NUMERICAL SIMULATION OF THE DYNAMIC THERMAL PHYSIOLOGICAL COMFORT OF A CLOTHED HUMAN BODY

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This paper reviews the methodology of numerical simulation of the dynamic thermal responses of human body and clothing and discusses the influence of various properties of clothing materials on the dynamic thermal comfort and sensations. The conventional mathematical models describing the heat transfer and moisture transfer processes are the basic energy and mass conservation equations, which follow Fourier'law and Fick's law respectively. The two transfer processes are considered essentially independent with each other. From the two equations, two fundamental criteria are generated to describe the thermal properties of clothing material, i.e. thermal resistance (Clo) and water vapor resistance (i_m), which have been widely used in modeling the thermal comfort and/or thermal stresses of a clothed human body. However, the heat and moisture transfer processes are not independent with each other in clothing materials and at skin surfaces as they are coupled by the phase changes of water and absorption/desorption of water vapor by the fibers. A mathematical model describing the coupled heat and moisture transfer processes was developed, in which the dynamic sorption kinetic of fiber was taken into account. This model is able to illustrate how the moisture sorption capacity (called hygroscopicity) of clothing material influence the thermal and moisture comfort and sensations in various transient conditions where insensitive perspiration and dry environment are the dominant features. For extremely cold environmental conditions, the temperature difference between the body and external environment is huge so that heat transfer by radiation becomes very significant. A mathematical model has developed to take into account the radiation effect on the basis of the previous models. Using the model, the temperature and moisture profiles in clothing can be calculated to illustrate how different fibers and fabric materials influence the thermal comfort and moisture sensations in cold conditions. Besides, the liquid transport process in clothing cannot be neglected as a wearer may be often exposed to wetted situations due to sweating and/or raining/snowing. A mathematical model has been developed recently to describe the dynamic interactions between heat transfer by conduction and moisture transfer by diffusion, sorption/desorption, water evaporation/condensation and capillary actions. With specification of boundary conditions of the temperature and humidity at the clothing-skin and clothing-environment interfaces, the dynamic changes of the distribution of the temperature, moisture contents in the air and fibers of clothing and the volumetric fraction of the liquid water throughout the fabric can be calculated. This model is particularly useful in simulating the thermal comfort and sensations under sweating situations and/or externally wetted conditions and illustrate how the liquid moisture transport behavior of clothing (called moisture management) effect the thermal functional performance of garments. To simulate thermal functional performance of clothing under complex wear situation of sweating in extremely cold environment such as ski, a mathematical model has been developed more recently to describe various dynamic coupling effects among the heat transfer by conduction and radiation and moisture transfer by diffusion, sorption/desorption, evaporation/condensation, liquidation/solidation and capillary actions. These mathematical models, which are solved mainly by numerical computation methods, can be utilized to study the thermal comfort and thermal/moisture sensations under various transient conditions and to analyze the heat (cold) stresses under hot (cold) environment for given clothing materials. More importantly, the models can be utilized as effective engineering design tools to optimize the thermal functional performance of clothing for intended wear situations, which is illustrated by a series of computational results with comparison of experimental observations.

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