Analysis of heat transfer from human body and effect of clothing surface on heat transfer mechanism

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\textit{COMSOL CONFERENCE 2018 LAUSANNE}

OCTOBER 22-24

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Introduction

Motivation

- Heat transfer from human body to the environment through clothing:

- Experimental method is time consuming and expensive
- Applicability of numerical and analytical model is very limited in this fields
Introduction

Motivation

- Most numerical and theoretical models neglect the heterogeneity of an enclosed air layer
- The assumption of homogeneous air gap can induce an error in simulated heat flux
- Error can affect further modelling of thermal physiology and comfort
Aim

- Assumption of homogeneous air gap and effect of clothing surface on heat transfer mechanisms
- Validation of the numerical model to the experimental data
- Validation of developed analytical model to the numerical model
Experimental setup

(a) Thermal cylinder inside the climatic chamber
(b) Spacer with fabric to cover thermal cylinder

- Selection of fold size
  - Based on 18 casual garments
  - Analysis of more than 300 folds

<table>
<thead>
<tr>
<th>Case</th>
<th>Height</th>
<th>Width</th>
<th>Ratio W/H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case1 Small fold</td>
<td>14mm</td>
<td>42.4mm</td>
<td>3.028</td>
</tr>
<tr>
<td>Case2 Medium fold</td>
<td>25mm</td>
<td>75.8mm</td>
<td>3.032</td>
</tr>
<tr>
<td>Case3 Big fold</td>
<td>38mm</td>
<td>115.2mm</td>
<td>3.032</td>
</tr>
</tbody>
</table>
Geometry and Boundary conditions

- Turbulent flow: Low Re k-ε
- Surface-to-surface radiation modelling
- Natural convection with Boussinesq approximation
- Stationary simulation

Inlet: 0.17 m/s  T: 20°C

Wall:
No slip (u=0 m/s)
Emissivity = 0.05

Pressure Outlet

Thermal cylinder
T=35°C
Diffuse surface, emissivity = 0.9

Fabric layer:
Thin Layer, Ret: 0.024 Кm²/W
Diffuse surface, emissivity = 0.9

Case 1
Case 2
Case 3

Pressure Outlet
Meshing

Mesh independence

Variation in heat flux is <0.08%

Y+ <1

Mesh1
Maximum element size:
Ref. region 1: 17 mm
Ref. region 2: 03 mm

Mesh2
Maximum element size:
Ref. region 1: 10 mm
Ref. region 2: 02 mm

Mesh3
Maximum element size:
Ref. region 1: 07 mm
Ref. region 2: 01 mm

Mesh4
Maximum element size:
Ref. region 1: 05 mm
Ref. region 2: 0.7 mm
Results

Effect of homogeneous assumption on heat transfer

Heterogeneous air gap

Homogeneous air gap

Average air gap of 16mm

Variation in temperature (K) distribution due to uneven fabric surface

Distance on thermal cylinder (X-axis)

Under prediction by 17%

Distance on thermal cylinder (mm)

Total heat transfer coefficient (W/m²)

Heat flux (W/m²)

Convective heat transfer coefficient (W/m²)

Radiative heat transfer coefficient (W/m²)

31 October 2018
Results

Validation of the numerical model against experimentally measured data

- $\text{RMSE}_{\text{max}} = 5.6 \frac{W}{m^2}, \quad SD_{\text{Exp}} = 3.5 \frac{W}{m^2}$

\[ h_{\text{EAL}_{eq}} = \sum_{j=1}^{n} h_{\text{EAL}_j} w_j \quad h_{\text{BAL}_{eq}} = \sum_{j=1}^{n} h_{\text{BAL}_j} w_j \]

$w_j$: Discretized element (% of area having certain air gap thickness out of total area)

$J$: Element number (-)

$n$: Total number of elements (-)

Results

Validation of analytical model with numerical model

![Graphs showing heat transfer coefficients over distance](image_url)

- Total heat transfer coefficient (W/m²)
- Convective heat transfer coefficient (W/m²)
- Radiative heat transfer coefficient (W/m²)

Distance on thermal cylinder (X-axis)
Results

(a) Velocity profile in climatic chamber (m/s)

(b) Temperature profile (K)

(c) Velocity (m/s) and temperature (K) distribution in an enclosed air layer due to natural convection
Conclusion

• Assumption of homogeneous air gap is not valid while simulating heat transfer from clothing surface

• Analysis of clothing surface and fabric properties on heat transfer mechanism

• Presented numerical model is validated against the experimental data

• Analytical model is validated with the help of the numerical model

References


Acknowledgement
The authors gratefully acknowledge co-workers from EMPA such as Dr. Emel Mert for providing measurement data for validation of model, Max Aeberhard for his technical support during thermal measurements.
Danke für Ihre Aufmerksamkeit.
Thank you for your kind Attention.