COMSOL CONFERENCE
2018 LAUSANNE

UNIVERSITÉ HAUTE-ALSACE

Empa
Materials Science and Technology

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

Ankit Joshi[1,2], Agnes Psikuta[1], Marie-Ange Bueno[2], Simon Annaheim[1], René M. Rossi[1]

COMSOL CONFERENCE 2018 LAUSANNE

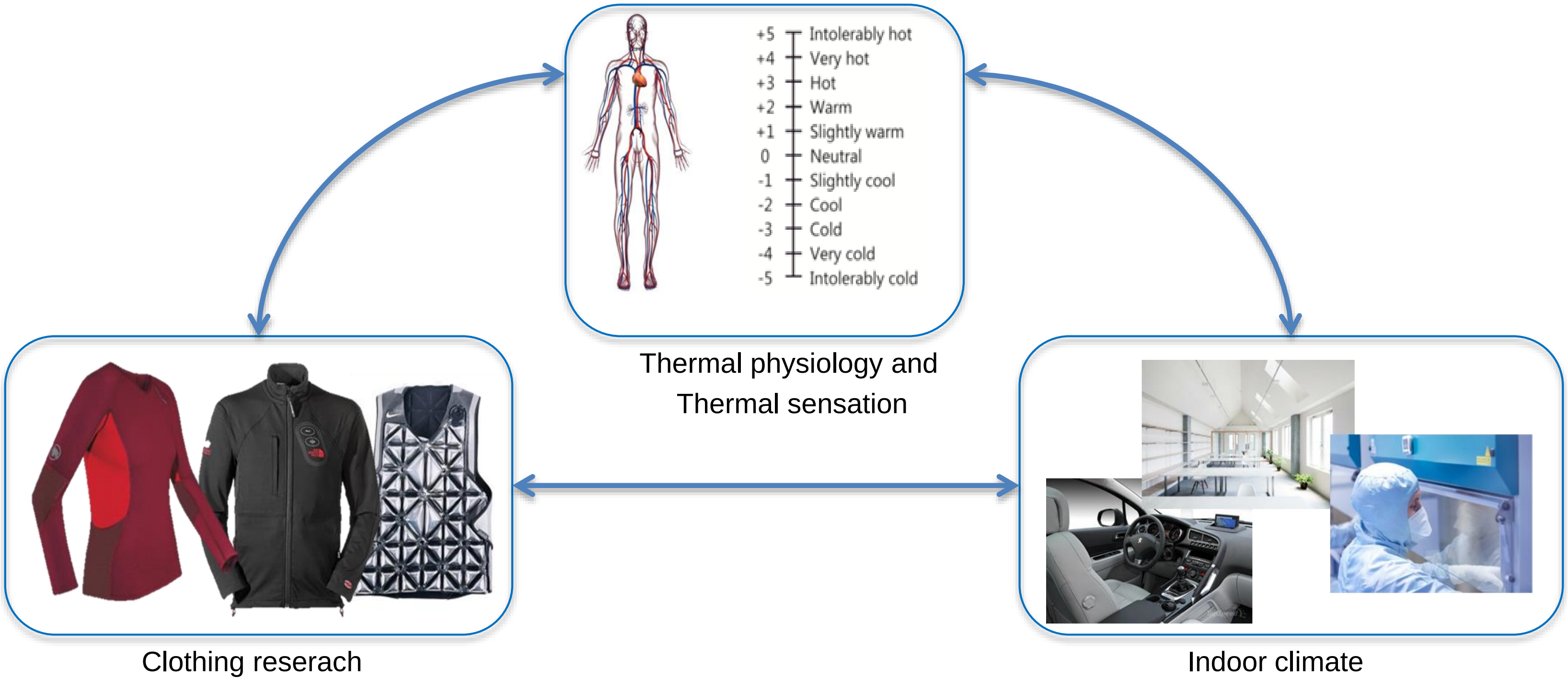
OCTOBER 22-24

1 Empa, Swiss Federal Laboratories for Materials Science and Technology, St. Gallen, Switzerland
2 Laboratoire de Physique et Mécanique Textiles, ENSISA, UHA, Mulhouse, France

Introduction

Motivation

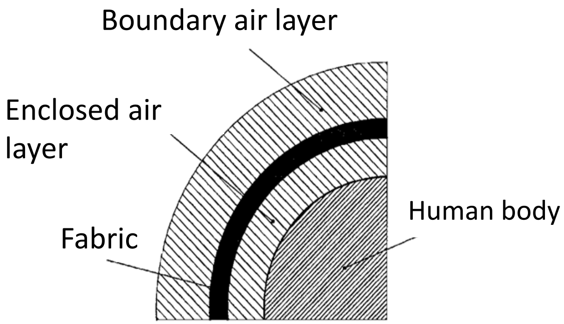
- Heat transfer from human body to the environment through clothing:



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

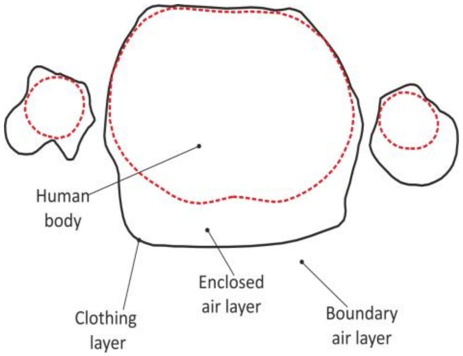
Introduction

Motivation



Simplified*

**ISO 9920:2007*



Realistic

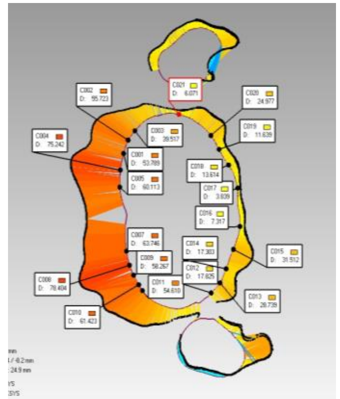
- Most numerical and theoretical models neglect the heterogeneity of an enclosed air layer
- The assumption of homogeneous air gap can induce an error in simulated heat flux
- Error can affect further modelling of thermal physiology and comfort

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



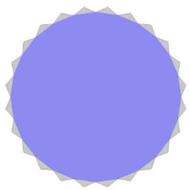



- Selection of fold size
  - Based on 18 casual garments
  - Analysis of more than 300 folds

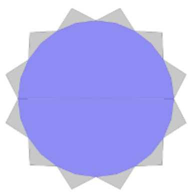
(a) Thermal cylinder inside the climatic chamber

(b) Spacer with fabric to cover thermal cylinder

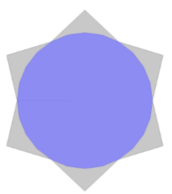
	Height	Width	Ratio W/H
Small fold	14mm	42.4mm	3.028
Middle fold	25mm	75.8mm	3.032
Big fold	38mm	115.2mm	3.032



Case1
Small fold

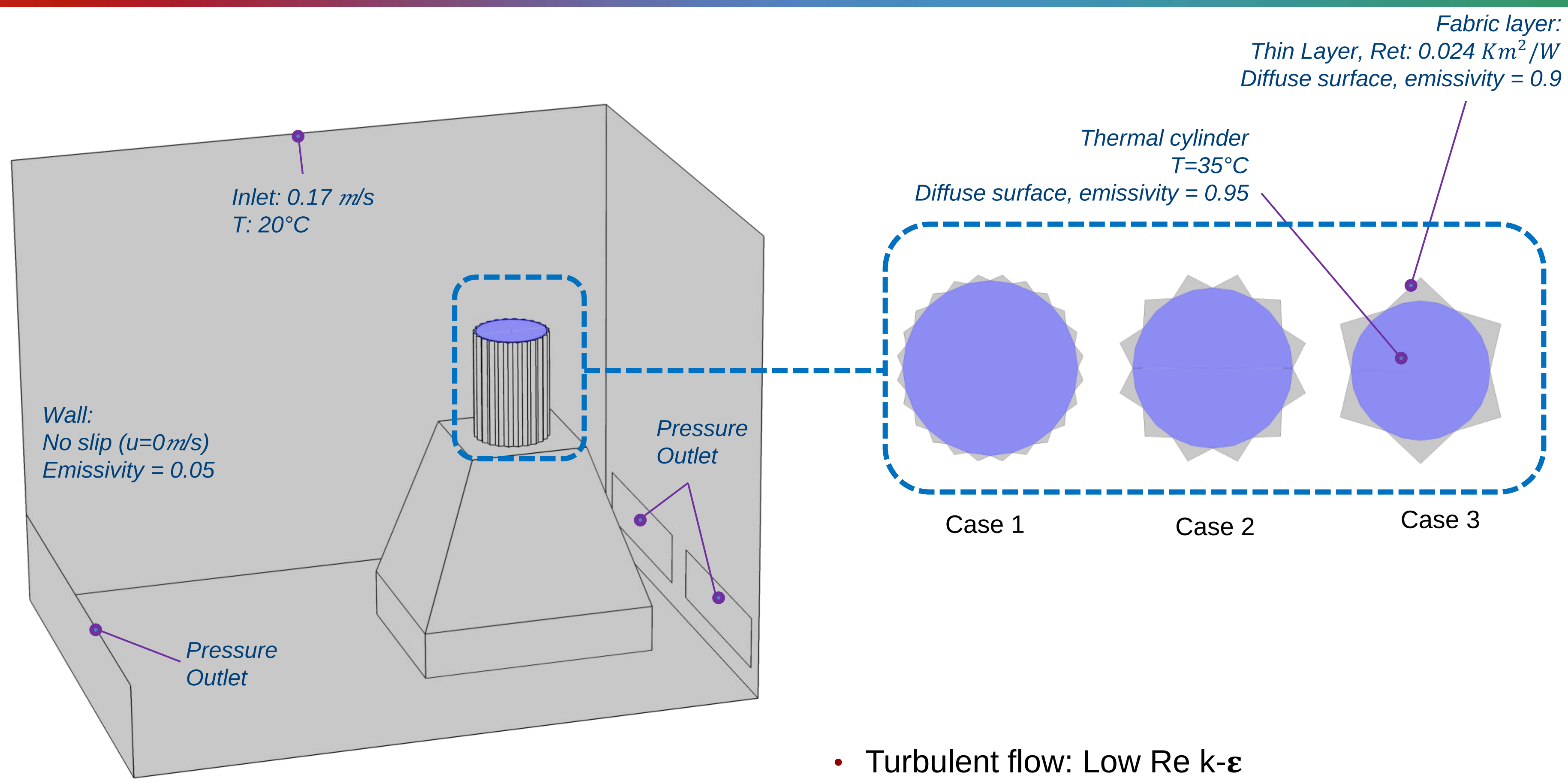


Case2
Medium fold



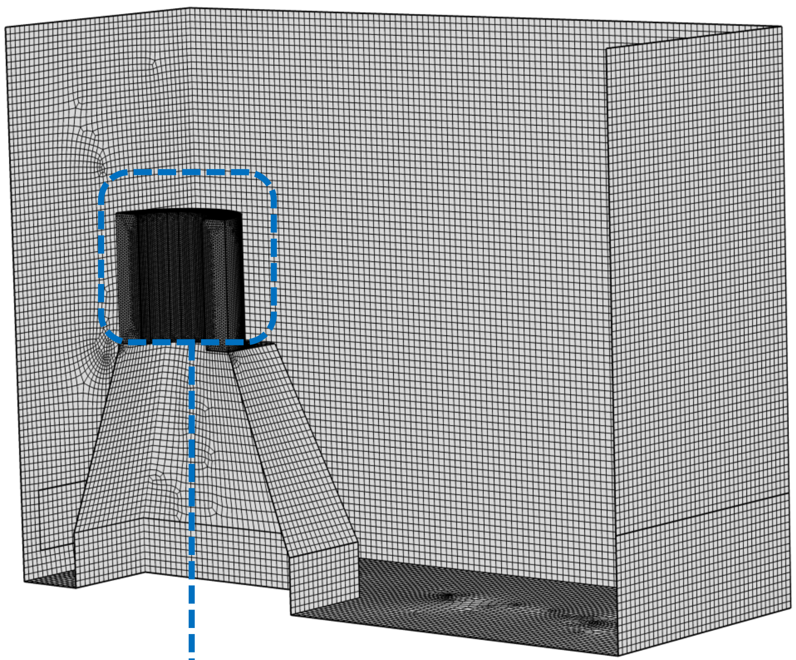
Case3
Big fold

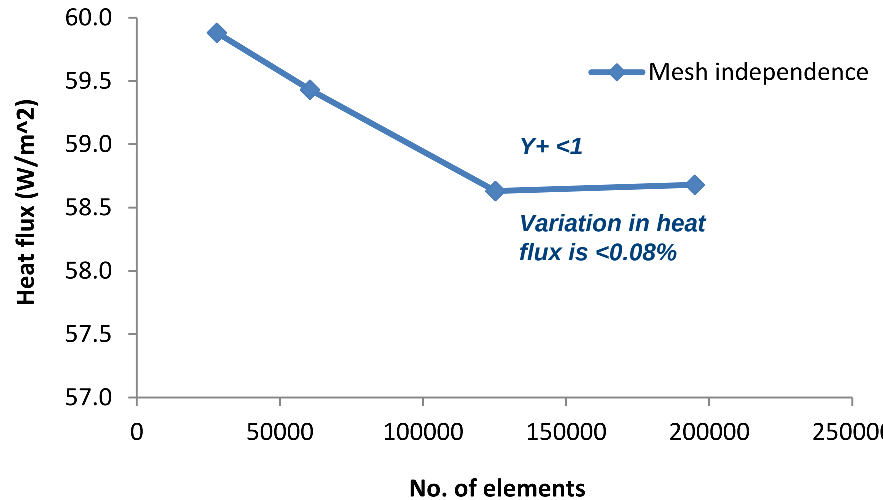
Geometry and Boundary conditions

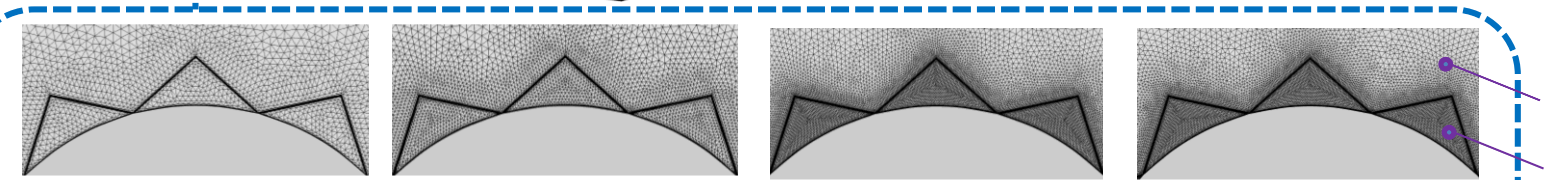


- Turbulent flow: Low Re k-**ε**
- Surface-to-surface radiation modelling
- Natural convection with Bousinesq approximation
- Stationary simulation

Meshing







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

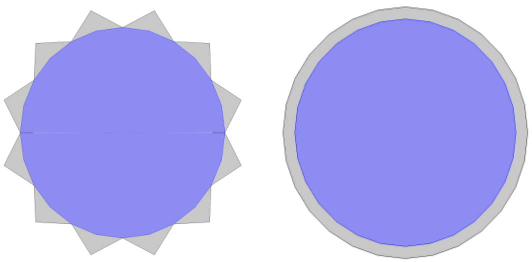
Mesh4
Maximum element size :
Ref. region 1: 05 mm
Ref. region 2: 0.7 mm

Results

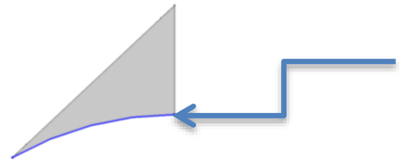
Effect of homogeneous assumption on heat transfer

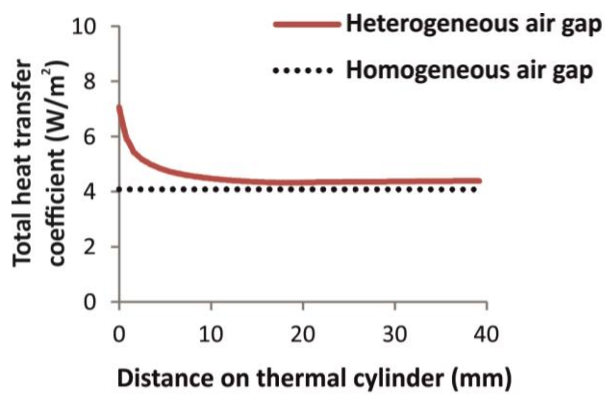
Hetrogeneous air gap

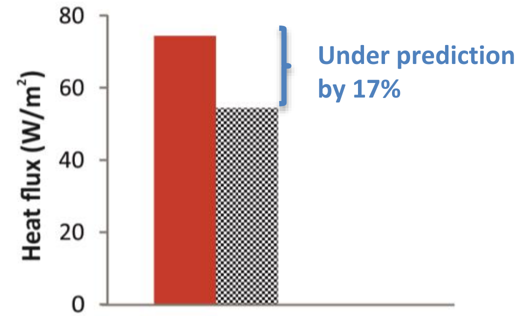
Homogeneous air gap

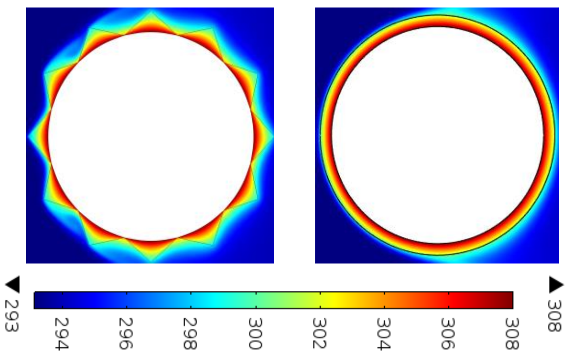


Average air gap of 16mm

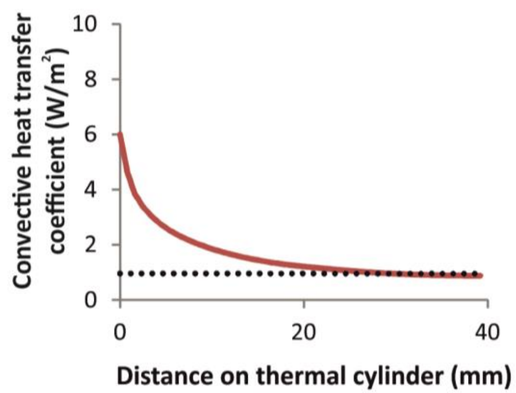


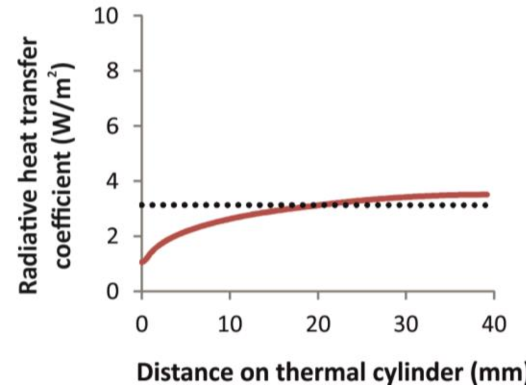






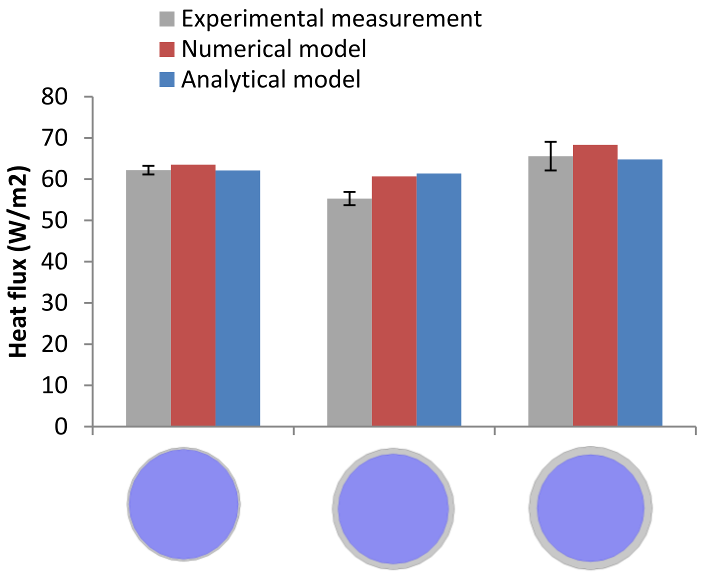
Variation in temperature(K) distribution due to uneven fabric surface

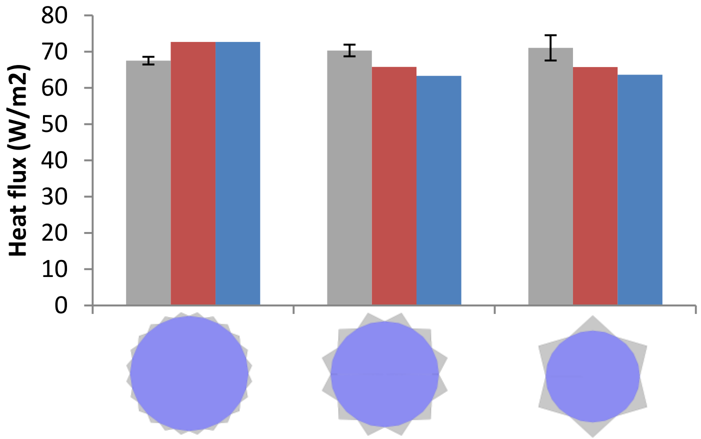




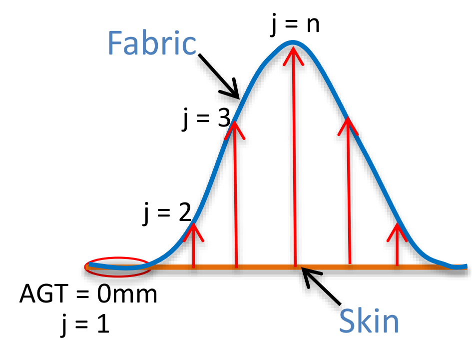
Results

Validation of the numerical model against experimentally measured data





- $\boldsymbol{RMSD_{max} = 5.6\frac{W}{m2}, \quad SD_{Exp} = 3.5\frac{W}{m2}}$



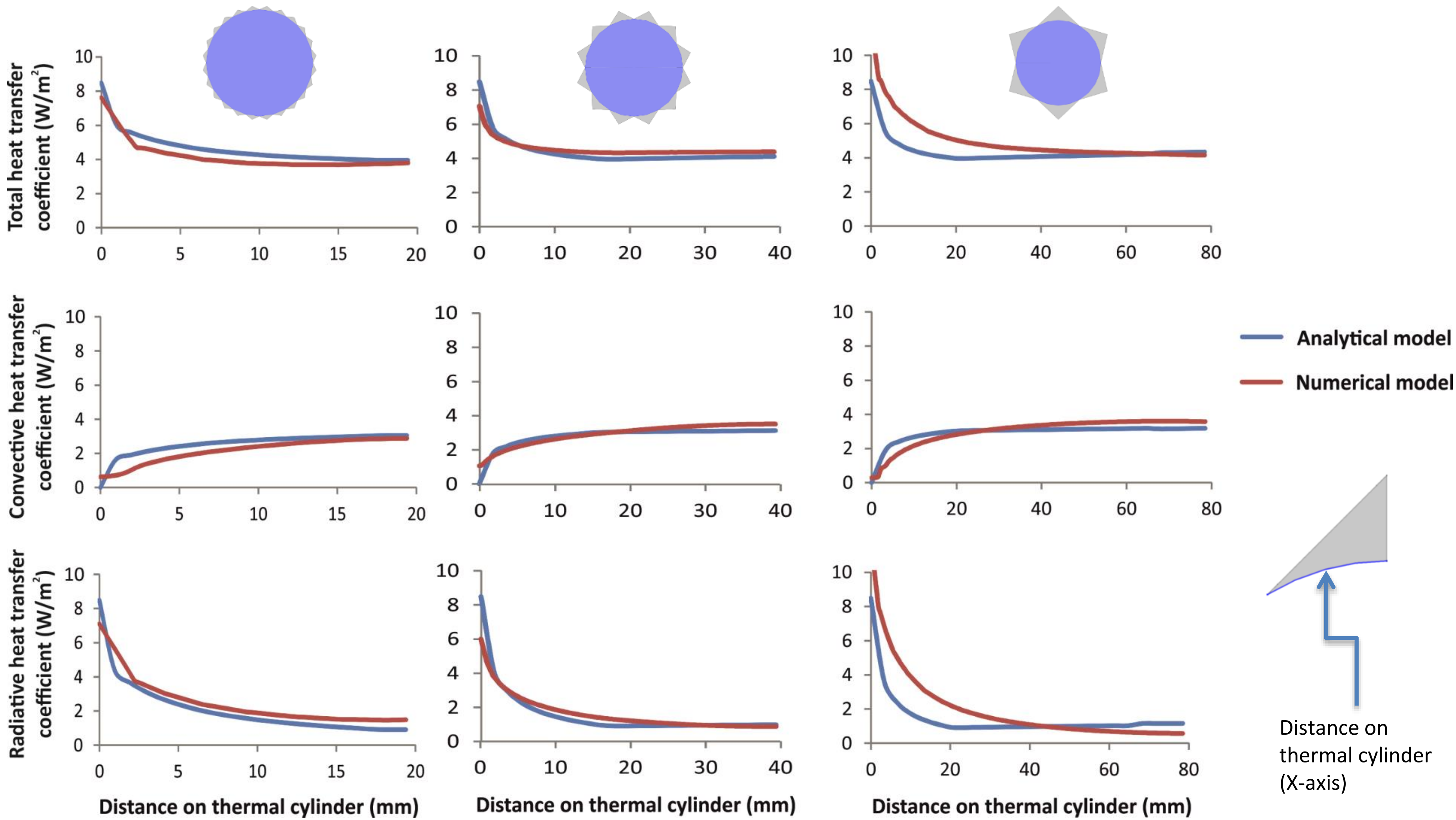
$$h_{EAL_{eq}} = \sum_{j=1}^{n} h_{EAL_j}\, w_j \qquad\qquad h_{BAL_{eq}} = \sum_{j=1}^{n} h_{BAL_j}\, w_j$$

w_j: Discretized element (% of area having certain air gap thickness out of total area)
J : Element number (-)
n : Total number of elements (-)

Exp. data, Mert et al. (2015) Int J Biometeorol 59:1701–1710

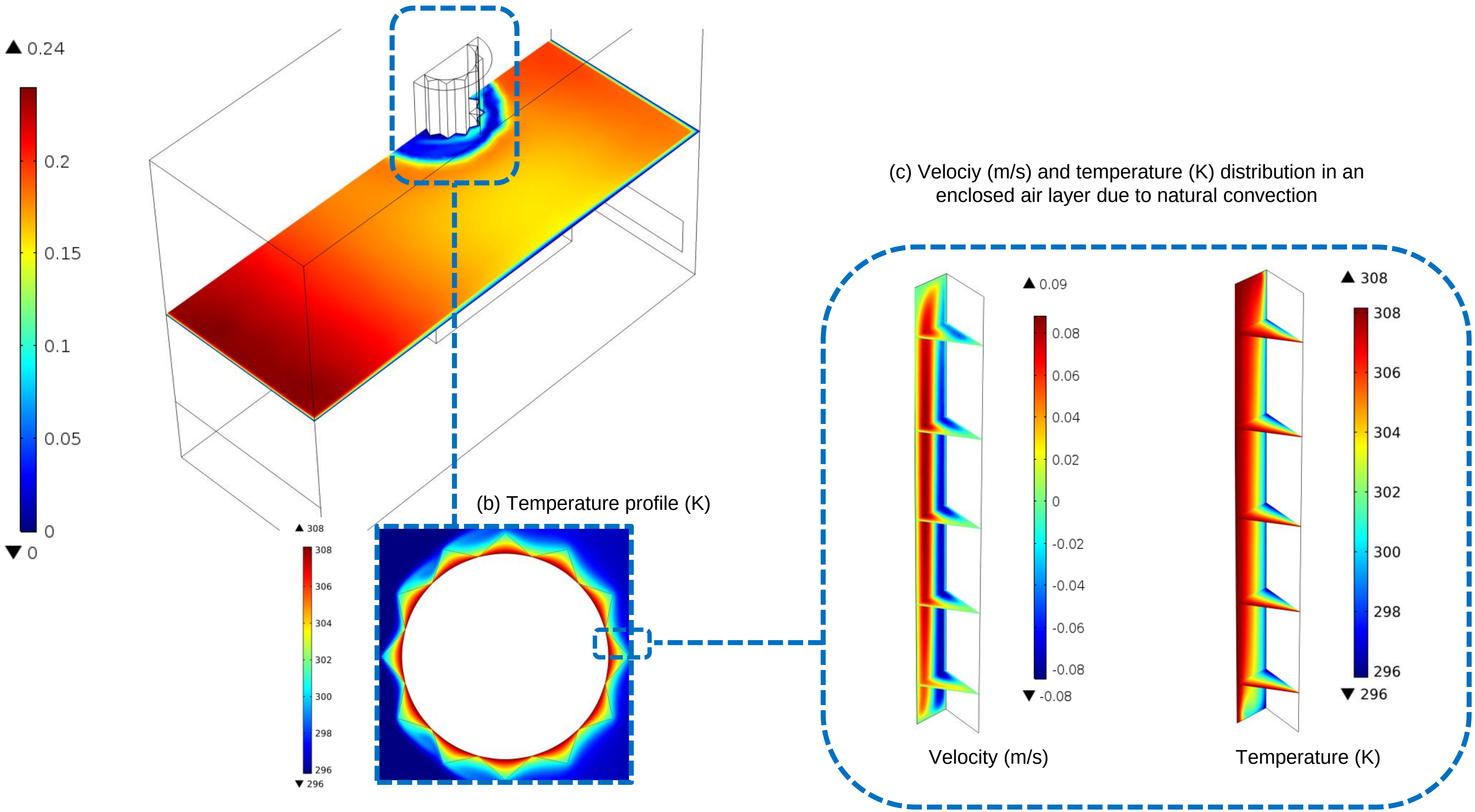
Results

Validation of analytical model with numerical model



Results

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



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

[1] A. Joshi, A. Psikuta, M.-A. Bueno, S. Annaheim und R. Rossi, «Analytical clothing model for sensible heat transfer in skin-clothing-environment system considering spatial heterogeneity and natural convection,» International Journal of Thermal Sciences, Under review 2018.

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.

Empa
Materials Science and Technology