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Subgroups holding different conceptions of scales rate room temperatures differently

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ABSTRACT

Current thermal comfort models are fairly inaccurate at predicting occupants' thermal comfort from parameters of indoor environment. The predicted variables, thermal sensation and thermal comfort, are commonly measured using scales. These scales might themselves contribute to the problem of poor prediction due to inter- and intra-individual differences in respondents' interpretation of scales. Until now, it is unclear whether variation in scale use is systematic and potentially statistically controllable.

This study investigated (1) whether there are subgroups holding different conceptions of scales and (2) whether these conceptions are associated with different ratings of sensation and comfort under experimental conditions.

Sixty-three participants completed a free positioning task that assessed the relative distances between labels belonging to the ASHRAE thermal sensation scale and their distribution along various dimensions (sensation, preference, comfort, pleasantness, acceptability, and tolerability). Subsequently, the participants rated office rooms at cool, neutral, and warm conditions regarding the same dimensions.

Latent class regression on the free positioning task revealed subgroups showing distinct and interpretable patterns such as preferences for different temperature ranges. Remarkably, these patterns were mirrored in the participants' ratings under the experimental thermal conditions.

The results suggest the existence of different conceptions concerning the relationships between the labels of the ASHRAE scale. The prediction of participants' ratings of thermal conditions in concrete situations can be significantly improved when taking these conceptions into account.

1. Introduction

Occupants' feedback is essential to determine whether a building (or building concept) provides suitable environmental conditions for the desired type of activity and to detect the potential for optimisation [1–4].

Despite more than 100 years of research on thermal comfort [5,6], dissatisfaction with thermal conditions is among the most commonly reported complaints in office buildings [7,8].

Thermal conditions are often designed and controlled according to related standards. The most common standards are the Standard 55 by the **A**merican **S**ociety of **H**eating, **R**efrigerating, and **A**ir-Conditioning **E**ngineers [9] and the European Standard EN 15251 [10]. Both implement Fanger's [11] predicted mean vote model (PMV), which predicts the mean thermal sensation of a large group of people under existing thermal conditions, and specific versions of the adaptive comfort model, which relates comfortable indoor temperatures to outdoor temperatures [12–16].

While these standards are necessarily simplified, current approaches in thermal comfort research discuss the necessity to explain the diversity observed between individuals and different contexts [17]. For example, Kingma and van Marken Lichtenbelt [18] observed physiological differences between sub-populations and argued that related fundamental assumptions have to be revised. Hawighorst et al. [19] and Schweiker et al. [20] have shown that individual differences in psychological factors, such as the level of self-efficacy, lead to systematic

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differences in thermal perception. Related to the context, differences in thermal perception are related to higher expectations regarding aspects of indoor environmental quality such as thermal comfort in green or certified office buildings compared to conventional office buildings [21–23].

In contrast, thermal comfort models imply strict, in part over-simplified, assumptions and neglect these "human" and contextual factors modulating perception and confounding assessments of thermal comfort. Not surprisingly, previous research shows a gap between the predicted comfort based on comfort models on the one hand and the experienced comfort at the workplace on the other hand [24]. Recently, Schweiker and Wagner [25] showed that the most commonly used thermal comfort indices such as the PMV [11] and the predicted thermal sensation based on the standard effective temperature (SET) [26] are poor at predicting individual thermal sensation votes.

An important common feature of the PMV, SET, and the adaptive models is that they are based on subjective assessments of thermal conditions using a thermal sensation scale [11,27]. Today, the most commonly used scale in thermal comfort research and in post-occupancy evaluations (systematic evaluations of opinions about buildings from the user perspective) is a 7-point categorical scale measuring thermal sensation using the anchors "cold", "cool", "slightly cool", "neutral", "slightly warm", "warm" and "hot" and is referred to as the ASHRAE scale [9]. In thermal comfort research, studies dealing with scales themselves are scarce see for example Schweiker et al. [28] for a review and [29–33]. However, verifying their assumptions is crucial because scales are fundamental in virtually all thermal comfort studies. For example, it is common practice to transform the ASHRAE scale, which is a categorical scale using verbal labels, converted into numerical values (e.g., from -3 to $+3$) for statistical analyses [34]. This procedure, however, is based on the assumption that the verbal labels of the scale are equidistant. Equidistance means that the differences between neighbouring labels in different sections of the scale are perceptually equivalent (e.g., that the difference between "cold" and "cool" is equivalent to the difference between "neutral" and "slightly warm"). This assumption was challenged by Schweiker et al. [28]. In their study, more than 50% of the participants stated that they perceived the distances between the labels of the ASHRAE scale as not equal. The study used a novel free positioning task: a horizontal line representing the continuum of temperatures was presented to the participants and they positioned the ASHRAE labels on this line according to their personal perception and concept. Although all participants positioned the labels in the same order as they are presented on the ASHRAE scale (e.g., no participant positioned "warm" as being warmer than "hot"), there was considerable variation among participants concerning the relative positioning of the labels and the distances between them (see Figure 4 in Schweiker et al. [28]). These findings suggest that participants hold different conceptions concerning the meaning of the scale labels and the relationship between them. These conceptions might potentially confound the measurement of thermal sensation and comfort. However, up to now it has not been systematically studied whether holding different conceptions is related to different judgments of thermal sensation or comfort in specific situations (e.g., when working in offices or at home). Furthermore, the paper by Schweiker et al. [28] did not provide deeper insights why there is such high heterogeneity between participants' conceptions. Before being able to provide explanations for the observed heterogeneity, it is necessary to determine whether there are patterns representing different conceptions in the data. Those patterns might provide a starting point for better understanding the underlying causes. Therefore, the research question addressed in this paper is: Does this heterogeneity reflect conceptions that are unique to each participant? Or are there subgroups of participants that share similar conceptions?

The related objectives of this study were to test:

1. Whether there are identifiable subgroups, showing distinct response patterns in the free positioning task used by Schweiker et al. [28].
2. Whether the response patterns in the free positioning task (reflecting different conceptions), are related to perception and evaluation of thermal conditions in experimentally controlled office rooms, which would suggest that the conceptions are practically relevant.

In case the high variation between individuals can be grouped into a number of subgroups with similar conceptions, these different conceptions could be transferred into interpretable, measureable, and useful sources of data. In addition, the existence of subgroups would allow in a second step to analyse factors that influence the membership in one specific subgroup.

Knowing the participants' conception could also help improving statistical predictions of perception or responses under specific thermal conditions by means of the free-positioning task, which is urgently needed to optimize thermal conditions and satisfaction in buildings. In addition, such knowledge could help improving the existing instruments applied in post-occupancy evaluations through a profound understanding of processes of perception.

2. Methods

All testing sessions were performed in the Laboratory for Occupant Behaviour, Thermal comfort, Satisfaction and Environmental Research (LOBSTER) belonging to the Building Science Group, Germany.

2.1. Application periods

In order to balance seasonal influences, the study comprised two sessions testing two different groups of participants using identical methods. The first period took place in winter (in January and February 2016), the second period in summer (July and August 2016). The data from both periods was analysed jointly.

2.2. Participants

Sixty-three healthy participants took part in the study; 32 in the winter and 31 in the summer session. Participants were recruited using announcements placed on a local online job market for students and on the institutional homepage. The participants received a fixed allowance of 10 € per hour and an additional flexible allowance between 2€ and 8€ depending on their performance during some cognitive tasks. After appointment agreements, participants received detailed instructions concerning the outline and procedures of the study. They were asked not to consume any alcohol the evening before their participation and to get a sufficient amount of sleep. However, whether they adhered to these instructions could not be checked. Clothing instructions consisted of long trousers, a short-sleeved top and a long-sleeved top, i.e. aiming at a clothing insulation value of 0.7 CLO. Before starting with the experimental procedures, the participants were informed again about the study's terms, which had been approved by the local ethics committee, and gave written informed consent.

All participants were above 18 years of age and assured to be either native speakers or to have a comparable language level in German. One participant was excluded from participation due to insufficient language level. During the first session (winter) 26 participants were enrolled at a university and 6 were either seeking work, employed or enrolled at high school. During the second session (summer) 26 participants were enrolled at a university and 5 were either seeking work or employed. None of the participants had participated in a thermal comfort study of the institution before. Additional demographic characteristics of the samples are summarized in Table 1.

2.3. Procedures

The testing procedure applied in each session is outlined in Fig. 1. At the beginning of each session, participants were interviewed using a