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Application of thermodynamic and fluid dynamic models for simulation of interaction in a system human-cloth-environment

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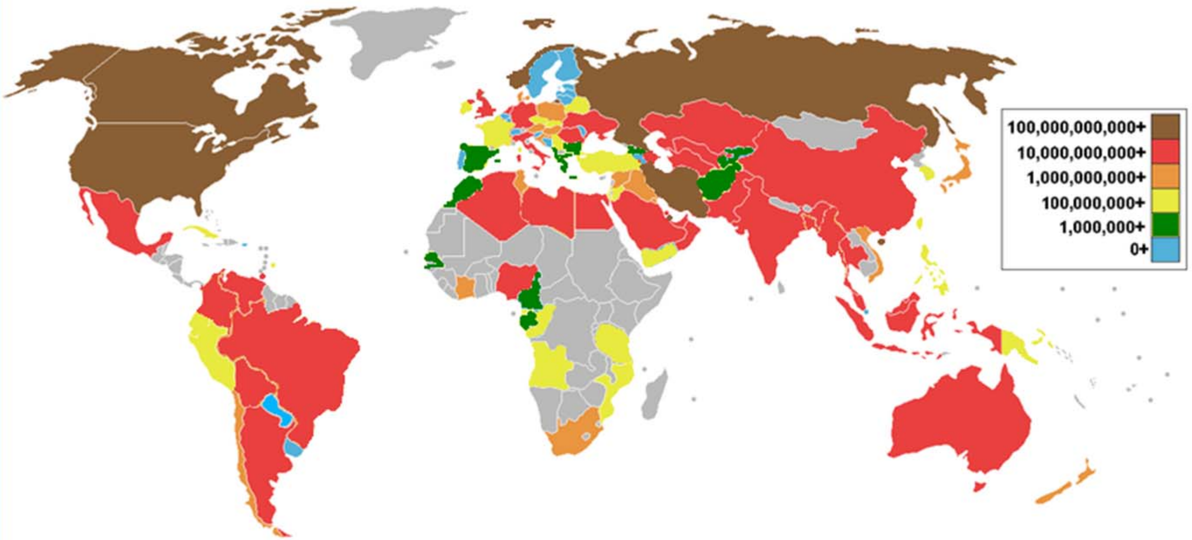
Motivation of the work

Distribution of the natural gas fields over the world



Most of natural gas and oil fields are located in the regions of extreme climate conditions

Employees of gas and oil companies have to work under

- **extreme low temperatures (up to minus 40 degrees of Celsius)**
- **strong wind conditions (up to 20m/s)**

The aim of this paper:

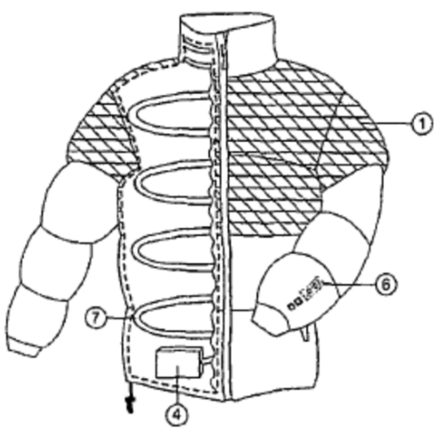
Development and application of CFD models for design of cloth for the work under low and high temperatures with and without wind

Practical task

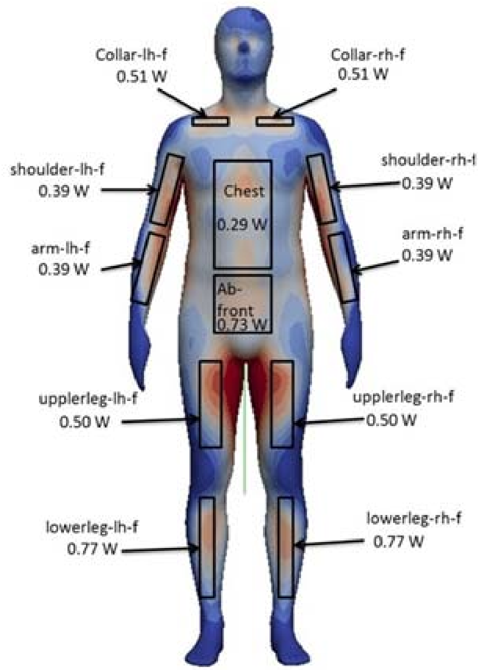
Task: to work appr. 50-60 minutes under -40 deg

Existing garment
without heating

Existing heating patents
Discrete heating
With and w/o control



Our concept:
Distributed controlled (active) heating to reduce required battery capacity



The cloth 30 mm thickness, manufactured from the Saviour with Flamestat Cotton (upper sheet), the insulation Thinsulate and Taeta as a lining. The cloth is used in oil industry for work at very low temperatures under oil contamination conditions

Why Computational Fluid Dynamics (CFD)?

Charlie I – 1968

Charlene – 2008

Charlie IV – 1994

Isaac? / Carl? / Sherlock? – 2013

- To reduce the costs of experiments
- To avoid the experiments with people
- To optimize technical solutions quickly

Mechanisms of interaction between human body and surrounding medium

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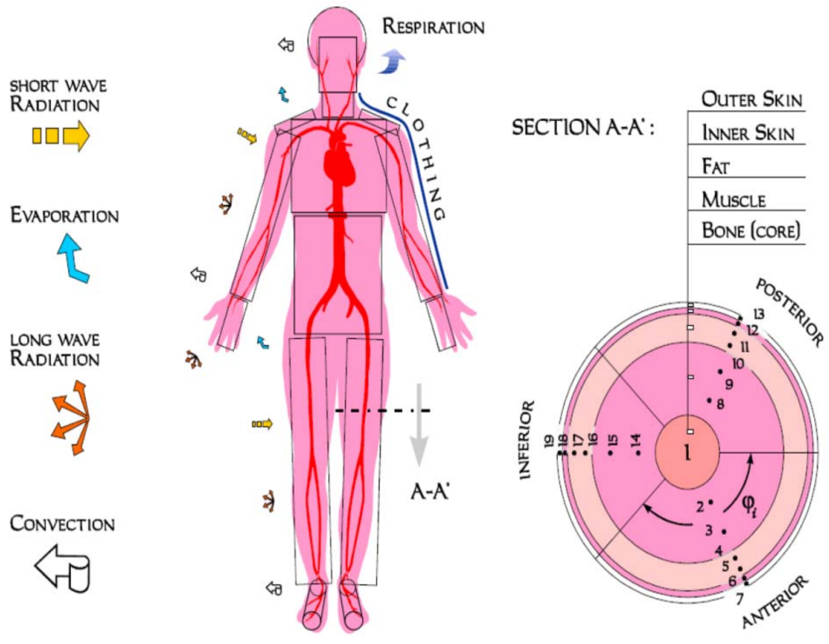

(taken from Fiala et al.)

+change of the thermodynamic properties of garment due to textile deformation caused by the wind

Mechanisms considered in this work:

- natural convection
- forced convection
- radiation (simplified models)
- Thermodiffusion
- Wind induced pressures

Mathematical model

$$\frac{\partial \overline{u}_i}{\partial x_i} = 0$$

$$\frac{\partial \overline{u}_i}{\partial t} + \overline{u}_j \frac{\partial \overline{u}_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial \overline{p}}{\partial x_i} + g_i\left[1 - \beta\left(\overline{T} - T_0\right)\right] + \nu \frac{\partial^2 \overline{u}_i}{\partial x_j^2} - \frac{1}{\rho}\frac{\partial\ \overline{\rho u'_i u'_j}}{\partial x_j}$$

$$\frac{\partial \overline{T}}{\partial t} + \overline{u}_i \frac{\partial \overline{T}}{\partial x_i} = \left(\frac{\nu}{Pr} + \frac{\nu_t}{Pr_t}\right)\frac{\partial^2 \overline{T}}{\partial x_i^2}$$

Computational grid

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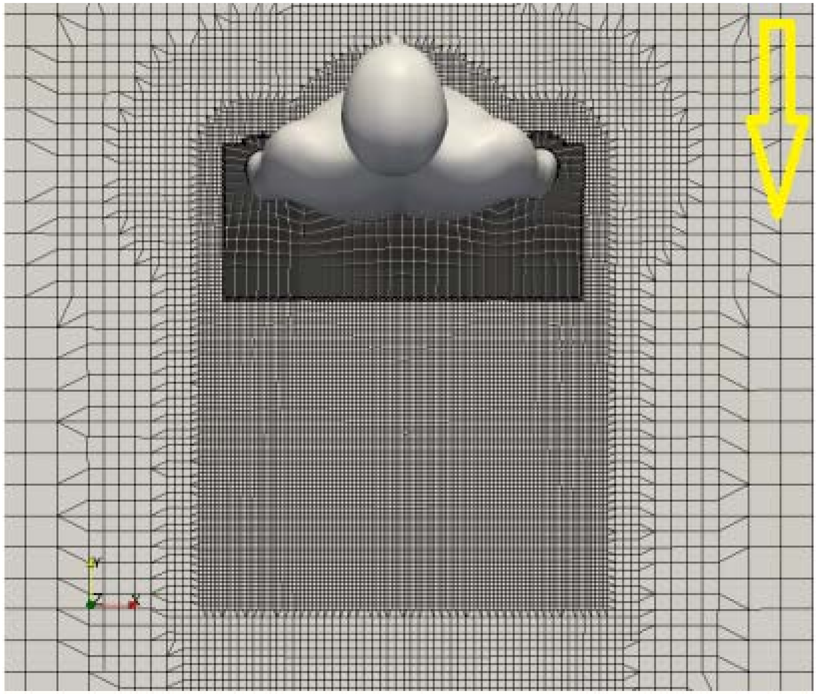
Finite volume method, openFoam code



Grid fragment for the flow around the body

9.8×10^6 cells

- Re=133000
- Maximal y^+ value of approximately 58.
- On the model sides the y^+ mean value is about 4.
- Simulations were performed for turbulent flow utilizing the k-omega-SST model

Vortex structures around the human body

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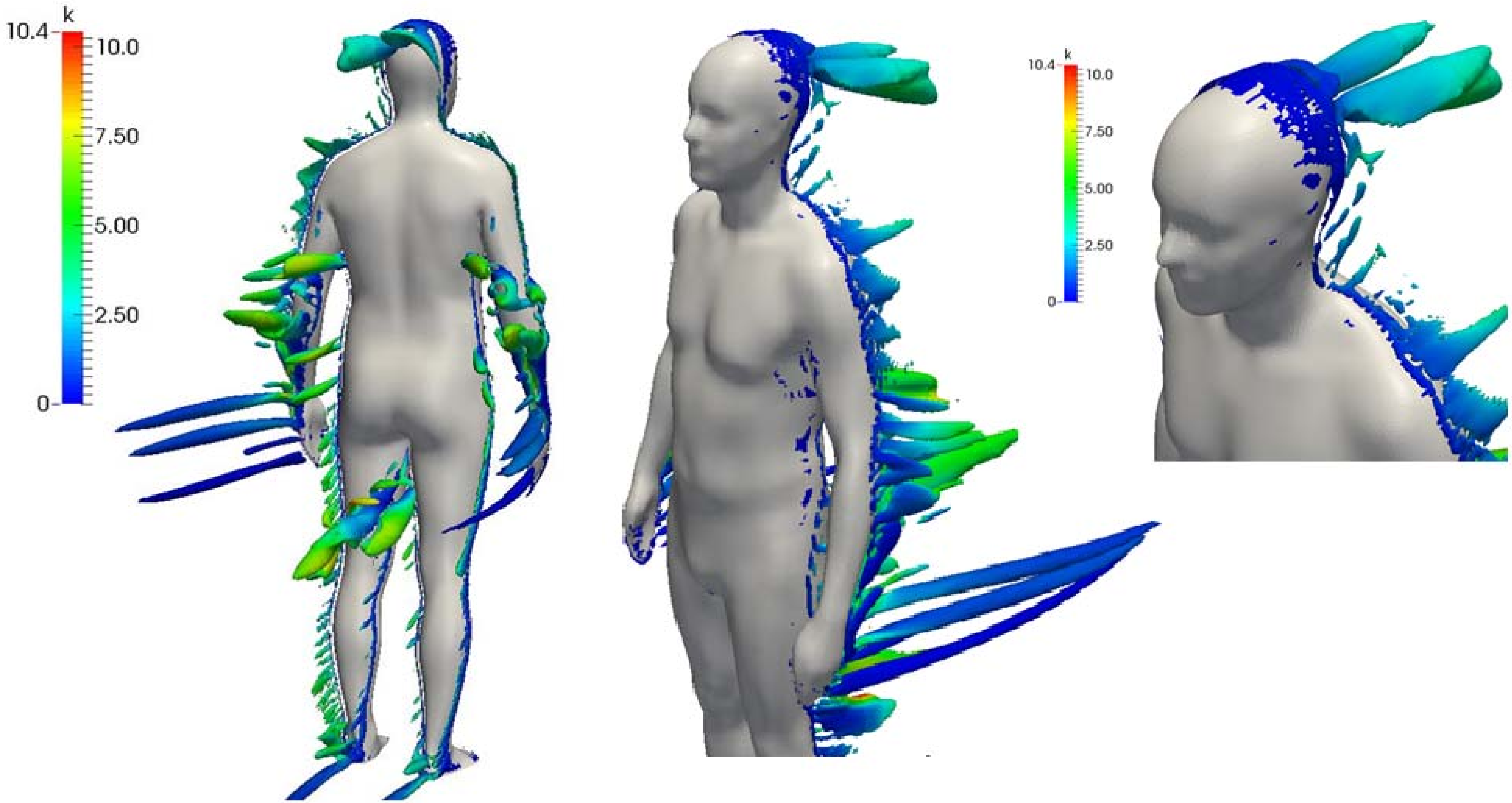
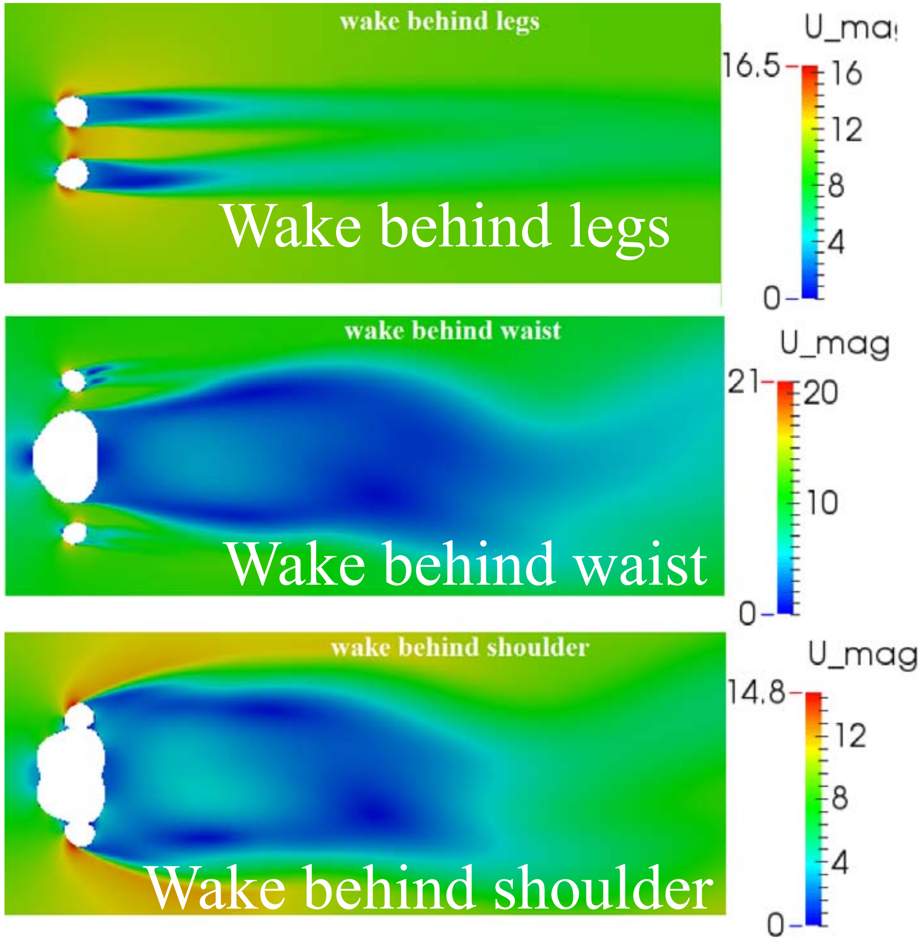
Visualization of vortex structures with the Q- criterion using a threshold of $Q=4\times10^3$ colored with the turbulent kinetic energy.



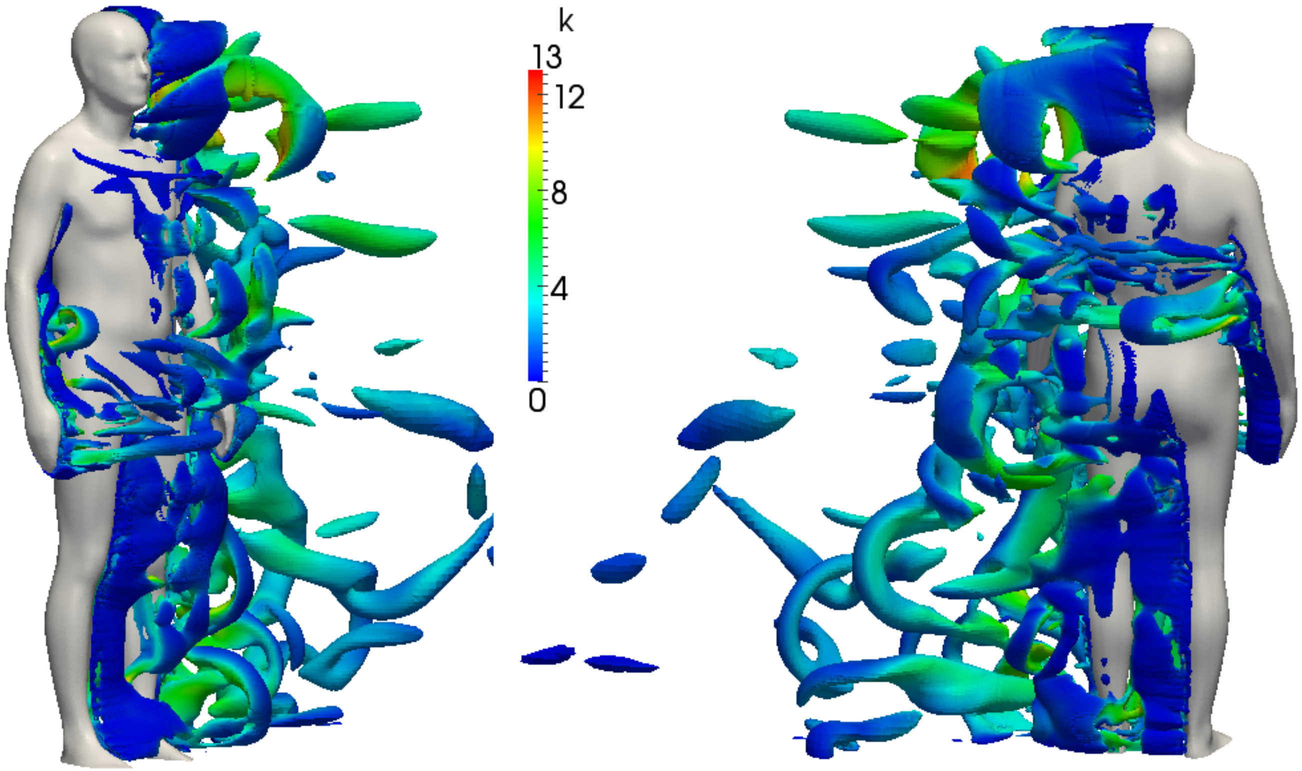
- **Vortex structures have form elongated in the streamwise direction.**
- **The strongest and largest vortices arise between legs and between body and arms, i.e. in areas of local flow contractions.**

Vortex flow around the human body



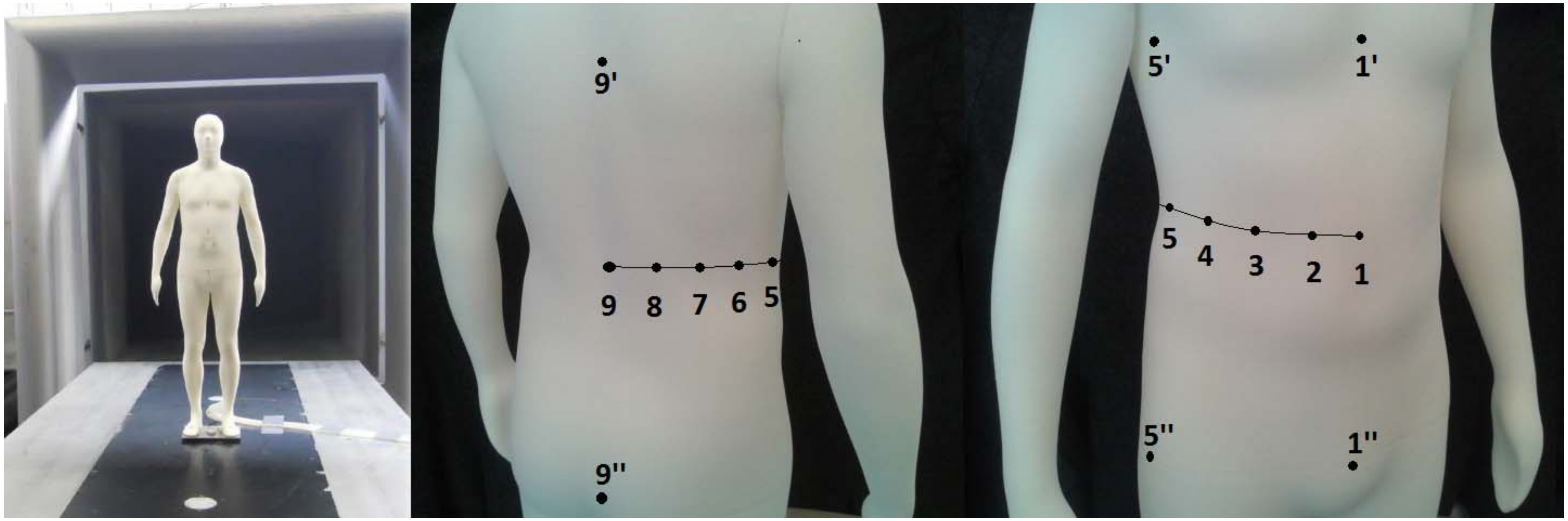
The wake behind the body is unsteady and performs transversal oscillations as shown in movie

Vortex flow around the human body



Flow around the body positioned along the main stream (side wind). The flow is proved to be more unsteady and contains vortices which are stronger than in the cross-flow case.

Wind tunnel measurement of pressure



wind tunnel: test section - 2.8 m

square cross section - 1.4 x1.4 m2.

Height of the model- 700 mm

scale factor - 0.39.

Re= 133000

Pressure measurements using inclined manometers

Comparison, CFD versus measurement

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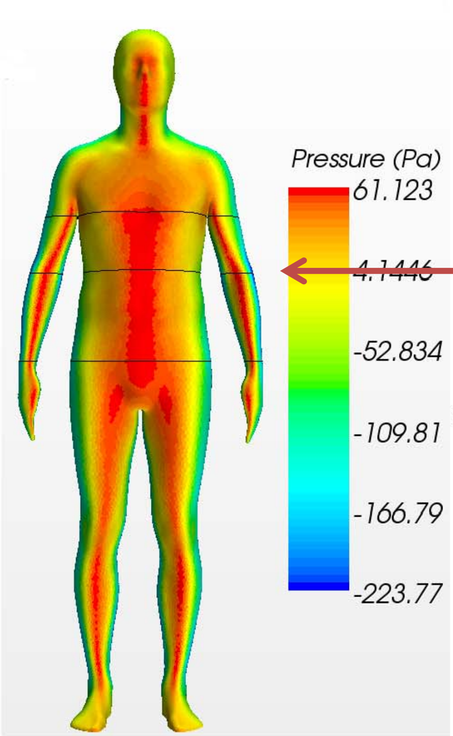
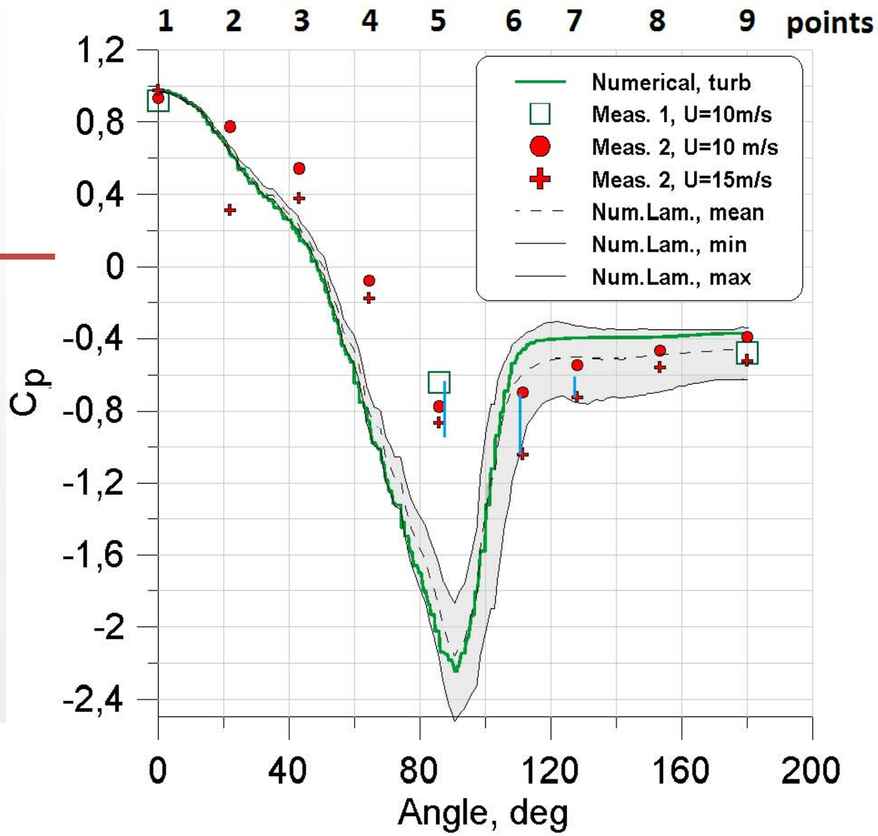
Pressure distribution



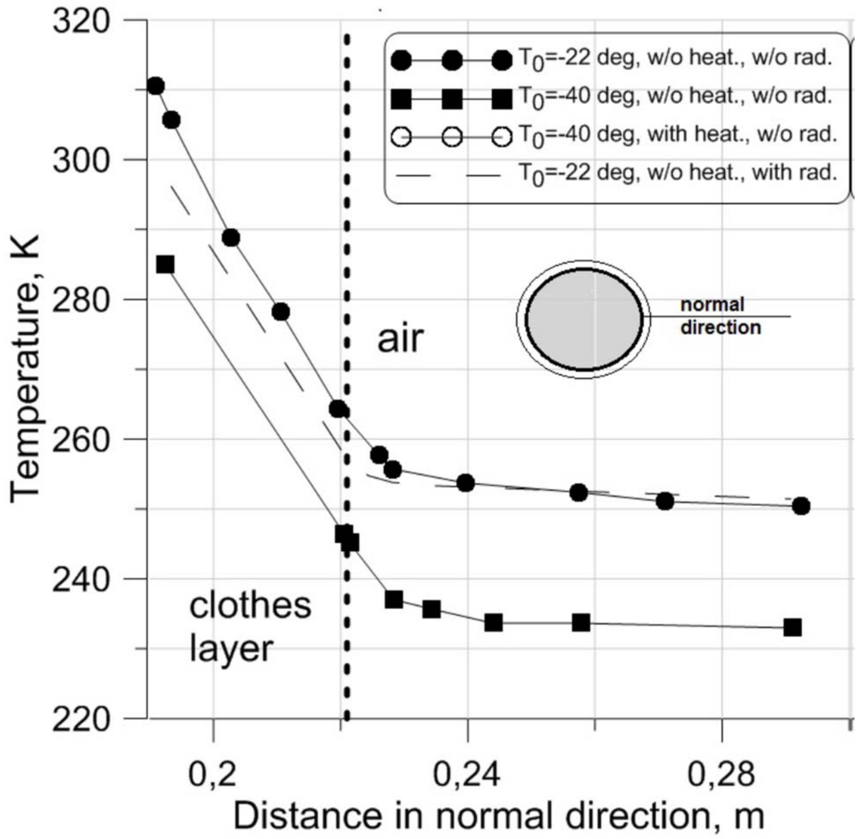


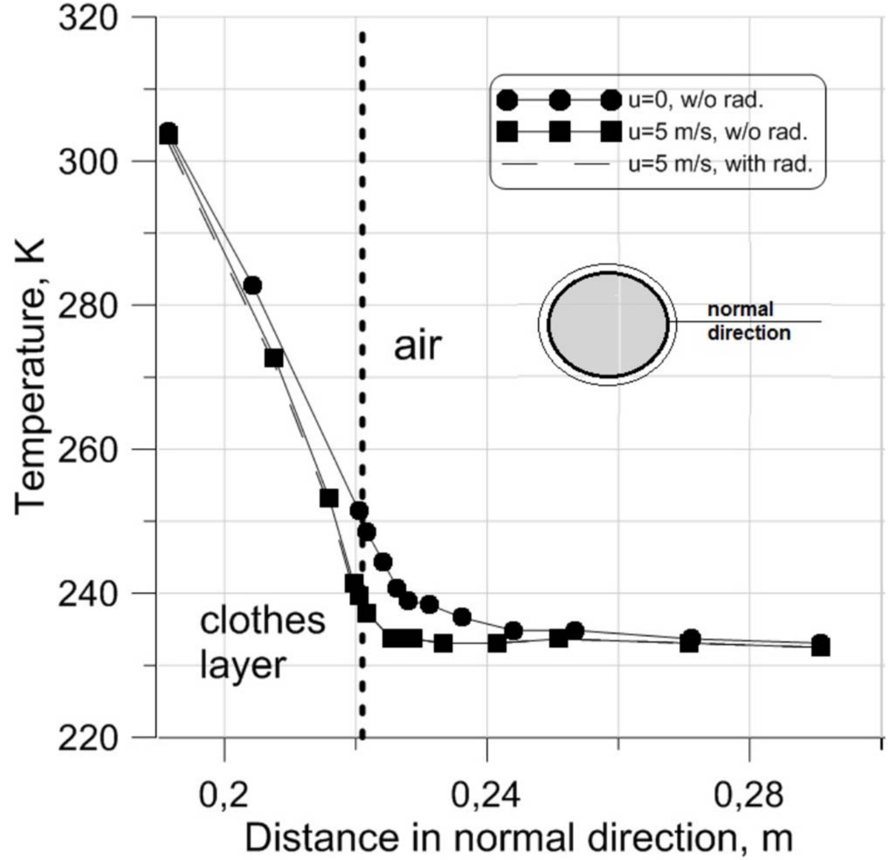
Sufficient discrepancy in flow separation area
It is not critical because the cloth is deformed only in over pressure area C_p>0, where CFD results are satisfactory

Influence of radiation

Model: OpaqueSolid
Emission rate 0.9

Wind speed 5 m/s, Temperature -40 deg





Influence of radiation under wind and low temperature is negligible

Change of thermal conductivity

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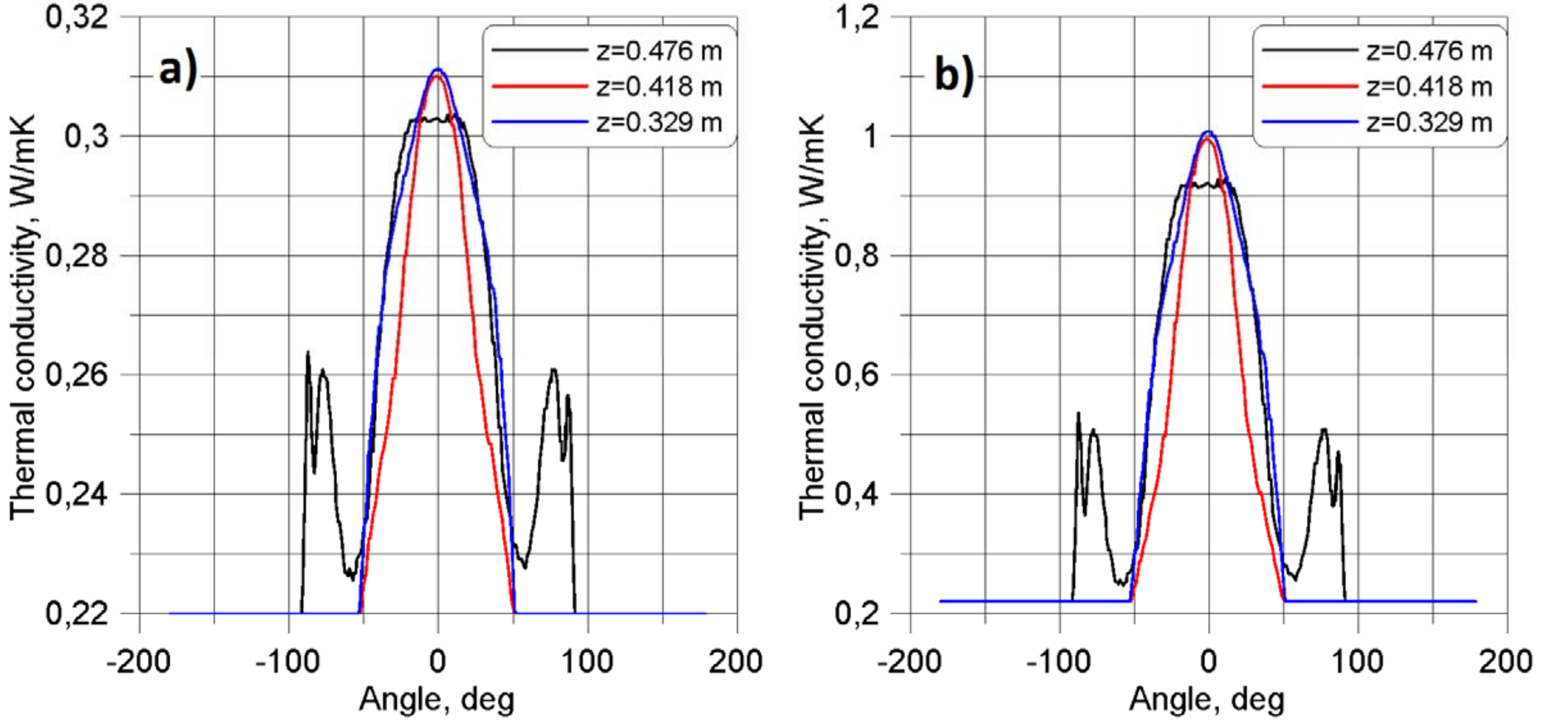
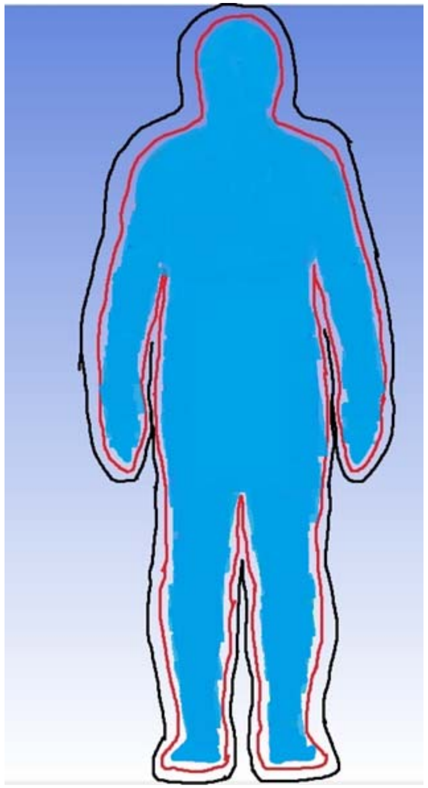
Estimations of pressure influence on cloth thermal conductivity was performed experimentally in the Thermal laboratory of the Don State Technical University.

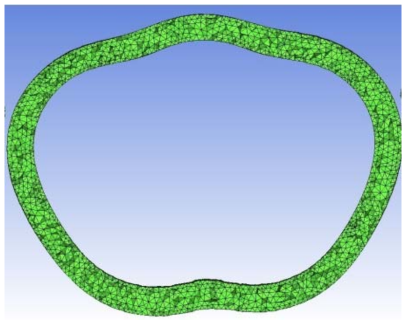


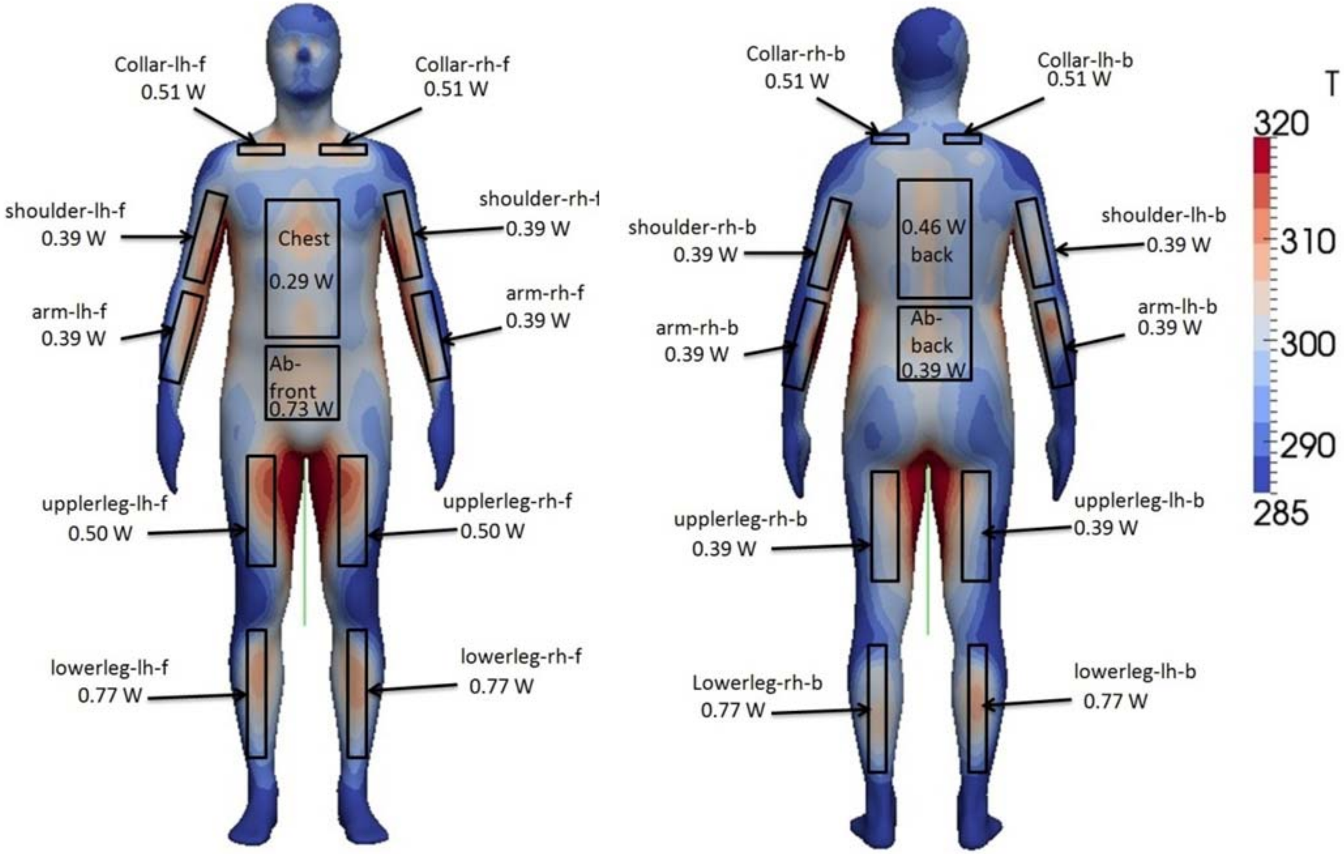
Change of thermal conductivity due to pressure induced by wind of 10 m/s (left) and 20 m/s (right). Thermal conductivity without wind is 0.22 W/mK

Increase of conductivity in the chest area:
Wind 10 m/s : 10 percent
Wind 20 m/s: 70 percent

First results of CFD design







Power and position of local heating calculated from CFD (OpenFoam)

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Practical implementation

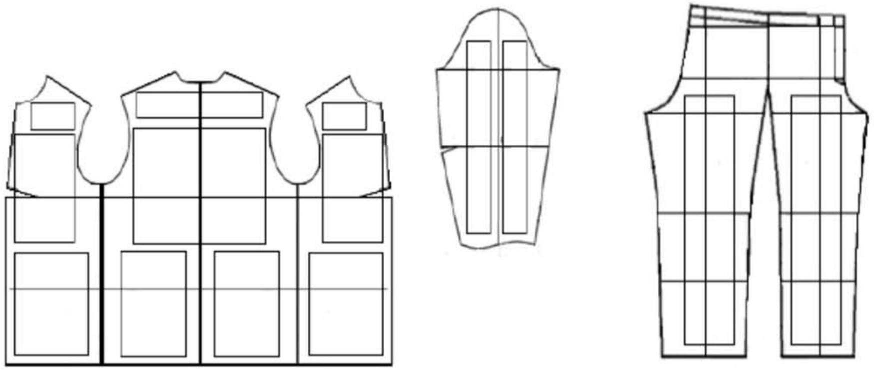

Abbildung 37 Skizze zum Einbau der Heizelemente in Hose (links) und Jacke (rechts)

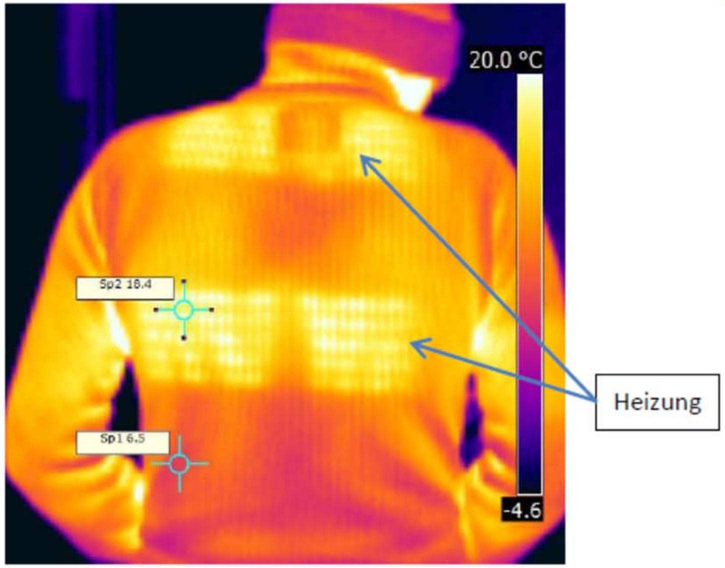

Abbildung 31 Infrarotaufnahme der gewebten Heizung unter Pullover

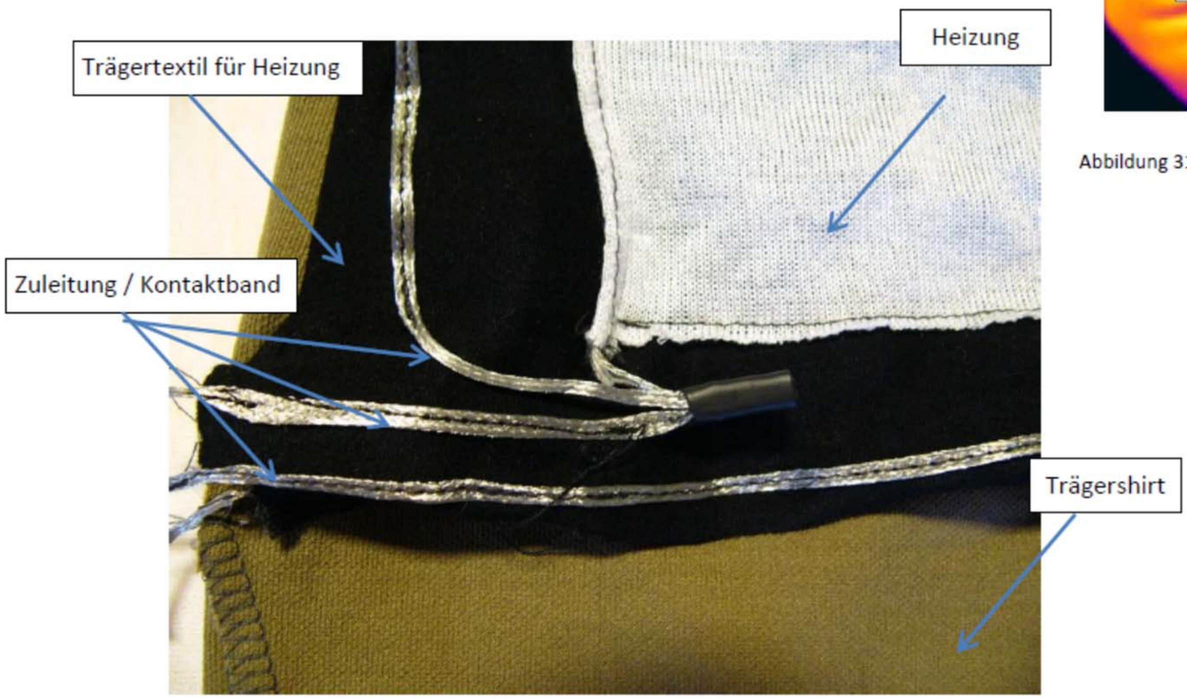

Abbildung 27 Verlegung der Zuleitung auf Trägertextil

Work done in cooperation with ITP GmbH (Weimar)!

Temperature on body

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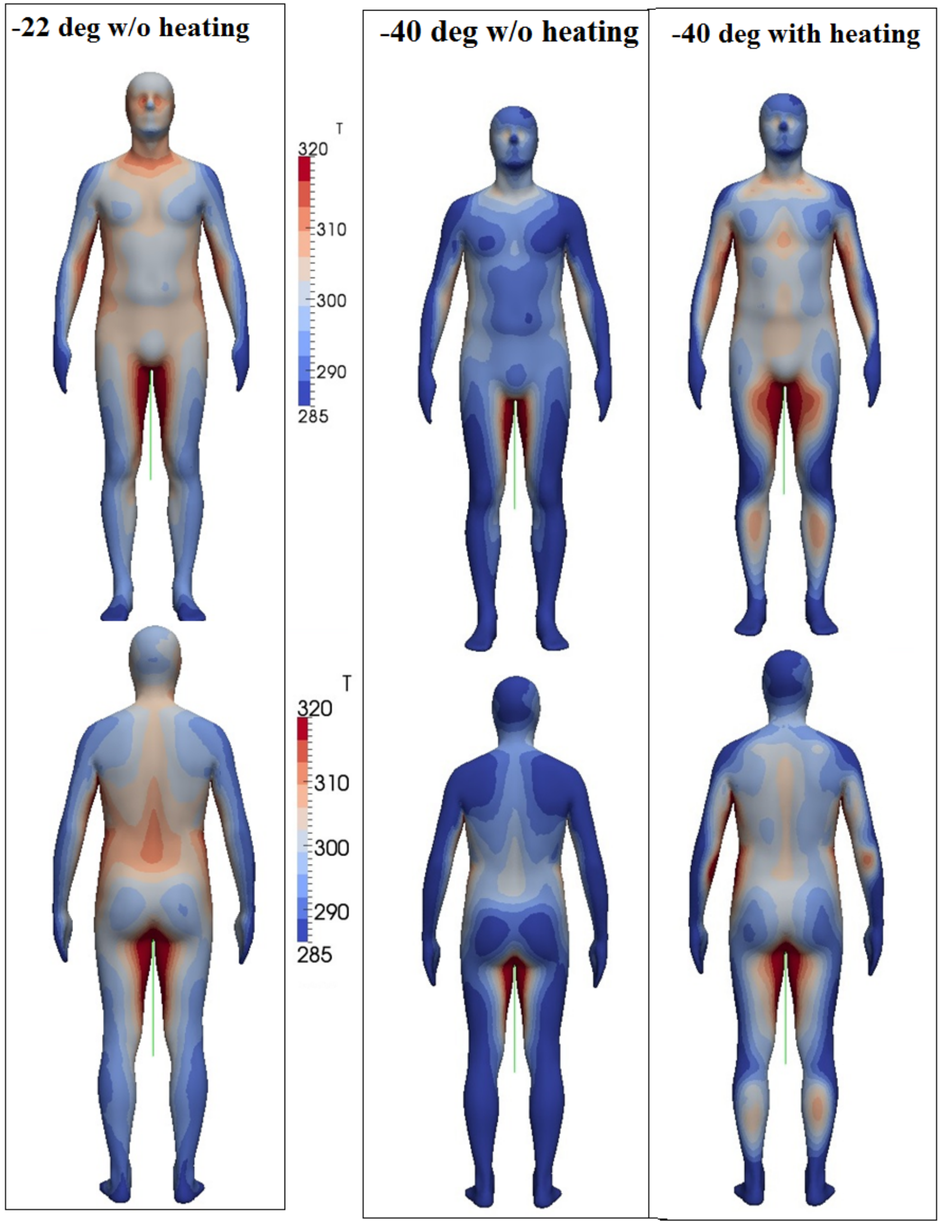
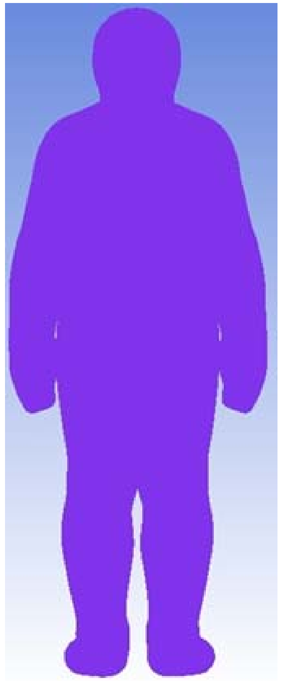
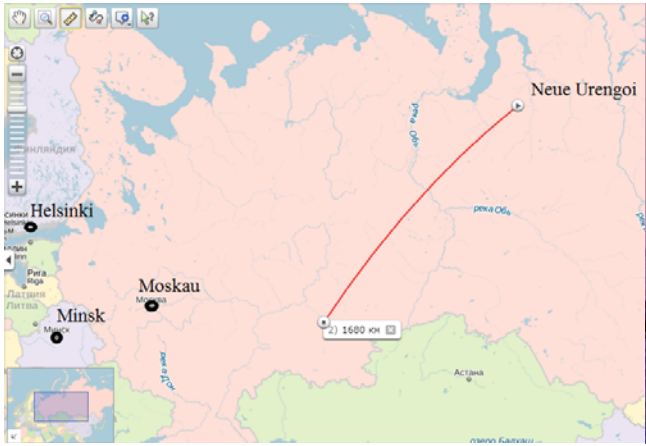




Temperature distributions on body at

- **-22deg without heating (left),**
- **-40 without heating (middle),**
- **-40 deg with heating (right)**

First field trials in Siberia



Conditions: Air temperature: -40 degC, wind 12 m/s, sensation temperature -50 degC
Testperson: (male, very good healthy condition, 27 years old)
Heating: one to one from CFD without wind consideration and radiation, only 11 W

Results:

- **All photo cameras failed**
- **Comfortable conditions 23 minutes without movement felt, cold on the back (he stayed with back to wind)**
- **After 33 minutes the test was stopped**

Next steps:

- ➢ Increase of heating power to account for wind influence and radiation
- ➢ Tuning of power in temperature chamber and trial tests.
- ➢ To understand and to solve many CFD problems encountered in this project.

Conclusions

- **The paper demonstrates capabilities of CFD for design of special protection garment.**

- **The results of the work are used for the design of real protection cloth for the work under low temperatures and wind conditions in oil and gas industry.**

Outlook

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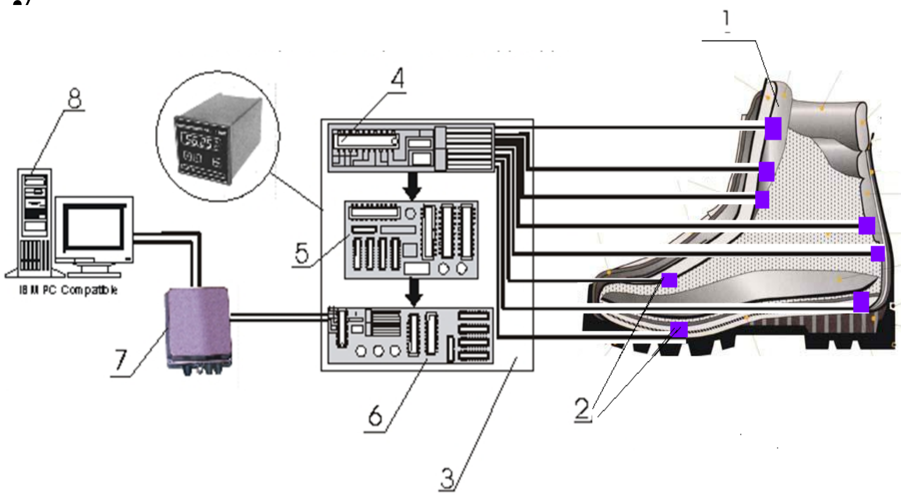
- **New experiments in Fraunhofer Institute Rostock. DFG Antrag.**

- **Wechselwirkung im System Fuß-Schuh-Umgebung**



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ДГТУ

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Thank you very much for your attention!

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BMBF

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FASIE

ФОНД СОДЕЙСТВИЯ
ИННОВАЦИЯМ