the scale. Results were analysed using MiniTab statistical software.

Results

Thermal Environment

In order to show the differences between each building based on objective measurements, i.e. internal temperature, it is instructive to show how both buildings perform under the same weather conditions. Building occupant studies are generally conducted in summer, hence it was necessary to obtain temperature data from September 2009 to reflect similar conditions to when the questionnaires were administered 6 months prior. From temperatures averaged across all dataloggers, it was established that the NV building experienced significantly warmer temperatures (average = 23.5°C, $p = 0.000$) than the MM building over the same period (average = 22.2°C). Figure 1 below highlights the discrepancies between the internal temperatures within these buildings. Temperatures inside each building were far greater than the surrounding outdoor air temperature throughout the day (mean = 16.3°C, $p = 0.000$). As a NV building, internal temperatures closely match changes in outdoor weather conditions, whereas the MM building contained its indoor temperatures within a narrower band.

Figure 1 indicates that internal temperatures within the MM building rarely exceed 25°C due to the BMS switching into AC mode whenever average temperatures reached the 25°C trigger temperature. Less than 10% of occupied office hours (i.e. 8am-6pm weekdays) within this building experienced indoor temperatures greater than 25°C. In contrast, temperatures inside the NV building varied between 20-28°C. Internal temperatures in the NV building exceeded the 25°C threshold almost 50% of all occupied office hours.

Using a 7-day running average of daily mean outdoor temperatures, Figure 1 also presents the 80% thermal acceptability band limits derived from the ASHRAE Standard 55 adaptive comfort model (ASHRAE 2004). These indicate the suggested range of internal operative temperatures that should not be exceeded within the occupied zone (de Dear 2007). As seen in Figure 1 below, average temperatures inside the NV building exceeded the upper limit of acceptable adaptive comfort on four separate occasions in September. In contrast, the MM building never exceeds these limits; in fact indoor temperature only exceeded the 25°C trigger temperature on one occasion.

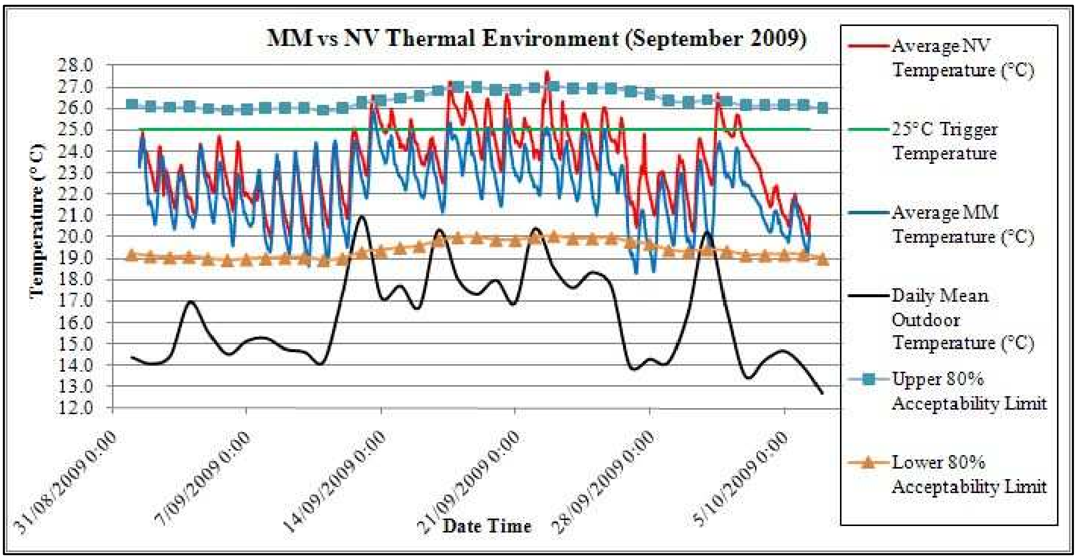

Figure 1: Indoor and outdoor thermal environments comparing the NV and MM buildings (September 2009)

POE and NEP Analysis

In total, 163 POE and NEP questionnaires were distributed in the MM building and 40 in the NV building. With a 53% response rate, the MM building returned 86 completed questionnaires (39 male, 47 female), and 29 (13 male; 16 female) were completed from the NV building (73% response rate). Incomplete or suspect responses were omitted from the samples in a basic quality assurance check. POE responses for both buildings were benchmarked against the Australian BUS database (as summarised in Table 1). The NEP questionnaire items were tested for internal consistency and were found to have strong coefficient alphas ($\alpha = 0.82$) suggesting good internal consistency.

As shown in Table 1 (below), both buildings generally measure poorly in regards to the POE summary variables. The NV building appears worse than the MM building in most summary variables; it was found that the average forgiveness factor (FF) was significantly higher than that for the MM building, with FF scores greater than 1.0 indicating greater levels of tolerance. The NV building had a significantly higher mean NEP score (4.04, $p = 0.005$) than the MM building (3.69), plausible for environmentally educated academics. Interestingly, the NEP score for the MM building is relatively high for occupants associated with economics, finance and business studies as scores greater than 3.0 generally indicate pro-environmental attitudes.

Table 1: A summary of POE and NEP results for the MM and NV buildings

Study Variable	MM (n = 86)	NV (n = 29)	Significance
Forgiveness Factor	0.99	1.17	p = 0.019
Comfort Index	-0.39	-0.70	Not sig.
Satisfaction Index	0.02	-0.10	Not sig.
Perceived Productivity	-5.34	-10.71	p = 0.000
NEP	3.69	4.04	p = 0.005

In order to analyse environmental attitudes and their relation with forgiveness factors within each building, it was important to isolate a control group that would not be biased towards any environmental or building-related concepts. Administrative staff within both buildings undertake various clerical duties and management aspects for their respective faculties. Since they are not considered to have academically inclined responsibilities, these groups were considered separate from the buildings' academic staff (summarised in Table 2).

Within the NV and MM buildings, administrative staff had slightly lower levels environmental concern compared to the academic staff within the building. Also, both groups were significantly different in regards to their FF, with the academics scoring higher levels of tolerance for each building. Table 2 indicates that the administrative staff of the NV building had significantly higher NEP scores (3.21) than those located inside the MM building (2.66, $p = 0.016$). Correspondingly, the same group measured higher degrees of forgiveness (NV = 0.89, MM = 0.74, $p = 0.004$).

Table 2: Analysis of Forgiveness Factor and NEP results for the MM and NV buildings

Study Variable	MM Academic (n = 64)	NV Academic (n = 22)	Significance
Forgiveness Factor	1.02	1.14	p = 0.017
NEP	3.80	4.20	p = 0.000

Study Variable	MM Admin (n = 13)	NV Admin (n = 7)	Significance
Forgiveness Factor	0.74	0.89	p = 0.004
NEP	2.66	3.21	p = 0.016

Since the NEP questionnaire items are measured across a 5-point Likert scale, responses were binned according to their item response (from low to high, 1 to 5). Weighted according to the number of FF samples within each NEP bin, a linear regression model was fitted to test any correlation between NEP and FF scores for these two case study buildings. As illustrated in Figure 2, there is a strong positive relationship between environmental attitudes and forgiveness factors ($R^2 = 98.9\%$, $p = 0.001$) suggesting higher levels of environmental beliefs yielded higher levels of tolerance.

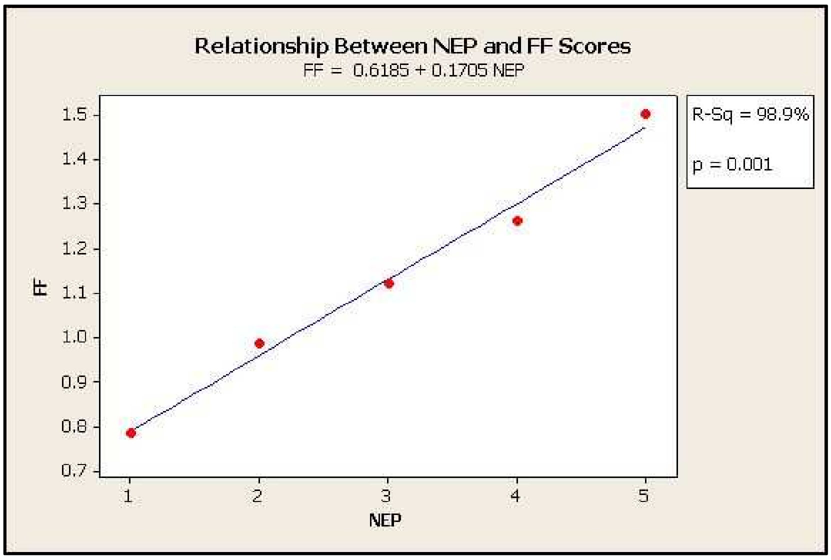

Figure 2: Relationship between NEP and FF scores for both study buildings.

Discussions

With higher temperatures recorded in the NV building (Figure 1), it is reasonable to expect that perception of productivity at temperatures up to 28°C would be significantly lower than a MM building. Occupants in both buildings have often complained about indoor temperatures in summer months, particularly on the north façade. This anecdotal feedback is consistent with a trend emerging from Australian green buildings that have undergone the BUS POE (Leaman et al. 2007). In comparing 22 green-intent buildings against 23 conventional HVAC office buildings, Leaman et al (2007) reported that green buildings were perceived as hotter in summer and cooler in winter. Green-intent buildings, such as the NV and MM buildings in this study, are *expected* to perform this way. In comparing the 'forgiveness' scores from Leaman et al (2007) (summarised in Table 3 below) to those results in Table 1 (above), it was found that the MM building is poorly received by its users (forgiveness = 0.99, equal to that of conventional AC buildings in Australia). Contrastingly, the NV building measured significantly higher NEP scores indicating greater tolerance to perceived thermal variance (forgiveness = 1.17), consistent with other green-intent buildings already in the BUS database.

Table 3: Forgiveness scores by ventilation type: Australian BUS building database (n = 45)

Study Variable	Green-intent (NV, ANV, MM)	AC	MM (MQ)	NV (MQ)
Forgiveness Factor	1.02	0.99	0.99	1.17
n	22	23		

Note: Higher values indicate occupants more tolerant or 'forgiving' of the conditions. Building types include natural ventilation (NV), advanced natural ventilation (ANV), mixed-mode (MM) and air-conditioning (AC).

The correlation of NEP and FF scores shown in Figure 2 supports the hypothesis that green building users are more prepared to overlook and forgive less-than-ideal conditions than their 'brown' (non-green) counterparts suggesting there is a possible link between occupant satisfaction and environmental attitudes. Whilst the NEP Scale was originally designed to measure environmental concern of the general public, with both samples containing tertiary-educated participants there is a limit to what can be drawn from these results. Nonetheless, it amplifies how occupant attitudes and expectations play an important role in the way green-intent buildings are designed, built and received.

Conclusions

Green buildings have greater thermal variations than their AC counterparts, in which centralised HVAC provides static indoor temperatures to all occupants all-year round. This paper suggests green building users are more forgiving of their building, consistent with the hypothesis that green buildings need green occupants. Whilst the study only represents two green buildings at MQ, it highlights the increasing awareness to the psychological dimensions of occupant adaptation, such as attitudes, expectation and control. Given the urgency to mitigate global warming, it has become apparent that people's attitudes, and the behaviours they entail, can be manipulated. Whilst buildings take years to build and even months to retrofit, the path to altering people's expectations of the built environment presents the low-lying fruit. According to this study, the forgiveness of green buildings can be cultivated. Given the multitude of sustainable and pro-environmental behaviour literature, there is great potential for occupants to be 're-educated' about the role buildings play in addressing global climate change. The emergent practical applications of adaptive building design calls for the clear communication of intent by designers to the users and building managers to ultimately assist in the transition to an energy efficient, low-carbon future.

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