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Occupant performance and building energy consumption with different philosophies of determining acceptable thermal conditions

J. Toftum*, R.V. Andersen, K.L. Jensen

International Centre for Indoor Environment and Energy, Department of Civil Engineering, Technical University of Denmark, DTU, building 402, DK-2800 Lyngby, Denmark

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ABSTRACT

Based on building energy and indoor environment simulations, this study uses a recently developed method relying on Bayesian Network theory to estimate and compare the consequences for occupant performance and energy consumption of applying temperature criteria set according to the adaptive model of thermal comfort and the more conventional PMV model. Simulations were carried out for an example building with two configurations (with and without mechanical cooling) located in tropical, subtropical, and temperate climate regions. Even though indoor temperatures differed significantly between building configurations, especially in the tropical climate, the estimated performance differed only modestly between configurations. However, energy consumption was always lower in buildings without mechanical cooling, particularly so in the tropical climate.

The findings indicate that determining acceptable indoor thermal environments with the adaptive comfort model may result in significant energy savings and at the same time will not have large consequences for the mental performance of occupants.

1. Introduction

Conventional methods of determining acceptable indoor thermal conditions have been based mostly on human heat transfer models coupled with the estimation of psycho-physical, group-average indices of thermal sensation and comfort (e.g. Refs. [2,4,14]). Probably, the best-known and most widely used model is the PMV model, which was developed with human subjects exposed to well-controlled environments in climate chambers [11]. The PMV model has been validated in a wide range of studies in the field, probably most comprehensively in ASHRAE's worldwide research in buildings with HVAC systems that were situated in cold, temperate and warm climates and were studied during both summer and winter [5,9,10,18].

de Dear and Brager [8] argued that the PMV model inappropriately regarded building occupants as passive recipients of their indoor environment exposure and suggested that occupants should be allowed to be active in modifying their indoor environment as they preferred. They proposed an optional method to determine acceptable indoor thermal conditions, also known as the adaptive model of thermal comfort, which is a regression equation that relates the neutral temperature indoors to the monthly average temperature outdoors. The adaptive model has been included in recent versions of ASHRAE Standard 55 and EN 15251 for buildings with spaces without mechanical cooling, where the thermal conditions are controlled primarily by the occupants through opening and closing of windows [2,3].

Application of the adaptive model of thermal comfort in warm climate regions may result in relaxed temperature criteria and may therefore provide a potential means to reduce the consumption of energy used to cool buildings. One of the main themes of the discussion that rose at the introduction of the adaptive model was if it would also provide an acceptable degree of occupant satisfaction in spaces without mechanical cooling. It is likely that occupants in such spaces are used to larger temperature variation and therefore have lower expectations and would judge a given warm environment as less severe and less unacceptable than would people who are used to stricter climate control [12]. In the discussion, however, the effect of relaxed temperature criteria on occupant performance to some degree was sidestepped, possibly because no obvious approach was available to estimate the effects on occupant performance of indoor temperatures.

Jensen et al. [17] proposed a technique to assess the effects of the thermal indoor environment on the mental performance of office employees and to compare the economic consequences of different building designs based on occupant performance and

* Corresponding author. Tel.: +45 45254028; fax: +45 45932166.
E-mail address: jt@byg.dtu.dk (J. Toftum).

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energy use. The approach combines Bayesian network theory with dynamic simulation of the indoor environment and of the energy consumption as well as with dose–response relationships between indoor climate parameters and mental performance. The Bayesian network is based on the compilation of subjective thermal sensation data and the associated objective thermal measurements from 8,100 occupants of climate controlled buildings and 4,700 equivalent data records from buildings without mechanical cooling located in different parts of the world [7]. In the current study the technique is used to estimate and compare the consequences for occupant performance and energy consumption of applying temperature criteria defined by the conventional method (PMV) and the adaptive comfort model in an example building with and without mechanical cooling located in tropical, subtropical, and temperate climate regions.

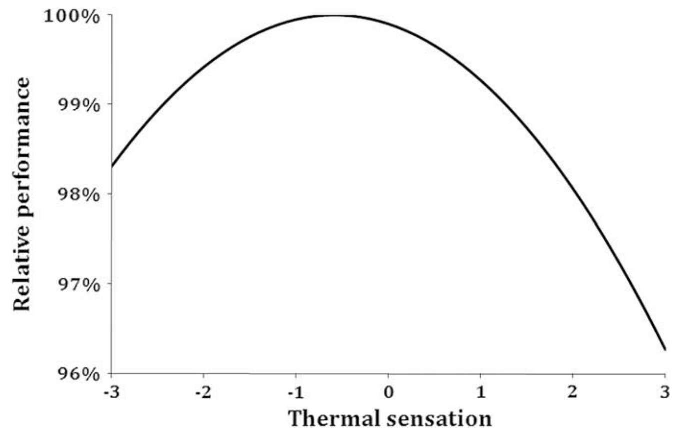

Fig. 2. Dose–response relationship between thermal sensation and mental performance.

2. Methods

Input to the assessment of employee performance was hourly values of operative temperature simulated for a space in a building with and without mechanical cooling, located in Singapore (tropical – latitude 1°14′ N), Sydney (subtropical – latitude 34°0′ S), San Francisco (temperate – latitude 37°47′ N), and Copenhagen (temperate – latitude 55°40′ N). Based on observations recorded in thermal comfort field studies in the two building configurations, a Bayesian network was used to infer the probability of the occupants being satisfied with the thermal conditions [17]. Since occupants in non-mechanically cooled buildings may be more forgiving of a warm environment than would people who are used to air-conditioning, different thermal sensation distributions would result from identical temperatures in the two building configurations. This is illustrated in Fig. 1, which is based on data from de Dear [7]. The distributions of thermal sensation votes cast by occupants in buildings with and without mechanical cooling at 22 °C follow an almost perfect Gaussian distribution, although without mechanical cooling the prevalence of warmer votes was somewhat higher. At 27 °C the distribution in buildings with mechanical cooling was left-skewed and almost 50% of the occupants in these buildings voted warm or hot, whereas more than 80% of the occupants in buildings without mechanical cooling at the same temperature voted slightly cool, neutral or warm.

As suggested in several earlier studies, thermal sensation for people in near thermal comfort conditions is more likely to influence performance than temperature *per se* (e.g. Refs. [20,21]). Using thermal sensation to quantify effects on performance of the thermal climate, the different distributions of thermal sensation votes will affect the outcome, whereas temperature as input would yield identical performance estimates at identical temperature levels.

Simulated hourly temperatures were thus used to estimate the thermal sensation distribution with and without mechanical cooling and, for both populations, to subsequently estimate mental

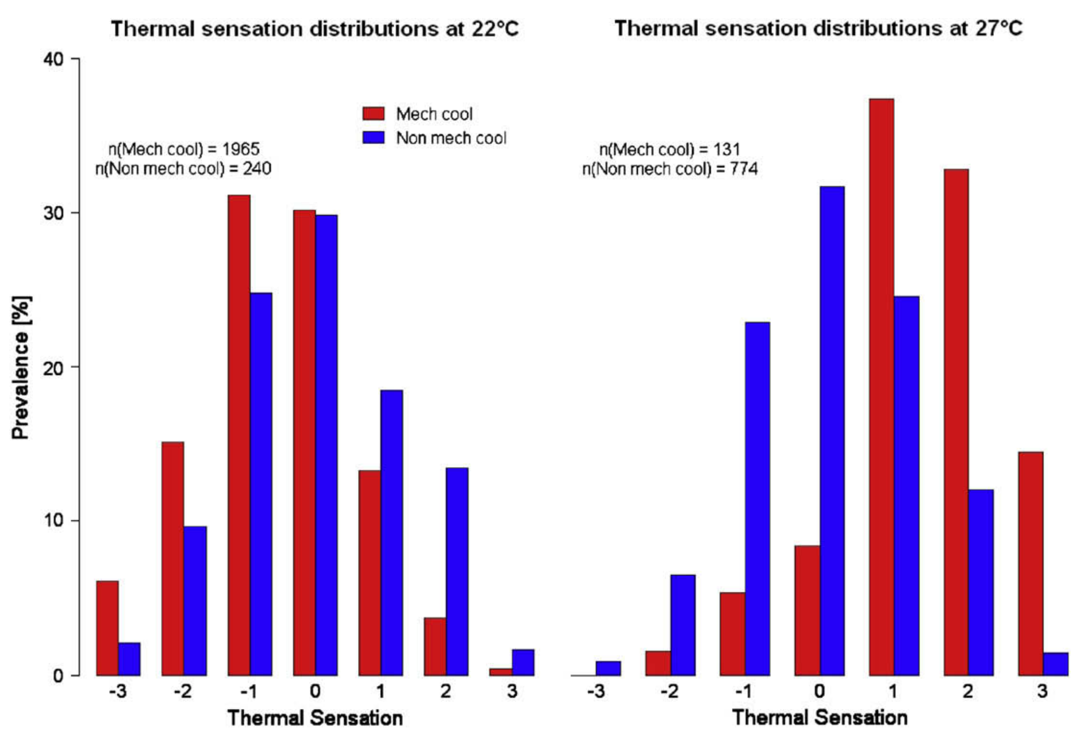

Fig. 1. Distribution of thermal sensation votes cast in buildings with and without mechanical cooling at recorded temperatures 22 °C and 27 °C. Data adopted from de Dear [7].