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Models of human thermoregulation and the prediction of local and overall thermal sensations

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This study aims at comparing the predictions of skin temperature from different models of human thermoregulation and investigating the currently available methods for the prediction of the local and overall thermal sensations. In this paper, the Fiala model, the University of California, Berkeley (UCB) thermoregulation model and a multi-segmental (MS) Pierce model were tested against recently measured data from the literature. The local and overall thermal sensations were predicted for different room conditions, obtained from a recent experimental study, using the UCB comfort model coupled with the MS-Pierce model. The overall thermal sensation was further predicted using three other models. The predictions were then compared with the subjective votes obtained from that study. The equivalent temperature approach was also investigated based on the same experimental study. The results show comparisons of the predicted skin temperature by the thermoregulation models, under steady state and dynamic conditions, with the measured data as well as the predictions of the thermal sensations from the different models.

1. Introduction

Models of human thermoregulation have gained more importance with the concept of local thermal comfort. The local thermal sensation and comfort, corresponding to body segments, are mainly based on the local skin temperatures as stipulated in the concept of the equivalent (homogeneous) temperature [1]; and the University of California, Berkeley (UCB) comfort models [2]. Such models of human thermoregulation can be used to predict the local skin temperatures, along with other physiological variables, hence evaluating the local thermal sensation and comfort of individuals. Recent models of human thermoregulation are based on regression analysis for the simulation of active thermoregulation controls [3,4] or based on the approach that is given in Stolwijk model [5].

The Fiala model comprises the so called passive and active models [3,4]. The passive model consists of 15 spherical or cylindrical body elements and uses up to 7 different tissue materials. Most of the body parts are divided into anterior, posterior and inferior to account for asymmetries and hidden parts of the body. The passive model simulates the physical interaction between the human body parts and tissue layers as well as the interaction with the surrounding environment. The active model is based on statistical approach to simulate the human body's active controls such as the peripheral vasomotion, sweating and shivering heat production. The Fiala model contains lots of fine details, accounts for many different factors and is considered as a unique mathematical model of human thermoregulation.

The UCB thermoregulation model by Huizenga et al. [6] was developed on the basis of Stolwijk's model [5] and the research work by Tanabe [7]. In its original form, the model consists of 16 body segments but can be extended to have unlimited segmentation of body parts. The main modifications to the original Stolwijk (in addition to the segmentation) were: the improvement to the blood flow models including counter flow heat exchange at the limbs segments and perfusion from blood vessels to tissues; the addition of a clothing node to model the heat and moisture capacitances; the addition of heat transfer by conduction to surfaces in contact with the body; the improvement to the estimation of the convection and radiation heat transfer coefficients; the explicit radiation heat transfer calculation using angle factors; and the addition of a radiation heat flux model. As stated by the developers, the model is able to predict the core and extremity skin temperatures with reasonable accuracy under a range of environmental conditions.

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