Heat and Mass Transfer in Mountaineering Boots: a Thermal Manikin Study

Eleonora Bianca[1], Francesca Dotti[1] Ada Ferri[1] and George Havenith[2]

[1] Polytechnic of Turin, Corso Duca degli Abruzzi, 24, Turin, Italy
[2] Loughborough University, Epinal Way, Loughborough LE11 3TU, England

Abstract: The pathways traveled by sweat from the skin to the environment in human clothing can be manifold [1], [2]. This study investigates the movement of moisture and the concomitant heat loss from the sock to the microclimate and external environment in mountaineering boots, considering the low material permeability (estimated permeability index i_m=0.07). As it is not how much sweat is produced in a cold environment that matters, but how much of it can evaporate, a thorough study was conducted to analyze the different contributions to heat exchange in this context. Tests were performed on a thermal manikin with a 100% cotton sock loaded with different amounts of water (0g, 5g, 15g, and 30g) as determined in previous studies [3], [4] at 10°C and 50% RH. Long-term tests were carried out with the maximum amount of water loaded (30g) to observe the different phases of heat and mass transfer until complete evaporation of all moisture (both from the socks and the boots). In addition, evaporation tests were carried out under semi-isothermal conditions ($T_{amb}=T_{man}\neq T_{socks}$) [5] at 34°C and 12% RH (same vapor pressure as cold tests) to isolate the evaporative contribution without any convective or condensation heat loss component. The results showed a small evaporation component from the shoe, but an initial increase in heat loss due to evaporation-condensation pathways from the sock to the shoe's inner surface in agreement with similar previous studies [6]. The higher the amount of loaded water, the higher the heat loss due to free water evaporating from the sock and condensing on the inside of the boots. The estimated contribution of condensation to heat loss was found to be greater than that of evaporation in the first 120 minutes of the test (3.1 kJm^{-2} against 1.9 kJm^{-2}). Since previous studies [7] have shown that evaporation efficiency decreases as the evaporation front shifts towards the boot and away from the socks, we determined a parameter, λ_{eff}, based on the effective latent heat of evaporation and the apparent evaporative cooling efficiency, η_{app}, which is determined by the ratio between the apparent evaporative heat loss of the manikin (which takes into account both the increase in convective contribution due to condensation) and the evaporative contribution determined by the water loss over the specified time period.

Keywords: *insulative properties, footwear, thermal manikin, thermal manikin.*

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