Analysis of Heat Transfer From Human Body and Effect of Clothing Surface on Heat Transfer Mechanism

A. Joshi[1], A. Psikuta[1], S. Annaheim[1], R. M. Rossi[1], M.-A. Bueno[2]

[1]Empa, Swiss Federal Laboratories for Materials Science and Technology, St. Gallen, Switzerland
[2]Université de Haute Alsace, Laboratoire de Physique et Mécanique Textiles (LPMT EA 4365), Mulhouse, France

Abstract

Heat transfer from human body to the environment through clothing layer depends on many factors such as environmental conditions, thermal properties of clothing and size and shape of enclosed air layers (air layers between body surface and clothing). In clothing science, most numerical and theoretical analyses of the heat transfer assume spatially homogeneous enclosed air layers, which oversimplify the realistic conditions. The shape of the enclosed air layer affects the formation of the respective adjacent air layer on the outer side of clothing, and finally, the total heat transfer from the human body. However, the effect of the spatial heterogeneity on various heat transfer mechanisms is still not analysed in detail. The aim of this study is to analyse the effect of heterogeneous air layer on various heat transfer mechanisms such as convection, radiation and conduction.

To analyse the heat transfer from the human trunk (represented by a thermal cylinder) through heterogeneous air layers, the heat transfer module and COMSOL Multiphysics® was applied. The radiative heat transfer was modeled using the surface-to-surface radiation model. The flow inside enclosed and boundary air layers was modeled using low Reynolds number k-ε model. The natural convection was modeled by considering incompressible flow with a Boussinesq approximation. The simulations were performed using the stationary solvers. The fabric is considered as a thin film with a given thermal resistance (m^2K/W) in the simulations.

The average air gap thickness of the enclosed air layer was simulated for heterogeneous (fabric with folds) and homogeneous (smooth fabric surface) air gap distribution with the same average air gap thickness (16mm). However, the total heat transfer coefficients along the surface of thermal cylinder varied significantly. The heterogeneous surface affects the heat transfer mechanisms as shown in Figure 1(c), because velocity distribution around each fold was heterogeneous and affected the convective heat transfer in the respective boundary air layer. The natural convection and conduction in the enclosed air layer were also affected by the heterogeneous temperature distribution on the fabric surface, which resulted from the spatial heterogeneity of an enclosed air layer. Furthermore, the folds resulted in different view factors and re-radiation from the fabric surface which affected the radiative heat transfer.

It can be concluded that the heterogeneity of an enclosed air layer must be taken into consideration for theoretical analysis of heat transfer from the human body to the environment through clothing. The assumption of homogeneity underpredicts the total heat flux and can induce an error up to 19%.

Figures used in the abstract

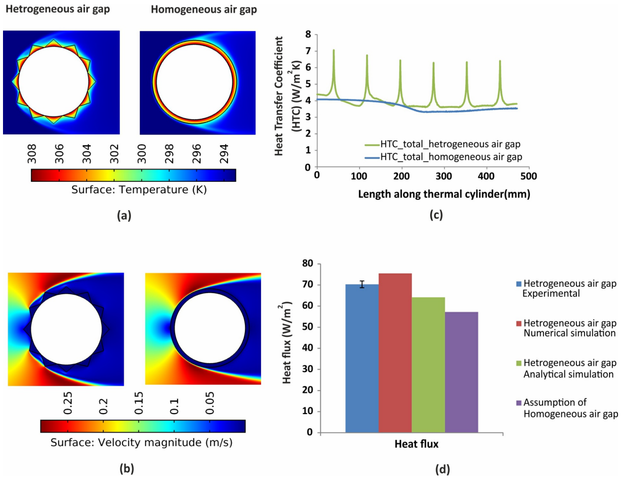

Figure 1: Figure 1 Temperature and velocity contour for heterogeneous and homogeneous enclosed air layer (a) and (b), Heat transfer coefficient along the length of the thermal cylinder (c), Heat flux for different cases (d).