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Thermal comfort conditions in sustainable buildings – Results of a worldwide survey of users' perceptions

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ABSTRACT

The users' perceptions of thermal comfort in 36 sustainable commercial and institutional buildings in 11 countries have been investigated. This paper describes and analyses the users' overall perceptions of temperature and of air quality in both summer and winter, and in particular whether they found conditions hot or cold, stable or variable, still or draughty, dry or humid, fresh or stuffy, or odourless or smelly. The results from these analyses indicated a good degree of satisfaction with internal thermal comfort conditions overall. The temperatures and air quality factors of these buildings proved to be better, on average, than a set of more conventional buildings However, conditions were perceived to be on the cold side in winter and on the hot side in summer. This indicates that more attention must be given to these aspects of design and operation.

1. Introduction

Over the last decade or so building designers and developers have been producing sustainable buildings for their more environmentally conscious clients. Many of these buildings have been highly rated in terms of relevant Building Sustainability Rating Tools (BSRTs) or have received awards for their low energy design. In the main, these ratings and awards are based on the building design and its potential for low energy and sustainable operation, and their focus tends to be on technical aspects of building design [1]. Indoor environmental quality is certainly one of these aspects, but the concern is usually with the provision of comfortable temperatures and humidities, adequate air quality, sufficient lighting and appropriate acoustic conditions (all of which are specifiable and measurable).

Our interest has been in how these buildings are performing from the point of view of the building users. While measurements of all the physical factors (air and radiant temperatures, humidity, air movement, clothing insulation and activity levels) would likely provide insights into the thermal performance of these buildings, at the end of the day what really matters is whether sustainable buildings are perceived to be thermally comfortable by their occupants. Buildings that perform poorly from the users' point of view are unlikely to be sustainable in the long term.

It is only very recently have there been some moves towards developing BSRTs that assess the environmental quality of the building once it is in operation. As far as can be ascertained, only the groundbreaking Indoor Environmental Quality protocol of the Australian NABERS suite [2] of BSRTs is designed to enable such an assessment. Not only does it specify a range of physical measurements, it also involves conducting a questionnaire survey of the building occupants [3]. Two methods are approved for the survey, one developed by Building Use Studies of London, UK, the other by the Center for the Built Environment, University of California, Berkeley, USA. Our aim here, using the Building Use Studies survey methodology under licence [4], was to determine whether the occupants of a worldwide set of 36 sustainable buildings found them to be thermally comfortable.

2. Methodology

For the last five years the performance in practice of a large number of commercial and institutional buildings in 11 countries worldwide has been investigated by Baird [5], to ascertain the users' perception of a range of factors: operational, environmental (including thermal, acoustic and lighting aspects), personal control, and satisfaction. This paper is part of a series [6–8] describing different aspects of the findings of that research programme. It focuses on the environmental factors relating to the occupants' perception of thermal comfort, including temperature, air quality and conditions overall in both summer and winter, as appropriate to the climate of the building location.

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2.1. The buildings

The buildings surveyed were as follows, by country:

- Australia: 40 Albert Street and 60L, Melbourne; Red Centre and Institute of Languages, UNSW, Sydney; Student Centre and General Purposes Building, Newcastle University; Scottsdale Forest Ecocentre, Tasmania.
- Canada: Computer Science and Engineering, York University; Liu Institute, University of British Columbia; Toronto Military Families Resources Centre; National Engineering Yards, Vancouver.
- Germany: 2006 Science Park, Gelsenkirchen.
- India: Torrent Research Centre, PDEC Buildings and AC Buildings, Ahmedabad.
- Ireland: St Mary's Credit Union, Navan.
- Japan: Nikken Sekkei HQ, Tokyo; Tokyo Gas Earthport, Yokohama.
- Malaysia: Menara UMNO, Penang; MEWC HQ, Putrajaya.
- New Zealand: AUT Akoranga, Auckland; Landcare Research, Auckland; Erskine Building, University of Canterbury, University of Otago Library, Dunedin; Nelson Library; Universal College of Learning, Palmerston North; Environment House, Wellington; Conservation House; Wellington; Paraparaumu Public Library.
- Singapore: Institute of Technical Education, Bishan.
- UK: Arup Campus, Solihull; City Hall, London; Eden Foundation, St Austell; Gifford Studios, Southhampton; Renewable Energy Systems HQ, Kings Langley; ZICER Building, University of East Anglia.
- USA: Natural Resources Defence Council, California; NRG Systems, Vermont.

These were selected on the basis of their sustainability 'credentials'. Virtually all of them were recipients of national awards for sustainable or low energy design or highly rated in terms of their respective countries building sustainability rating tool (LEED [9], BREEAM [10], CASBEE [11], Green Star Australia [12] Green Globes [13], etc) or in some way pioneered green architecture. Of course, willingness on the part of the building owner and tenants to be surveyed was also an essential prerequisite, and not all building owners approached felt in a position to accept our invitation.

Around 2500 staff responded to the questionnaire, the vast majority scoring every question. Numbers ranged from a low of 13 responses from the small staff group at the Toronto Military Families Resource Centre to a high of 334 at London City Hall, with a mean of approximately 70 respondents per building. Most of the buildings were in temperate climates of one kind or another (ranging from warm-temperate to cold-temperate). Their systems of ventilation ranged from full air conditioning, through mixed-mode, to natural ventilation.

2.2. The thermal comfort questions

The 'Comfort' questions on the survey form were introduced using the following statement:

'This section asks how comfortable you find the building in both winter and summer'.

The questionnaire was then split into winter and summer sections in which the same set of eight questions was posed under three main headings:

- *Conditions Overall* in winter/summer – are they unsatisfactory–satisfactory?
- *Air* in winter/summer – is it still–draughty; dry–humid; fresh–stuffy; odourless–smelly?
- *Temperature* in winter/summer – is it uncomfortable–comfortable; too hot–too cold; stable–varies during the day?

Respondents were asked to rate their perceptions of each factor on a 7-point scale. Note that the ideal rating could be 1, 4, or 7, depending on the scale selected for any particular factor.

3. Results

In this section the results will be presented and analysed, first for winter conditions, and then for summer conditions.

3.1. Occupants perceptions of comfort in winter

The scores for each of the eight winter factors are presented below in Table 1, in terms of their median, mean, and standard deviation (SD) values for the relevant number (N) of buildings. Also listed are the 'ideal' scores for each factor and a corresponding benchmark (BMK) score (based on the average of the previous 50 buildings assessed by BUS at the time of each survey).

Dealing first with the two factors for which '7' would have been the ideal score, it can be seen that *Temperature* (*uncomfortable–comfortable*) and *Conditions Overall*, with means of 4.46 and 4.45 respectively, both scored towards the better side of the range (i.e., greater than 4, the mid-point of the range) and were slightly better than the corresponding benchmarks.

For the three factors for which '1' would have been the ideal score, *Air* (*fresh–stuffy*) and *Air* (*odourless–smelly*), with means of 3.82 and 3.09 respectively, are on the better side of the range (in this case less than 4, the mid-point of the range); and both were much better than their benchmark values. In the case of *Temperature* (*stable–varies*) the mean score was 4.33, on the worse side of the mid-point, but still better than the benchmark average of 4.49.

For the three factors for which '4' would have been the ideal score: *Temperature* (*too hot–too cold*) scored 4.63, well into the cold range and worse than the benchmark; *Air* (*still–draughty*) at 3.58 was on the *still* side of ideal, but close to the benchmark; *Air*

Table 1
Scoring for comfort in winter.

Sub-heading	Factor	*N*	Median	Mean	SD	BMK	Ideal
Conditions Overall	Unsatisfactory–Satisfactory	32	4.38	4.45	0.61	4.41	7
Temperature	Uncomfortable–Comfortable	32	4.47	4.46	0.64	4.24	7
	Too hot–Too cold	35	4.67	4.63	0.53	4.37	4
	Stable–Varies	35	4.50	4.33	0.62	4.49	1
Air	Still–Draughty	35	3.67	3.58	0.62	3.60	4
	Dry–Humid	35	3.32	3.33	0.36	3.19	4
	Fresh–Stuffy	35	3.91	3.82	0.76	4.43	1
	Odourless–Smelly	35	3.22	3.09	0.64	3.34	1