

Thermal comfort and building energy consumption implications – A review



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HIGHLIGHTS

- We review studies of thermal comfort and discuss building energy use implications.
- Adaptive comfort models tend to have a wider comfort temperature range.
- Higher indoor temperatures would lead to fewer cooling systems and less energy use.
- Socio-economic study and post-occupancy evaluation of built environment is desirable.
- Important to consider future climate scenarios in heating, cooling and power schemes.

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ABSTRACT

Buildings account for about 40% of the global energy consumption and contribute over 30% of the CO₂ emissions. A large proportion of this energy is used for thermal comfort in buildings. This paper reviews thermal comfort research work and discusses the implications for building energy efficiency. Predicted mean vote works well in air-conditioned spaces but not naturally ventilated buildings, whereas adaptive models tend to have a broader comfort temperature ranges. Higher indoor temperatures in summertime conditions would lead to less prevalence of cooling systems as well as less cooling requirements. Raising summer set point temperature has good energy saving potential, in that it can be applied to both new and existing buildings. Further research and development work conducive to a better understanding of thermal comfort and energy conservation in buildings have been identified and discussed. These include (i) social-economic and cultural studies in general and post-occupancy evaluation of the built environment and the corresponding energy use in particular, and (ii) consideration of future climate scenarios in the analysis of co- and tri-generation schemes for HVAC applications, fuel mix and the associated energy planning/distribution systems in response to the expected changes in heating and cooling requirements due to climate change.

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1. Introduction

There is a growing concern about fossil energy use and its implications for the environment. The increasing threat of global warming and climate change has raised the awareness of the relationship between economic growth, energy use and the corresponding environmental pollutants. There is a statistically significant positive association between economic growth, energy use and carbon emissions (e.g. in the ASEAN countries [1], China [2,3] and among a total of 69 countries involving high, middle and low income groups [4]). There have been marked increases in energy use in developing countries, and it is envisaged that such trend will continue in the near future. For instance, during 1978–2010 China's total primary energy requirement (PER) increased from about 570 to just over 3200 Mtce (million tonnes of coal equivalent), an average annual growth of 5.6%. Although its energy use and carbon emissions per capita are low, China overtook the US and became the largest energy consuming and CO₂ emissions nation in 2009 [5–7]. In their work on technology and policy options for the transition to sustainable energy system in China, Chai and Zhang [8] estimated that China's PER would increase to 6200 Mtce in 2050, of which fossil fuels would account for more than 70% and the corresponding emissions could reach 10 GtCO₂e (10×10^9 tonnes of CO₂ equivalent). It has been estimated that, by 2020 energy consumption in emerging economies in Southeast Asia, Middle East, South America and Africa will exceed that in the developed countries in North America, Western Europe, Japan, Australia and New Zealand [9].

The building sector is one of the largest energy end-use sectors, accounting for a larger proportion of the total energy consumption than both the industry and transportation in many developed countries. For example, in 2004 the building sector accounted for 40%, 39% and 37% of the total PER in USA, the UK and the European Union [9,10]. In China, building stocks accounted for about 24.1% in 1996 of total national energy use, rising to 27.5% in 2001, and was projected to increase to about 35% in 2020 [11,12]. Globally, buildings account for about 40% of the total PER and contribute to more than 30% of the CO₂ emissions [13]. This concern has led to a number of studies conducted worldwide to improve building energy efficiency: on the designs and construction of building envelopes (e.g. thermal insulation and reflective coatings [14–20], sensitivity and optimisation [21–23], and life-cycle analysis [24,25]); technical and economic analysis of energy-efficient measures for the renovation of existing buildings [26–31]; and the control of heating, ventilation and air conditioning (HVAC) installations and lighting systems [32–35]. A significant proportion of the increase in energy use was due to the spread of the HVAC installations in response to the growing demand for better thermal comfort within the built environment. In general, in developed countries HVAC is the largest energy end-use, accounting for about half of the total energy consumption in buildings especially non-domestic buildings [9,36–39]. A recent literature survey of indoor environmental conditions has found that thermal comfort is ranked by building occupants to be of greater importance compared with visual and acoustic comfort and indoor air quality [40]. This also affects the designs of the building envelope in general, and the windows

and/or glazing systems in particular [41,42]. It is therefore important to have a good understanding of the past and recent development in thermal comfort and the implications for energy use in buildings. This paper presents a review of thermal comfort research and development work and discusses the implications for energy use in the built environment. The aim is not to conduct a detailed analysis of or comprehensive comparison between different thermal comfort models and studies (such analysis and comparison can be found in Refs. [43–46]), but rather highlight issues that are more pertinent to energy conservation in buildings. The objective is to examine the implications of thermal comfort for energy consumption in the built environment. It is hoped that this review can contribute to a better understanding of how thermal comfort is related to and affects the broader energy and environmental issues involving social-economic, fuel mix and climate change. Broadly speaking, there are two main categories of thermal comfort models – heat balance and adaptive. Heat balance models have been developed using data from extensive and rigorous experiments conducted in climate chambers, whereas adaptive models are mainly based on measured/surveyed data from field studies. Climate chambers tend to have consistent and reproducible results, but the disadvantage is the lack of realism of the day-to-day working or living environments that field studies can represent.

2. Heat balance models

Heat balance models assume that the human body's thermoregulatory system is to maintain an essentially constant internal body temperature. As such, the effects of the immediate thermal environment are mediated by the physics of heat and mass transfer between the body and the surrounding environment. To maintain a constant internal body temperature people will respond physiologically to any thermal imbalance with its thermal environment. It is assumed that people's thermal sensations (e.g. feeling hot or cold) are generally proportional to the magnitude of these responses measured in terms of mean skin temperature and latent heat loss

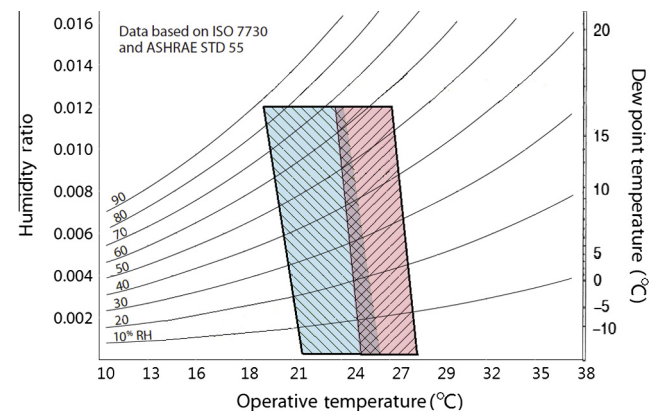


Fig. 1. Acceptable range of operative temperature and humidity for the thermal comfort zones (Ref. [49]).

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