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Development and validation of a methodology to challenge the adaptive comfort model

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ABSTRACT

Behavioural, physiological and psychological adaptive processes are presumed reasons for the discrepancies between predicted mean vote (PMV) and observed comfort votes during field studies. However, few is known about the individual portions of these processes to this effect. This paper describes the development of an experimental design which aims at identifying those portions and is meant for climate chambers with at least one façade connected to the exterior. The experimental design consists of distinctive settings with respect to variations in outside conditions and the number of control opportunities so that one or more of the three adaptive processes are blocked. The results of a first implementation of this experimental design presented show the ability to analyse the three processes individually with the data gathered by such procedures. As a result, the permission to interact with the built environment by means of using a fan or opening a window alone leads to an increased satisfaction with the thermal conditions. At the same time, the restriction of such behavioural reactions seems to be counterbalanced by an increased amount of physiological reactions such as an increased level of skin moisture and skin temperature. In conclusion, the developed experimental design looks promising in order to reveal the single effects leading to the phenomenon called adaptive comfort, while small adjustments are discussed for further improvements.

1. Introduction

The research on human thermal comfort as started by [10] led to various comfort models based on the heat balance of the human being and derived from extensive controlled climate chamber experiments. These models allow for an approximate representation of the human thermoregulation-system's reaction to the relevant physical parameters of the steady-state built environment together with the expected comfort sensation and perception of an average person [11,14,34].

Field studies observed comfort perception votes differing from those obtained by above models especially during warm conditions in naturally ventilated buildings (see e.g., [26],. Such observation led to the development of the adaptive comfort model with the hypothesis that these differences are due to behavioural, physiological and psychological adaptive processes [2,7,21]. However, beside giving a statistical approximation of the general effect of such adaptive processes on the thermal perception vote, little is known about the individual portions of the three types of adaptive processes to this effect.

Knowing such portions would enable us to extend the so-called *static* (the occupant is treated as a passive recipient of thermal stimuli [7] comfort models based on the representation of human thermoregulation in such a manner that they incorporate adaptive (re-)actions of the occupant.

The aim of the research presented in this paper is the extension of the existing comfort models, which are interesting and relevant for buildings (1) which are not or only passively cooled, (2) where the room conditions vary with the outside conditions, and (3) where the occupant can influence upon those conditions. The detailed knowledge and quantification of the occupant's comfort perception in such buildings together with their reactions to various conditions permits

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a planning of so-called energy saving concepts with less uncertainty. In addition, this would allow the designer of new buildings or retrofitting projects to concentrate on improving the most influential aspects (if applicable) and to increase thereby the thermal comfort and productivity of the individual office worker or occupant.

This paper focusses on the development and validation of a methodology which enables us to quantify the above mentioned portions of behavioural, physiological and psychological adaptive processes for warm indoor environments.

2. Reviewing the three components of adaptation

The three above mentioned adaptive processes are mentioned in [7] as *the three components of adaptation to indoor climate* and there defined as presented in Table 1. In the following, the clear distinction between them as found in the literature is discussed along with recent results for warm indoor environments.

2.1. Behavioural aspects of adaptive processes

Behavioural aspects include adjustments of the heat balance such as changing clothes, opening windows, or using fans. These actions – more concise, their frequency of occurrence and magnitude – depend on various physical factors like indoor or outdoor temperature (see e.g., [8,15,25],. They lead to changed thermal stimuli and differences in the thermal perception. However, the changes of the thermal perception can be partly explained with the heat balance models by using the altered thermal stimuli as input values, so that they are not necessarily related to adaptive processes. Nevertheless [31], showed in their study, that the frequency of air-conditioning usage is influenced also by individual characteristics and the thermal background of the occupant. Their models include as statistically significant variables a running mean of the outside temperature of the foregoing nights as well as the climatic conditions experienced by the subjects during their childhood. This implies that there are adaptive processes leading to differences in the behaviour of the occupant. However, such differences could be as well due to physiological long-term adaptation described in section 2.2 or due to habituation as mentioned in section 2.3.

Adaptive opportunities, e.g. the existence of an operable window, and constraints to control the thermal environment, e.g. accessibility of controls, are regulating the degree of actions which can be performed by the occupants. Being a characteristic of the building design and with respect to clothing levels sometimes agreed or forced manners, they can hardly be described as processes themselves. However, studies have shown that the perceived availability of thermal controls influences on thermal perception [5,16]. Whether this is due to the behavioural aspect itself or should be grouped into psychological aspects of thermal comfort was not explicitly assessed so far.

2.2. Physiological aspects of adaptive processes

At the highest level [7], distinguish between genetic adaptation and acclimation. Genetic adaptation is beyond that of individuals lifetime and not able to explain the changing thermal perception of an individual in the course of a year and therefore neglected here.

With regard to acclimation, one has to distinguish between physiological reactions to heat and adaptive processes to repeated stimuli of hot conditions. Sweating and vasodilation are examples for the former [30] with persons not acclimatized to heat experiencing a higher core temperature, higher heart rate, and a limited work capacity [20]. Physiological adaptation to heat consists of a reduced metabolic rate or an increased sweat volume with lowered salt concentration and is well documented (see e.g., [20,27,29],. According to [1] this is to increase the tolerance towards heat while reducing the imposed stress [20]. states that a repeated exposure to heat reduces the increase in heart rate and rise in core temperature.

[22] distinguishes between short- and long-term acclimation. Due to short-term acclimation – the one more interesting for the German context, where summers can be characterized by alternating periods with moderate up to hot conditions – already 75% of the maximum possible degree of acclimation are reached within the first 4–6 days. After the exposure to heat, the changes within the thermoregulatory system vanish within 1–4 weeks.

Nevertheless, studies related to heat acclimation are dealing either with long-term acclimation to hot and humid or hot and dry climates or the short-term acclimation to extreme conditions as found during so-called *heat-waves*, i.e. with temperatures being beyond 30 °C. To what extend such processes occur for the office worker under moderate conditions and to what degree this adds to the effect shown by the concept of adaptive comfort was not dealt with sufficiently.

Table 1
The three components of adaptation according to [7].

Feedback type	Component	Description
Behavioural	Adjustment	Behavioural/technological changes to heat-balance
Physiological	Acclimatization	Long-term physiological adaptation to climate
Psychological	Habituation	Psychological adaptation and changing expectations

2.3. Psychological aspects of thermal comfort

Habituation and expectation are mentioned as reasons for psychological adaptation processes by [7]. Consequently, several papers addressed the topic of expectation [12,19,28], but the effect of habituation was not investigated further. Moreover, the question arises, whether habituation should be included into behavioural processes – in terms of routinely repeated (re-) actions to certain stimuli in a certain environment –, or kept as psychological aspect – and thereby representing the degree of congruence between *normal* behaviour and in the situation permitted behaviour.

[28] describe in total 6 parameters of psychological adaptation for the perception of the outdoor thermal environment – which will be to a high degree transferable to the indoor environment: naturalness, expectations, experience, time of exposure, perceived control, and environmental stimulation. According to their assumptions, all of them are interrelated, i.e. influencing other parameters and being influenced by them at the same time, except for naturalness, which is supposed to be not influenced by others. However, for the context of indoor environment, it must be difficult to distinguish between thermal conditions perceived as *natural* and those being expected. The same applies for experience and expectation, though one can expect that the expectation is partly based on the former experience. Time of exposure is described as the difference in the time people have to stay in conditions perceived as not comfortable, which in case of the indoor environment must be strongly related to the perceived control. Summing up, this leads to three distinctive psychological adaptive processes: habituation (if found to be important), expectation, and perceived control.

[4] investigated the relationship between higher expectations towards thermal conditions and non-thermal factors deriving from the individual human being and building. They found that the "risk" of having higher expectations is increased for women compared to men, for subjects below 31 years of age compared to older ones, work places equipped with air-conditioning compared to naturally