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The dynamics of thermal comfort expectations: The problem, challenge and impication

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ABSTRACT

In this paper we explore the notion of comfort expectations and ask the question whether they change as a result of long-term exposure to mild indoor climates. A comparative questionnaire survey was conducted in China where indoor thermal environments during winter in the northern region (with pervasive district heating) are much warmer than in the southern region (without district heating). Four subject groups were surveyed 1) subjects who had lived in the northern region of china with district heating all their life, 2) subjects who grew up in the southern region without district heating but as adults had moved to the north where district heating was pervasive, 3) subjects who had lived in the southern region of china without district heating all their life, and 4) subjects who grew up in the northern region with district heating but as adults had moved to the north where district heating was non-existent. Subjects who had lived their entire lives in the northern region with neutral-to-warm indoor climates had quite similar comfort perceptions and expressed the same levels of thermal acceptability as did those subjects whose life had been spent in the southern region, devoid of any district heating. Statistical analysis of the two sub-groups who migrated, north or south, indicated that it building occupants get accustomed to the thermally neutral lifestyle more easily and faster than do their counterparts who went from thermally neutral indoor climates of the north to the cold and uncomfortable indoor climates of the southern regions of China.

1. Introduction

Living in a favorable indoor climate contributes to one's thermal comfort perception, health and productivity [1]. What kind of indoor climate should be created and how to create it are questions closely correlated with building energy consumption. Considering the amount of energy that is poured into heating, ventilation and air conditioning (HVAC) services in countries such as United States [2], Europe [3], China [4,5] and elsewhere, it is essential to critically evaluate building occupants' thermal comfort requirements for indoor space conditioning and to better understand the perceptual processes that underpin those comfort requirements.

1.1. A brief review on indoor thermal environmental standards

There are two basic philosophies underpinning current indoor thermal environment standards. One being based on a heat balance calculation for the occupant and their indoor climate, the other is known as the adaptive comfort model. In the 1960s and 1970s, the heat balance comfort models attracted great attention from the human bio-meteorology research community [6]. As an example, the widely used Predicted Mean Vote and Predicted Percentage Dissatisfied (PMV-PPD) indices were proposed by P.O. Fanger at that time [7,8]. The PMV index predicts thermal sensation as a function of six heat-balance parameters including the subject's metabolic activity level, the clothing insulation they are wearing, and four indoor thermal environmental parameters: air temperature, mean radiant temperature, air velocity and relative humidity. The PMV model has since been applied as the official method of evaluating thermal comfort by many national and international

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standards organizations [9], including ISO standard 7730 [10], ASHRAE Standard 55 [11], CEN 15251 [12] and Chinese GB/T 50785 [13].

Most current standards, with the notable exception of ASHRAE Standard 55, have ranked classifications to identify indoor thermal environmental quality based on PMV-PPD values (see Table 1). The higher the classification the narrower the range of permissible PMV values, corresponding to a tighter permissible temperature range. Despite the prefacing rhetoric that the categories do not represent “quality classes”, there is clearly presumption running through the thermal comfort standards (excluding ASHRAE 55) and the stakeholders actually using them, that the absence of any perceptible thermal stimuli in the indoor environment represents the highest possible quality – that built environments should strive for thermal imperceptibility (Category I) while buildings with less stringent indoor environmental requirements can make do with Category II or even III thermal conditions.

The psychometric chart has long been used to visualize the “comfort zone” – an envelope of operative temperature and humidity combinations recommended as design conditions for human occupancy. Separate seasonal comfort zones plotted on the psychometric chart have featured in every revision of ASHRAE's comfort standard 55. Fig. 1 shows the history of the ASHRAE winter comfort zone during the seventy years. When these historic comfort zones are overlain on a single psychometric chart the long-running uncertainty in ASHRAE's understanding of human thermal comfort is fully revealed. But discernible through the confusion in Fig. 1 is the long-term trend of winter comfort zones shifting to progressively warmer conditions during the last seven decades (1941 and 2010).

A fundamentally different approach to the PMV-PPD model of thermal comfort is known as the adaptive model [14]. Compared with the heat balance models, which view occupants in all building types and all climate zones as passive recipients of thermal stimuli, the adaptive approaches emphasize the role occupants play in creating their own thermal comfort state through physiological, behavioral and psychological processes [15]. To date most research attention has been directed at the physiological and behavioral levels of human thermal adaptive response, with the psychological layer being relatively ignored. The key element of the psychological thermal adaptation is comfort expectation [16]. The first implementation of the adaptive approach in a comfort standard was that of de Dear and Brager [17] who used a quality-assured database of thermal comfort field studies from all major climate zones of the world [18] in the 1990s. This adaptive comfort model relates indoor comfort temperatures with outdoor climates, and in 2004 the de Dear and Brager adaptive model [17] was adopted in ASHRAE Standard 55 [19] application to natural ventilated buildings as an alternative method alongside the PMV-PPD approach for buildings relying on HVAC equipment for the provision of occupant comfort. After ASHRAE 55's adaptive comfort initiative in 2004 similar adaptive models were gradually incorporated into other standards such as Europe's CEN 15251 [12] and the Chinese GB/T 50785 [13].

Table 1
Thermal environmental category label in different standards.

	Category	PMV ranges	PPD (%)
ISO 7730	I	−0.2 < PMV < +0.2	<6
	II	−0.5 < PMV < +0.5	<10
	III	−0.7 < PMV < +0.7	<15
EN 15251	I	−0.2 < PMV < +0.2	<6
	II	−0.5 < PMV < +0.5	<10
	III	−0.7 < PMV < +0.7	<15
	IV	PMV < −0.7 or PMV > +0.7	>15
ASHRAE 55	–	−0.5 < PMV < +0.5	<10
GB/T 50785	I	−0.5 < PMV < +0.5	<10
	II	−1 < PMV < −0.5 or +0.5 < PMV<1	10–25
	III	PMV < −1 or PMV>1	>25

1.2. Statement of the problem

Since air-conditioning was invented at the start of last century, indoor climate in modern buildings has progressively been delivered in a standardized format that emphasizes constant through time, uniformity through space, and targeting perceptual thermal neutrality. This trend has been made possible by adoption of HVAC in virtually every built environment of the contemporary lifestyle. The rapid development of HVAC engineering technologies coupled with increases in affordability have witnessed a sharp increases in HVAC penetration in the commercial and residential building sectors (as shown in Fig. 2). Pervasive HVAC throughout our homes, workplaces and modes of transport are compressing the dynamic range of thermal exposures in our daily lives and they are converging ever closer to theoretically ideal conditions. But this begs the question as to whether there has in fact been a commensurate increase on building occupant thermal satisfaction? Statistical analysis by Arens et al. [20] of several thousand thermal satisfaction votes inside ASHRAE's global comfort database [18] demonstrated convincingly that having a Category I thermal environment (ISO 7730 in Table 1) did not translate into higher levels of occupant thermal satisfaction compared to Category II or Category III environments. Approximately 80% thermal satisfaction was achieved across Categories I, II and III within the ASHRAE Global Comfort database. Is it possible that people living in ‘ideal’ indoor climates for a long periods have higher and higher thermal expectations causing them to become increasingly “fussy” about their thermal environment, resulting in no increment in satisfaction, or sometimes even decrements in satisfaction compared to their counterparts occupying environments with much greater dynamic thermal range? This question goes the very core of thermal perception; it is answered in the affirmative if one subscribes to the adaptive theory of thermal comfort. By contrast, the heat-balance theory of thermal comfort (PMV/PPD) views thermal perception in an absolute, deterministic process, and according to that theory occupant satisfaction should improve incrementally as we step up from Categories III to II and then to I. In contrast, the adaptive theory of comfort construes thermal acceptability in a relativistic framework, and so a given indoor thermal environment is evaluated relative to the subject's thermal expectations rather than some objective environmental criteria. The field evidence adduced in the Arens et al. paper [20] tends to support that thermal acceptability is apparently a relative judgement.

The question posed above can be easily inverted as well; when people are exposed to decreasing thermal environmental “quality” (to use the deterministic language of PMV-PPD), do they adjust their thermal comfort expectations downwards so that their overall level of thermal satisfaction shows no appreciable deterioration? Expressed in another way, “can people who have been “spoiled” by exposure to very comfortable thermal environment learn to accept an inferior quality indoor climate easily and quickly?” Do thermal comfort expectations show symmetrical dynamics? That are both the downwards and upwards trajectories of thermal comfort expectations symmetrical? The significance of these seemingly simple questions cannot be overstated as the two global demographic superpowers of the 21st century, India and China, embark upon the largest construction boom in the history of humankind.

Although comfort field studies and associated adaptive theory have managed to shed some useful light on how occupants adapt to indoor thermal environments, to date the evidence relevant to