Numerical simulation study on the heat and mass transfer through multi-layer textile assemblies

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Introduction

In order to gather information to allow the optimization of clothing systems, a numerical study was developed on the coupled heat and mass transport phenomena through multi-layer textile assemblies made wool and polyester.

Question

- ***How does the layers relative position affect the heat and mass loss from the body?***
- ***What is the influence of sorption and vaporization/condensation enthalpies on the heat loss from the body?***
- ***How does the sweat rate affect the clothing thermal performance?***

Approach

- FEM-based approach for 1D geometry
- 2 layers of equal thicknesses (wool and polyester)
- Multi-layer in equilibrium with ambient conditions prior to skin contact onset
- Ideal contact assumed on the skin-textile boundary
- Convective heat transport (natural convection) assumed on the external boundary

Initial conditions

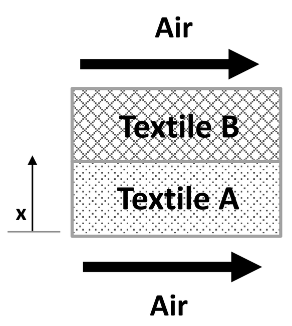

Figure 1. Multi-layer in equilibrium with ambient conditions

Exposure conditions

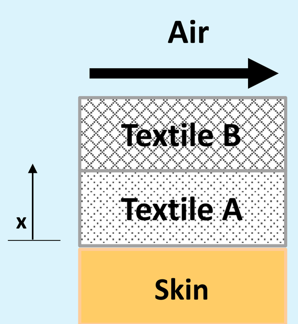

Figure 2. Multi-layer in contact with skin and exposed to convective flow

Computational methods and boundary conditions

Following the approach suggested by Gibson and Charmchi[1] the coupled heat and mass transfer through textiles was described considering: diffusion of water vapour through porous, heat conduction through solid phase, sorption/desorption of water vapour into fibre and water phase change.

Energy and mass balance equations were solved using PDE module for the following boundary conditions,

Table 1. Boundary conditions and initial conditions when the fabrics are in contact with the skin

	Air-Textile boundary	Skin-Textile boundary
Initial conditions	T_{air}=20°C, RH_{air}=50%	-
Exposure conditions	Natural convection (indoor) T_{air}=20°C, RH_{air}=50%	T_{skin}=34°C [2], Sweat rate = 9 -240 g·m^{-2}·h^{-1} (person resting)[3]

Conclusions:

- The relevancy of sorption and vaporization/condensation enthalpies escalates for increasing sweat rate
- The influence of layers' relative position escalates with increasing sweat rate

Main results:

Effect of sweat rate level

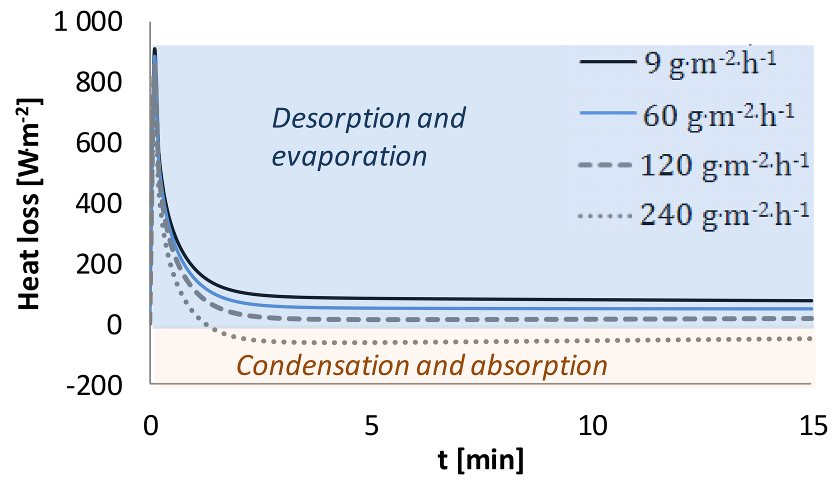

Figure 3. Body heat loss versus time for different sweat rates; wool facing skin

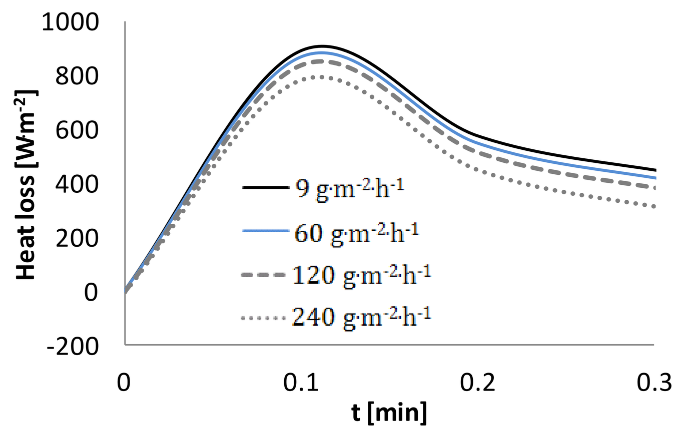

Figure 4. Body heat loss versus time for different sweat rates; wool facing skin (first moments)

Sweat sorption has substantial influence over the heat transport across the multi-layer.

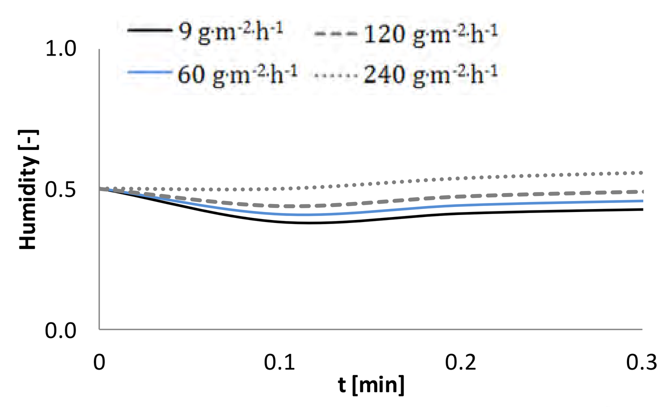

Figure 5. Humidity versus time for different sweat rates ; wool facing skin

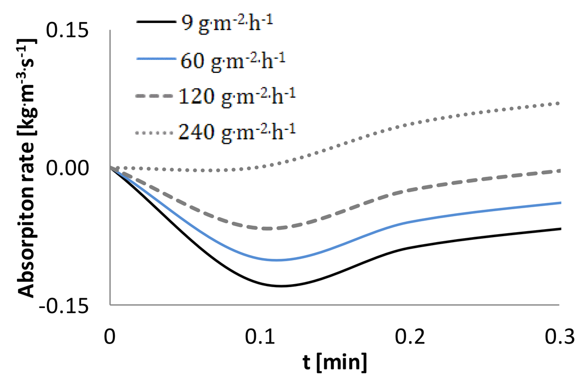

Figure 6. Water rate absorption versus time for different sweat rates ; wool facing skin

For small sweat rates, humidity within textile porous decreases at the initial moments.

For higher sweat rates, the vapour pressure within textiles porous increases more than the saturation pressure, thus humidity increases and absorption occurs.

Effect of sorption and vaporization/condensation enthalpies

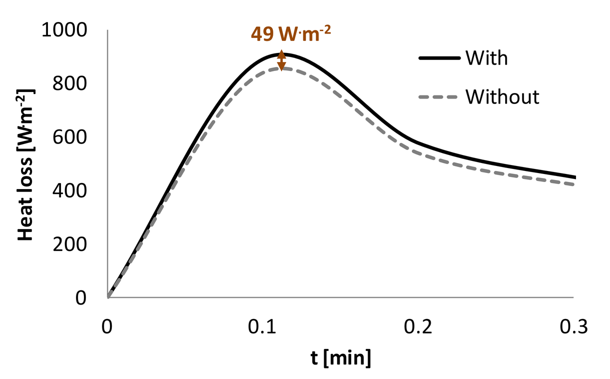

Figure 7. Body heat loss versus time for wool facing skin , with and without enthalpies (sweat rate set 9 g·m^{-2}·h^{-1})

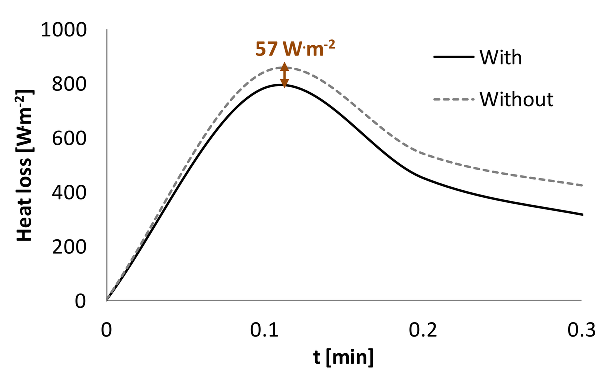

Figure 8. Body heat loss versus time for wool facing skin , with and without enthalpies (sweat rate set 240 g·m^{-2}·h^{-1})

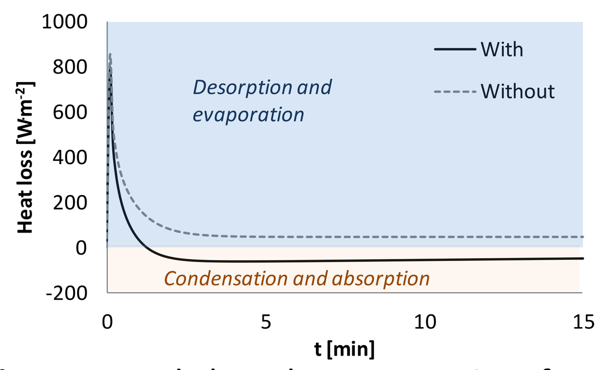

Figure 9. Body heat loss versus time for wool facing skin, with and without enthalpies (sweat rate set 240 g·m^{-2}·h^{-1})

For small sweat rates, the heat loss from skin increases when the enthalpies are considered due to desorption and evaporation of water from the multi-layer.

For high sweat rates, the heat loss from the skin decreases when the enthalpies are considered due to water condensation and absorption.

Layers relative position

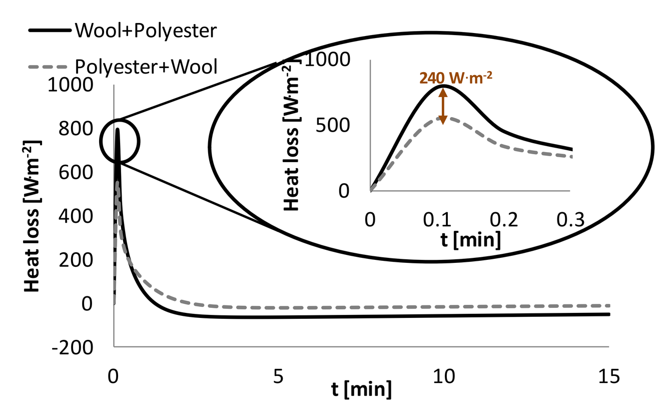

Figure 10. Body heat flux versus time for wool facing skin and polyester facing skin (sweat rate set 240 g·m^{-2}·h^{-1})

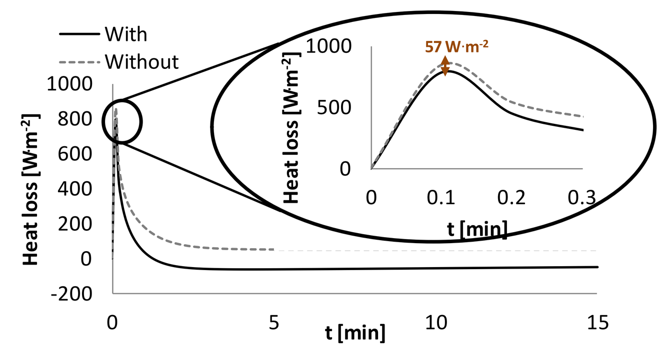

Figure 11. Body heat flux versus time for wool facing skin, with and without enthalpies (sweat rate set 240 g·m^{-2}·h^{-1})

Influence of layers relative position escalates with increasing sweat rates.

Maximum heat loss is highly dependent on skin-facing layer thermal inertia.

References:

1. Gibson, P.,Charmchi, M., *The Use of Volume-Averaging Techniques to Predict Temperature Transients Due to Water Vapor Sorption in Hygroscopic Porous Polymer Materials*, Journal of Applied Polymer Science, 64, 493-505 (1997)
2. K. Parsons, *Human thermal environments* , Second edi. Taylor & Francis , 2003 , pp. 141
3. E. W. Rosenberg , H. Blank , S. Resnik, *Sweating and water loss through the skin*, *J. A. M. A.* , vol. 179, no. 10 , 1962 , pp. 809-11

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