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Occupants' behavioural adaptation in workplaces with non-central heating and cooling systems

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ABSTRACT

Occupants' behaviour when improving the indoor environment plays a significant role in saving energy in buildings. Therefore the key step to reducing energy consumption and carbon emissions from buildings is to understand how occupants interact with the environment they are exposed to in terms of achieving thermal comfort and well-being; though such interaction is complex. This paper presents a dynamic process of occupant behaviours involving technological, personal and psychological adaptations in response to varied thermal conditions based on the data covering four seasons gathered from the field study in Chongqing, China. It demonstrates that occupants are active players in environmental control and their adaptive responses are driven strongly by ambient thermal stimuli and vary from season to season and from time to time, even on the same day. Positive, dynamic, behavioural adaptation will help save energy used in heating and cooling buildings. However, when environmental parameters cannot fully satisfy occupants' requirements, negative behaviours could conflict with energy saving. The survey revealed that about 23% of windows are partly open for fresh air when air-conditioners are in operation in summer. This paper addresses the issues how the building and environmental systems should be designed, operated and managed in a way that meets the requirements of energy efficiency without compromising wellbeing and productivity.

1. Introduction

Occupants' behaviour in terms of improving the indoor environment plays a significant role in saving energy in buildings. Therefore, the key step to reducing energy consumption and carbon emissions from buildings is to understand how occupants interact with the environment they are exposed to in terms of using energy; though such interaction is complex. People adjust themselves to maintain and improve their well-being through physiological, psychological and behavioural reactions to the environmental stimuli. We define these actions as Occupant Behaviour. The physiological balance of the human body can be achieved as a result of the gradual diminution of the strain induced by these stimuli. The behavioural reactions will lead to actions such as switching heating/cooling on/off, opening/closing windows or blinds, the putting-on/taking-off of clothes, switching lights on/off, etc, which are also, influenced by occupant's expectations about their actions' effects. As a result, occupant behaviours will affect building performance in terms of energy use.

The principle of adaptive thermal comfort is expressed as: if change occurs such as to produce discomfort, people react in ways which tend to restore their comfort [1]. The majority of researchers into adaptive thermal comfort mainly focus on developing adaptive thermal comfort models under the free running condition [2–7]. Recently, Indraganti [8] has studied behavioural adaptations of occupants in apartment buildings in India. Yun and Steemers studied the window use pattern in UK naturally ventilated buildings [9]. There are broad interests in understanding how people react through behavioural adaptation when the indoor thermal temperatures are in various conditions, such as extremely hot, moderate and extremely cold.

This paper introduces a field study carried out in office workplaces in Chongqing University, located in Chongqing, China. This is a collaborative research work between the University of Reading in the UK and Chongqing University in China. The surveyed five-story building has mix functions of classrooms and office rooms. The office rooms are located on the third to fifth floors. The surveyed subjects are mainly university academic, administrative and

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Table 1
Summary of voting scale information.

Index	Scale						
	−3	−2	−1	0	+1	+2	+3
Thermal sensation (AMV)	Cold	Cool	Slightly cool	Just right	Slightly warm	Warm	Hot
Thermal preference	–	Want much cooler	Want a slightly cool	No change	Want a slightly warm	Want much warmer	–
Previous day thermal experience at the moment	–	Much cooler than at present	A slightly cooler than at present	The same as at the moment	A slightly warmer than at present	Much warmer than at present	–
Thermal acceptability	–	–	–	Not acceptable	Acceptable	–	–
Perceived environmental control level	0 No control	1 Light control	2 Medium control	3 High control	4 Total control	–	–

research staff. A total of 148 people participated in the survey, which account for around 40% of the staff at the faculty.

The workplaces have no centrally controlled heating and cooling systems but are equipped with air-conditioning units which operate in cooling mode in summer and heating mode (electrical heaters are embedded) in winter. This unique case provides a good opportunity for the investigation of occupants' responses to the environment to which they are exposed and their behavioural adaptations.

2. Research method

This field study was carried out in 2010 covering both typical seasons (e.g. summer: June–August and winter: December–February) and the transition seasons (e.g. spring: March–May and autumn: September–November). A workplace thermal sensation and adaptive responses questionnaire survey has been employed in this research, along with onsite monitoring and investigation of the physical environment.

2.1. Local weather conditions

Chongqing is located in southwest China, which has typical hot summer and cold winter climatic conditions. The mean outdoor air temperatures in the coldest and hottest months are 0–10 °C and 25–30 °C [10], respectively. The mean outdoor relative humidity during whole year is up to 70–80% [11]. The surveyed workplaces were originally designed as naturally ventilated buildings without any centrally controlled heating/cooling systems. In the last 10 years, air-conditioning units have been installed in offices in order to improve the workplace thermal environment due to the economic growth of the country. Although air-conditioning units are available in all surveyed workplaces, the use of these units is purely dependent on occupants' needs.

2.2. Questionnaire survey

The questionnaire used in this study is designed based on the method provided by the ASHRAE Standard 55 [12] and contains three sections (see Appendix). The first section contains background and anthropological information such as gender, age and so on. The responses to those questions, except for those about clothing ensembles, are graded using different point scales. Respondents only need to tick the appropriate scale which is in accordance with their own conditions at that moment for each corresponding question. The clothing levels at the time are recorded according to the ASHRAE standard [12]. The activity level of the occupant is equivalent to the metabolic rate, covering 1.1–1.3 met[1] to determine the index of Predicted Mean Vote (PMV) values, because subjects in surveyed offices were usually doing sedentary activities such as typing, reading and writing, etc. involving use of computers. The chairs involved in this investigation are of standard type, therefore the insulation of 0.1 clo is included in clothing insulation values. The second section of the questionnaire is the thermal part including overall thermal comfort sensations, thermal acceptability and preference, previous day thermal experience and thermal expectations, respectively. The third section seeks information about the perceived environmental control level, the purpose of control and additional control measures. Table 1 shows the information and voting scale in the questionnaire survey.

Table 2
Subjects' age and gender.

% Season		Spring	Summer	Autumn	Winter
Age	<24	55.6	58.3	48.6	41.4
	25–35	27.8	31.3	31.4	31.0
	36–45	13.9	8.3	17.1	17.2
	46–60	2.8	2.1	2.9	10.4
Gender	Male	55.6	64.6	60.0	58.6
	Female	44.4	35.4	40.0	41.4

2.3. General information

The building where the field studies carried out is of masonry construction with a north–south orientation and built over 50 years ago. All windows are single-glazed with aluminium frames. Air-conditioners are installed in each surveyed office and can be operated individually according to the occupants' wishes. During the survey period, 148 occupants completed questionnaire forms leading to 1178 datasets being received. In each season, more than half of the occupied subjects participated in this study. Among them, 48 participants provided 341 datasets in summer and 154 datasets were collected from 29 subjects in winter; in the transition seasons of spring and in autumn, there were 36 and 35 respondents, respectively. In all seasons, young persons who were less than 24 years old accounted for around half of all subjects. The gender distributions in each season were nearly equal except in summer and autumn when there were 20% more male respondents. The basic information regarding subjects is summarised in Table 2.

2.4. Measurement of physical and environmental parameters

Air temperature (T_a), air velocity (V_a), mean radiant temperature (T_r), which is represented by global temperature (T_g) in this investigation [13,14], and relative humidity (RH) were measured while subjects were completing the questionnaire to reveal the real-time thermal conditions of their office environments. On the survey day,

[1] Met-the unit used to describe the energy generated inside the body due to metabolic activity. 1 met = 58.2 w/m^2; Clo, clothing insulation; 1 clo = 0.155 m^2 K/W.