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Determination of the local evaporative resistances of two typical office clothing ensembles and the effect of air speed and body movement

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Introduction

Using thermophysiological and coupled thermal sensation models to design and evaluate thermal indoor environments can contribute to energy efficient, healthy and comfortable building systems. Since a number of researchers also focus on personalized air-conditioning systems [1–4], predicting local skin temperatures and local thermal sensation becomes more important. Hence, the simulations models require accurate and reliable local input data. The study by Veselá et al. [5] showed that the local thermal parameters of typical office clothing ensembles are missing in the literature. To close the gap, a study was conducted to determine the local thermal properties, namely local clothing dry insulation, local clothing area factors and local clothing evaporative resistance of a number of office clothing ensembles. This paper focuses on the local evaporative resistance. The results for the local evaporative resistance of two typical office outfits are presented and discussed including the effect of air speed and body movement.

Methods

Measurements for the local evaporative resistance in isothermal conditions were performed according to standards ISO 9920 [6] and ASTM F2370-10 [7] using the sweating agile manikin SAM at Empa, St. Gallen, Switzerland [8]. Two typical office clothing ensembles were selected. Outfit 1 consists of a short-sleeved t-shirt, briefs and jeans, and outfit 2 combines a long-sleeved smart shirt, briefs and semi-formal pants. To investigate the influence of air speed and body movement, five test cases (TC) were defined. For TC 1 to 3, the manikin was in upright, stationary position and the air speed v_{air} was set to $0.2\ m/s^{-1}$, $0.4\ m/s^{-1}$ and $1\ m/s^{-1}$, respectively. For TC 4 and 5, SAM was connected to the moving simulator and v_{air} was $0.2\ m/s^{-1}$ and $1\ m/s^{-1}$, respectively. During the measurements, the manikin surface skin temperatures, the power output of the manikin and all environmental parameters were recorded. The total and local evaporative resistances, $R_{et,i}$ and $R_{ecl,i}$, were then calculated for eight body parts, namely, upper and lower arms, chest, back, front and back hip, upper and lower legs. To calculate $R_{et,i}$ and $R_{ecl,i}$ correctly, the surface temperature of the manikin's skin, which is placed on the manikin to distribute the water evenly, is needed [7]. The skin surface temperatures were approximated according to Wang et al. [9].

Results and discussion

The results for $R_{et,i}$ and $R_{ecl,i}$ are presented in Figure 1 for the eight body parts and the two outfits. In most cases, the increase in air speed and the addition of body movements reduced $R_{et,i}$ and $R_{ecl,i}$. These results are to be expected because the higher convection at the garments outer surface reduced the water vapour concentration at that surface. The effects are larger for $R_{et,i}$ than $R_{ecl,i}$, since the adjacent air layer is excluded from $R_{ecl,i}$ calculation. However, $R_{ecl,i}$ is still mostly reduced by increased air speed and body movement, hence, it can be assumed that in both cases also the enclosed air layer between the manikin's surface and the garment is affected. Increasing the air speed to $0.4\ m/s^{-1}$, has much lower effect than the other test cases, and, considering the standard deviation, the results are often very similar to the values at an air speed of $0.2\ m/s^{-1}$.

The magnitude of the reduction by increased air speed and body movement is different for the eight body parts. The largest effects for increased air speed can be seen for $R_{et,i}$ and $R_{ecl,i}$ at the back. However, there is hardly any change for the addition of body movement (same air speed). Relatively, low effects can also be seen for $R_{ecl,i}$, for example, for the upper leg of outfit 1 and the lower arm of outfit 2. These small effects might be caused by different draping of the garments due to the attachment to the moving simulator. It seems that the air layer between the manikin's surface and the garment might be increased, which would lead to an increase in $R_{et,i}$ and $R_{ecl,i}$, counteracting any possible pumping effect, which reduces $R_{et,i}$ and $R_{ecl,i}$.

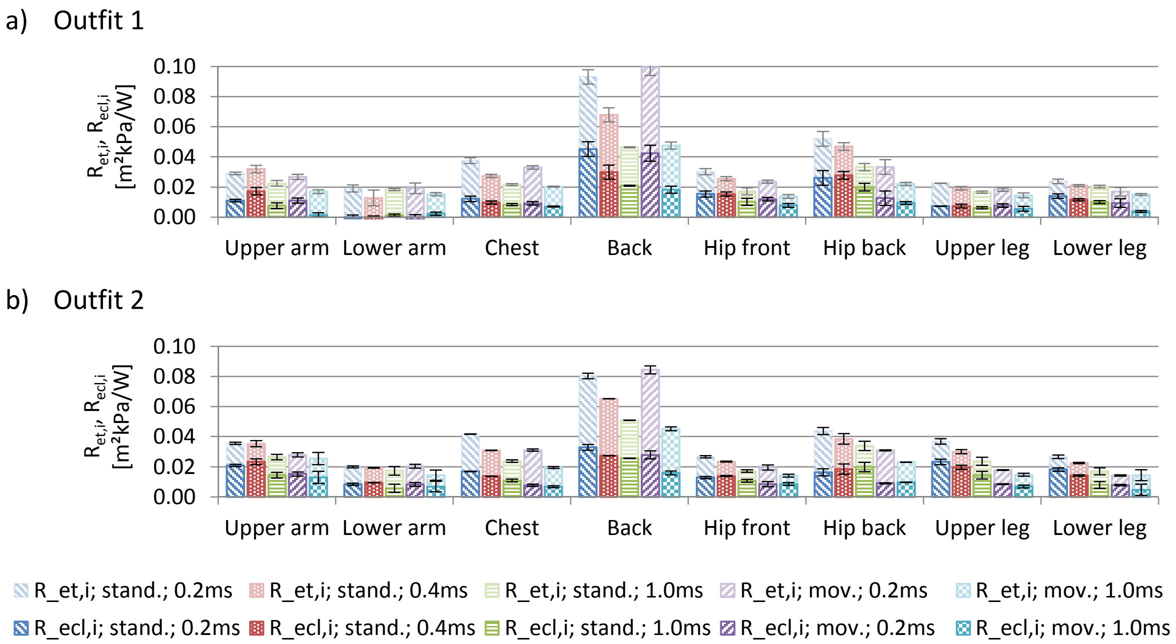

Figure 1 Local total and intrinsic evaporative resistances ($R_{T,i}$ and $R_{cl,i}$) for a) outfit 1 and b) outfit 2

A particular issue arises when measuring and calculating the local evaporative resistances as compared to the total values. Due to gravity and absorption of the skin, the (warm) water of one body part can travel to another site. This error might cause slight changes is the power that needs to be supplied to a body part, and hence, can lead to errors in the results. We tried to avoid this issue, by limiting the sweat rate in a way that the skin is just fully wetted.

Conclusions

This study enlarges the database for local thermal clothing properties of typical office clothing ensembles. Furthermore, it is shown that increased air speed and body movement mostly reduce the intrinsic and total local evaporative resistance at all body parts. However, the reduction cannot be generalized in our case because large differences exist between body parts and clothing ensembles. However, extended studies might find generalization methods or equations similar to the ones that are provided for overall evaporative resistance prediction [6].

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