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Thermal comfort and occupant adaptive behaviour in Japanese university buildings with free running and cooling mode offices during summer

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ABSTRACT

Thermal comfort is one of the most important factors for satisfying occupants within indoor environments, especially in regions that experience warm summer seasons, and analyses of thermal comfort and occupant behaviour are critical for the effective implementation of energy saving programs. This paper presents the results of studies on the thermal comfort and adaptive behaviour of occupants in university buildings with free running (FR) and cooling (CL) mode offices in Fukuoka, Japan. Both thermal measurements and thermal comfort surveys were conducted during the summer season. The mean thermal sensation vote (TSV) in FR and CL modes was 0.7 and −0.1, respectively. These data show that occupants in FR mode offices felt slightly warmer than those in CL mode offices, where occupants typically reported feeling neutral. The mean comfort temperature for both cases, as estimated by using the Griffiths method, was 26.6 °C. For personal clothing, we found that the use of clothing insulation was inversely proportional to the outdoor temperature. The adaptive behaviours of occupants were found to be more active in FR mode offices compared to those in CL mode offices, which were more passive. This indicates that amenable thermal conditions were present in the air conditioning (A/C)-controlled indoor environments where occupants expressed no wish to make changes.

1. Introduction

In accordance with global climate change, buildings need to be designed well so that they can achieve high levels of energy efficiency while maintaining the health and comfort of occupants. Occupant satisfaction is an important part of measuring a building's performance, as people spend over 80% of their time in indoor environments [1]. The indoor environment encompasses the conditions in closed spaces inside of buildings and the parameters of the indoor environment that influence the occupants' thermal comfort. Many surveys have shown that thermal comfort is one of the most important aspects that influences occupant perceptions in regard to the use of natural ventilation or air conditioner systems [2–5]. Nowadays, there is a trend where air conditioning (A/C) has become an essential feature of buildings to create and maintain thermally comfortable indoor conditions during working hours. However, each individual working in an office environment may experience different thermal sensations, and therefore, they often behave in different ways to mitigate thermal discomfort; these behaviours may include changing clothes, taking a drink, switching on/off air conditioners or stand fans and actively opening windows, blinds or doors [6–8]. Such behaviours can affect the overall energy consumption of buildings, and energy savings can often be achieved by adjusting thermostat settings. For example, in Japan where the Japanese government has been implementing the Coolbiz campaign policy, which mandates that every office building set the air conditioner thermostat to no less than 28 °C, this can lower the A/C cooling load while promoting energy savings and occupants can adjust by just wearing lighter clothing [9]. People have a natural tendency to engage in some form of adaptive behaviour as mentioned above to maintain comfortable environmental conditions. Wei et al. [10] have shown that the acceptability of the

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thermal environment strongly depends on occupant behaviours, and there are many previous studies, for example, those by Auliciems [11], de Dear and Brager [12], Indraganti et al. [13] and Rijal et al. [14], that have focused on occupant adaptive behaviours in regard to thermal comfort.

Since 2005, when the Kyoto Protocol was effectively enacted in Japan to reduce global warming and greenhouse gas emissions, many researchers and engineers have been studying thermal comfort as it relates to natural ventilation instead of A/C usage [9,15]. Moreover, several studies have focused on thermal comfort in relation to Japan's above mentioned Coolbiz campaign; in Coolbiz offices, workers are allowed to wear lighter and looser office clothing [9,16,17]. After the Fukushima earthquake and tsunami knocked out one of Japan's largest nuclear power plants in 2011, the Japanese government had to mandate vastly reduced levels of energy consumption [16]. Therefore, offices now have to comply with the government-prescribed indoor summer temperature of 28 °C, which was only a voluntary guideline when the policy was first enacted in 2005. Most office occupants in Japan use a stand fan for air circulation and wear loose clothing to cope with the hot thermal sensations in office rooms during the summer season [9,16,17].

Consequently, this context presents an interesting opportunity to study how the Japanese tolerate and adapt to indoor thermal discomfort during the summer season while the government promoting energy saving through Coolbiz campaign. Therefore, the main objectives of this research were to investigate the thermal comfort of occupants in free running (FR) and cooling (CL) mode offices in educational buildings equipped with A/C systems and to study their adaptive behaviours. This was accomplished by measuring indoor environmental variables such as air temperature, globe temperature, air velocity and relative humidity and through conducting occupant surveys. We investigated the adaptive behaviours of the occupants for both cases (i.e., FR and CL modes).

2. Research methods

2.1. Investigated buildings

Studies were conducted within two university office buildings located on the Chikushi Campus of Kyushu University, Fukuoka, Japan, as shown in Fig. 1, during the summer season from 7 to 28 August 2014. In summer, the mean outdoor temperature is around 28 °C, and the daily maximum typically reaches 32 °C in Fukuoka [18,19]. Table 1 summarizes general information about the buildings and their occupants.

The first building was comprised of two administrative offices, which are referred to as A1 and A2 herein, while the second building included two academic researcher offices, which are referred to as B1 and B2 herein; pictures of the investigated offices are shown in Fig. 2. There were five floors and four floors in buildings A and B, respectively.

All office rooms were equipped with split-type A/C systems, mechanical stand fans and window blinds. Generally, occupants in A1, A2 and B1 offices operated both the A/C and the mechanical stand fans daily; the A/C was used to reduce indoor temperatures as well as excess humidity, whereas the fan was just used to add velocity to the air. We categorized this condition as the CL mode office. In contrast, the situation was different in the B2 office, where the occupants preferred to open doors and windows and use stand fans instead of switching on the A/C system during the office hour period (from 8:00 until 18:00). This condition is referred to as the FR mode, and occupants had been previously exposed to this condition for more than 6 months.

2.2. Indoor thermal measurements

Field measurements were carried out in 2 h periods for two times per day over each working day in the morning and afternoon (i.e. 10:00 to 12:00 and 14:00 to 16:00, respectively). The following four indoor environmental parameters were measured: air temperature (T_a), relative humidity (RH), globe temperature (T_g) and air speed (V_a) (Fig. 3). All instruments were clamped onto a device that was placed at a height of 1.1 m above the floor. To take the measurements, the devices were placed at three different locations in each office room, as shown in Fig. 4. However, because we had only a limited number of hot wire anemometers, air velocity sampling took place at just one location in A1 and A2. The average value of these three positions was used to represent the thermal conditions in the office room. Table 2 summarizes the parameters and instruments used for the measurements. The outdoor air temperatures were obtained from the Fukuoka Airport weather station, which is located approximately 8 km away from the site where the field measurements were made.

Both mean radiant temperature (T_{mrt}) and operative temperature (T_{op}) were estimated by using the expression stated in the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 55 [20].

2.3. Thermal comfort survey

The thermal comfort survey used here was adapted from

Fig. 1. Field measurement sites **(a)** building A and **(b)** building B on the Chikushi Campus, Kyushu University.