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Thermal comfort and adaptation of the elderly in free-running environments in Shanghai, China

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ABSTRACT

This paper presents a field investigation on the thermal environment of elderly facilities in Shanghai, China. The thermal comfort and adaptive behaviour of the elderly in free-running environments were analysed through questionnaire surveys and physical measurements. For this purpose, a total of 17 elderly facilities with 42 buildings and 672 healthy elderly people over 70 were randomly selected. Results indicated that, in winter, the actual neutral temperature was lower than the predicted mean vote (PMV) temperatures, while in summer there was no significant difference between the actual thermal neutrality temperatures and the PMV predicted ones. The elderly preferred neutral thermal environments, but their thermal sensitivity was low and they were not sensitive to changes in temperature. The thermal adaptation behaviour of the elderly exhibited seasonal differences. The two most commonly used thermal adaptation methods in winter and summer were to change clothing and open or close windows. In winter, the effect of changing clothing on thermal comfort was not obvious, and opening or closing windows did not effectively regulate the indoor thermal environment. In summer, changing clothing played an important role in thermal adaptation, but the adjustment was limited, while opening or closing windows adjusted indoor temperature and wind speed, thereby improving the thermal comfort of the elderly. Furthermore, the results of this study may be a useful reference when designing or managing thermal comfortable environment for the elderly.

1. Introduction

Public awareness of the rapidly growing aging population has increased in recent years. Given growing concerns about this aged population, attention is now focused on thermal comfort in the design and planning of environments for the elderly [1–13]. Indoor thermal environments can significantly influence human health and comfort [14], and because elderly people live at least 80% of their time in an indoor environment [13,15], thermal comfort and adaptation are considered important issues in the design of indoor environments in homes for the elderly.

In the past decades, studies have confirmed that the thermal sensation of the elderly is different from that of the young. For example, Collins et al. [16] showed that when the elderly is able to control their environment, they prefer the same mean temperature but manipulate the ambient temperature much less precisely than young people. Natsume et al. [17] argued that thermal sensitivity decreases with advanced age, and Schellen et al. [18] suggested that during a constant-temperature session, the elderly prefer a higher temperature than young adults.

In ASHRAE 55–2013 [19], the predicted mean vote (PMV) index was adopted to predict the thermal comfort of the environment. Fanger [20] validated the PMV model for older adults by conducting experiments involving 128 elderly participants. Numerous studies have also compared the results of the PMV model to the observed thermal sensation in field surveys or climate-chamber research. One field survey performed by Cena et al. [21] indicated that there is a 0.5-point difference between the actual mean thermal sensation reported by elderly participants and the PMV measured using a thermal comfort meter and the Fanger Comfort Equation. Tsuzuki and Iwata [22] found that the PMV is lower than thermal sensation in elderly participants who tend not to feel cold and discomfort. Research by Schellen et al. [23] showed that for both transient and control conditions, the predicted thermal sensations were approximately 0.5 scale units higher than the measured values. van Hoof and Hensen [24] assessed thermal comfort using Fanger's

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PMV model and demonstrated the strengths and limitations of this model. The thermal sensation of the elderly thus may result from various factors, including physiological and psychological influence. The question remains: can the PMV model be used to predict the thermal sensation of the elderly? The answer must be validated in a specific and realistic thermal environment. In Hong Kong, Wong et al. [25] conducted a study at 19 centers for older people and found that older people likely have a different expectation of a thermoneutral environment than younger people. In Taiwan, Hwang and Chen [10] studied the thermal sensation of people older than 60 years, and discovered that the operative temperature range for 80% thermal acceptability in the summer was narrower than the range reported for younger people.

An alternative to the PMV approach is the adaptive thermal comfort model. The most common and widely adaptive models of thermal comfort were proposed by de Dear et al. [26] and Nicol and Humphreys [27,28]. They suggested that people have a natural tendency to adapt to changing conditions in their environment; this natural tendency is expressed in an adaptive approach to thermal comfort [27], and occupants in naturally ventilated buildings were tolerant of a significantly wider range of temperatures, explained by a combination of both behavioural adjustment and psychological adaptation [26].

According to the field investigation and questionnaire surveys of 87 Taiwanese old people in their homes conducted by Hwang and Chen [10], the predominant strategy of thermal adaptation for elders was opening windows in the summer and clothing adjustment in the winter. According to a field investigation [21] of thermal comfort in the homes of the aged in America and Canada from January to April 1984, the aged still felt comfortable even at relatively low temperatures, and their main thermal adaptation method was to increase thermal resistance with additional clothing. In fact, however, a higher indoor temperature was needed to ensure the aged did not suffer illness or injury related to low temperatures if they are relatively inactive. The field investigation on thermal comfort conducted in Canada during winters between 1985 and 1986 [29] supports a similar conclusion that the aged are in danger of suffering hypothermia under low indoor temperature due to the low activity levels. Therefore, in addition to improving indoor temperature, the aged should improve their thermal comfort by adjusting their levels of activities, rather than just clothing adjustment. An investigation conducted on thermal adaptation behaviour of over thirty American elderly people by White-Newsome et al. [30] indicated that the aged did not utilize all available measures to improve the thermal environment and failed to pay sufficient attention to possible injury caused by overheating.

Because a subject's thermal sensation differs according to individual, race, climate, habits and customs, and other factors [31], including regional variations in living habits, the thermal comfort and adaptation of the elderly is still a topic of interest in today's China. Therefore, this study conducted a field survey of 672 healthy aged people at 17 elderly facilities in Shanghai, China, with these research objectives:

(1) Verify applicability of the PMV model in predicting the thermal sensation and acceptable temperature of the elderly and predict the seasonal difference in thermal sensation and thermal comfort temperature;
(2) Investigate the thermal sensation, thermal satisfaction, and thermal preference of elderly people living in free-running environments, and study their thermal environment requirements when they are in a real indoor environment;
(3) Research the thermal adaptation behaviour of elderly people, and thereby understand the particularity of behaviours of the aged as well as seasonal difference in the particularity, and investigate the efficiency of regulation of their thermal adaptation behaviour.

2. Methodology

The survey included simultaneous measurement of indoor environmental parameters and assessment of the participants' sensation and adaptive behaviour using questionnaires. The surveyors were divided into two groups; one group measured parameters while the other administered the questionnaire. The field study began in January 2014 and finished in January 2015. Data on elderly facilities were collected mainly in winter and summer. December to March was considered as winter while June to August was summer.

2.1. Sample selection

2.1.1. Location and buildings

The field survey was conducted in Shanghai (120°51′–122°12′ E, 30°40′–31°53′ N), which has the highest percentage of aging population in China [32]. Shanghai experiences a northern subtropical monsoon climate, with four distinct seasons and abundant rainfall. The climate in Shanghai is moderate and moist, with a shorter spring and fall and a longer winter and summer. In 2013, the city's average annual temperature was 17.6 °C. Shanghai is in the hot summer and cold winter zone of China's building-climate zoning.

We selected 17 elderly facilities, and conducted surveys over 28 days in winter and 26 days in summer. In total, we surveyed 42 buildings, 25 during winter and 17 during summer. The survey sites and conditions are shown in Fig. 1 and Fig. 2.

The survey chose the bedroom environment of residential buildings in the elderly facilities as the research environment for indoor physical parameters, and also as the questionnaire research environment. Research conducted in Taiwan [10] indicated that air conditioner usage rate among the elderly was below 30%. Following an assessment of field conditions in shanghai, up to 97.2% of the rooms had air conditioners (AC), but most of the elderly people did not use these [33]. Therefore, only free-running thermal environments were considered in this research.

2.1.2. Participants

Statistical data from 2012 indicates that the average age of people living in elderly care centers in Shanghai was 85.2 years. To guarantee the reliability and representativeness of this research, 672 healthy individuals aged 70 and over were randomly chosen from the elderly facilities to participate in the survey. According to the frailty scales developed by Rockwood et al. [34,35] and listed in Table 1, this study treated participants in scales 1 to 4 as healthy, which indicates good status in their physical, psychological, and social aspects.

2.2. Field measurements

Outdoor temperature data were obtained from district meteorological stations in Shanghai. Instruments listed in Table 2 were utilized to measure indoor air temperature (t_a), relative humidity (RH), air speed (V_a), and black-globe temperature (t_g). The evaluation process of the indoor thermal environment was based on the ASHRAE 55–2013 [19] and GB 50785-2012 [36] standards. Data were collected at one central point if the indoor area was less than 16 m^2. If the indoor area was between 16 m^2 and 30 m^2, data were measured at two points; the diagonal line of the room was divided into three equal parts, and the two dividing points used as the