THE EFFECT OF RIBS ON COOLING ABILITY OF WETTED SHIRT KNITS AT LOW AIR VELOCITY

Lubos Hes[1] **and Monika Boguslawska-Baczek**[2]

[1] *Technical University of Liberec, Faculty of Textiles, Department of Textile Evaluation*
Studentska 2, 461 17 Liberec, Czech Republic,
[2] *Katowice School of Technology, Faculty of Architecture, Civil Engineering and Applied Art, Department of Design*
43 Rolna Street, 40-555 Katowice, Poland
lubos.hes@gmail.com

Abstract: *In hot-wet countries, a possible way to increase thermophysiological comfort of sweating dressed humans is to wear elastic shirts with larger surface, like rib fabrics. In the paper, the cooling ability of 6 various wetted fabrics with surface ribs subject to parallel air flow was investigated. It was found that at low air velocity the ribs did not provide the expected enhanced cooling effect. In the last part of the study, the cooling effect of thin wetted woven fabrics was investigated.*

Keywords: *thermal comfort, rib shirts, wet state, cooling flow.*

1 INTRODUCTION

At high body activity, typical for running sportsman, the body generates up to 1000 W of metabolic power, from which more than 80% should be transferred away from the body in the form of heat. At low outside air temperatures t_A, most of this heat Q [W] is transferred from the human skin of temperature t_{sk} and surface S by simple convection, characterized by the heat transfer coefficient α, as follows:

$$Q_{conv} = \alpha . S . (t_{sk} - t_{out}) \tag{1}$$

However, when the air temperature exceeds 25-30°C, the convection cooling is not sufficient. Then, body starts to generate sweat. In some body parts the partial pressure of the evaporated sweat/water reaches the saturate level p_{sat}. If the partial pressure of the water vapour (wv) in the outside air p_{out} is low enough, then the convection cooling flow generated by water evaporated from the active area $S.w$ (w lies between 0 and 1) is given by the relationship:

$$Q_{conv\ evap} = ß . L . w . S . (p_{sat} - p_{out}) \tag{2}$$

where L (2 500 000 J/kg) presents the latent heat of evaporation and $ß$ is the mass transfer coefficient.

The evaporative cooling is extremely efficient, provided the difference of the wv partial pressure is big enough. However, in hot/wet countries the mentioned driving force is too low. The only theoretical way to increase the cooling flow from the body of a moving person is to increase the mass transfer area (surface) of the shirt tightly covering the body of the person exposed to these extreme climatic conditions. The only way to increase this area is the use of relatively large ribs vertically outstanding from the fabric surface.

2 MATERIALS AND METHOD

Vertical ribs were prepared by sewing on 8 various single jersey knits made of 100% PES Coolmax and its blends with PES Thermocool, Modacryl and Lycra. Square mass extended from 169 to 213 g/m^2. The ribs dimensions were: height 5 and 10 mm, distance between the ribs was 10 and 15 mm.

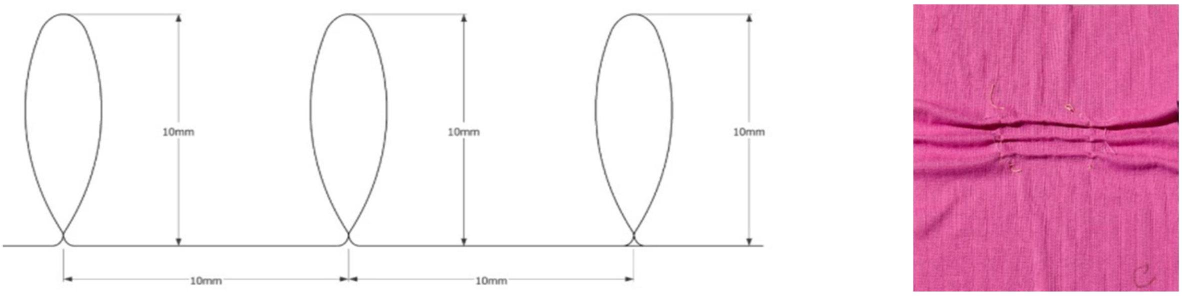

Figure 1 Geometry and appearance of vertical ribs on fabrics

2.1 Calibration of the 100% cooling flow

The Eq. 2 presents the level of cooling flow, where the parameter β is the convection mass transfer coefficient – see in [2]. This coefficient β can be determined by means of the dimensionless Sherwood *Sh* and Schmidt *Sc* numbers defined by the next relations (*b* is the dimension, *v* is the viscosity of the humid air):

$$Sh = \beta.b/D_u \quad (3)$$

$$Sh = 0.664\ Re^{1/2}.Sc^{1/3} \text{ (for air flow parallel to a plane)}$$

$$Re = v.b/v$$

where the term D_u is the coefficient of water vapour diffusion into air for t = 20°C and for p = 0.1013 MPa it reaches the value $1.136.10^{-5}$ m^2.s. The term *Re* is another dimensionless number, reaching here the value of 4970, for the velocity v = 1 m/s used in the PERMETEST instrument.

Having completed all the calculations we obtain the level of the Sherwood number:

$$Sh = 0.664\ Re^{1/2}.Sc^{1/3} = 39.48 \quad (4)$$

$$Sc = 0.60 \text{ (for air at room temperature)}$$

As $\beta = Sh.D_p/v$ then (for w = 1, S = 1 m^2) from the above theory and Eq. (2) follows:

$$Q_{conv\ evap} = ß.L.[(p_{sat} - p_{out}) =$$

$$= L.0.664\ Re^{1/2}.Sc^{1/3}\ D_p^{2/3}\ (p_{sat} - p_{out}).M_D/R.T = \quad (5)$$

$$= L.1.161.10^{-7}(p_{sat} - p_{out})$$

where the term $M_D/R.T$ presents a conversion parameter enabling the use of difference of wv partial pressure instead of dimensionless wv concentration drop.

$$Q_{conv\ evap} = 2.5.\ 10^6.1.161.10^{-7}.1250 = \\ = 362.8\ W/m^2 \quad (6)$$

The determined cooling flow presenting in the PERMETEST instrument the 100% cooling effect is quite high. However, in real situations, when a person is wearing a wetted dress under identical climatic conditions, this level of cooling is never achieved, as sweating coefficient *w* characterising the relative distribution of zones with intensive sweating is mostly lower than 0.4. Thus, the effective cooling flow around 200 W/m^2 already presents a realistic value.

3 EXPERIMENTAL RESULTS

Relative water vapour permeability *P* of the tested samples meaning the relative cooling flow Q_{cool} was determined by means of the Czech commercial PERMETEST instrument, which was in Czech Republic recently certified as satisfying the ISO 11092 standard. During the initial test on dry samples, the samples were (over the semi-permeable membrane) placed on the wetted microporous surface, which well simulates a human skin with 100% relative cooling flow. The lowest relative cooling effect, 59% exhibited sample No. 4 (modacryl + Thermocool), whereas the higher cooling effect, 72%, offered the sample No. 5 (PES Thermocool). Beside the measurement of cooling flow on dry smooth samples, also the cooling flow from dry rib samples was determined. All these values were determined for the air flowing with the velocity 1 m/s along the ribs.

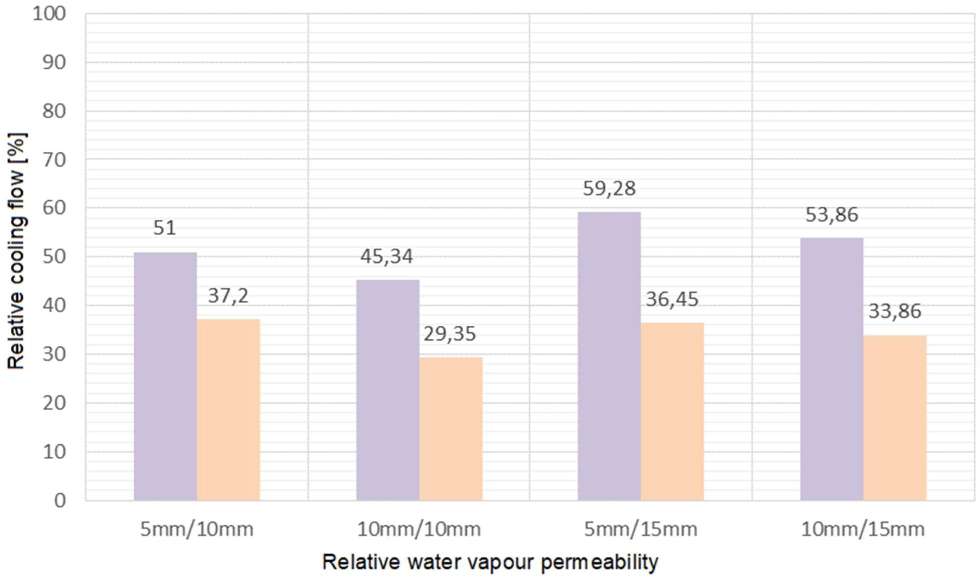

Figure 2 Relative cooling flow / Relative water vapour permeability of fabrics in dry state. Higher levels present the results for ait flow parallel with the ribs, then in case of the air flow across the ribs. It is evident, that the ribs provide lower wv permeability then smooth fabrics

Next experiments were focused on the objective of this study: investigation of the influence of the size of mass (heat) transfer area, executed by forming the surface ribs on the studied fabrics, on the cooling effect given by evaporation of moisture from these rib fabrics enhanced by convection heat transfer from the fabrics.

From the Figure 4 follows that against expectation, the rib fabrics under the applied experimental conditions exhibit lower heat and mass transfer of water vapour than smooth fabrics. Explanation of this observation may depend in the possibility that at low air velocity the thermal boundary layer is quite thick, runs above the ribs and does not create thermal contact with the bottom area between the ribs. Second explanation may take into consideration that cooling effect generated on the upper parts of the ribs is not properly conducted toward the basic level of the fabric, which is in direct contact with the simulated skin. The amendment of the limited heat conduction along the height of ribs may depend in the use special fibres (carbon fibres) with very high thermal conductivity in the design of the ribs. However, carbon fibres are stiff and do not conduct moisture as well as the COOLMAX fibres used in this research.

As long as the smooth textile surfaces provide the highest cooling effect, it will be important to investigate the effect of the fabric structure and composition. This research should respect the same experimental conditions as in the above study: the wetted fabrics will be placed (over the semi-permeable porous membrane) on the wetted surface which simulates sweating human skin.

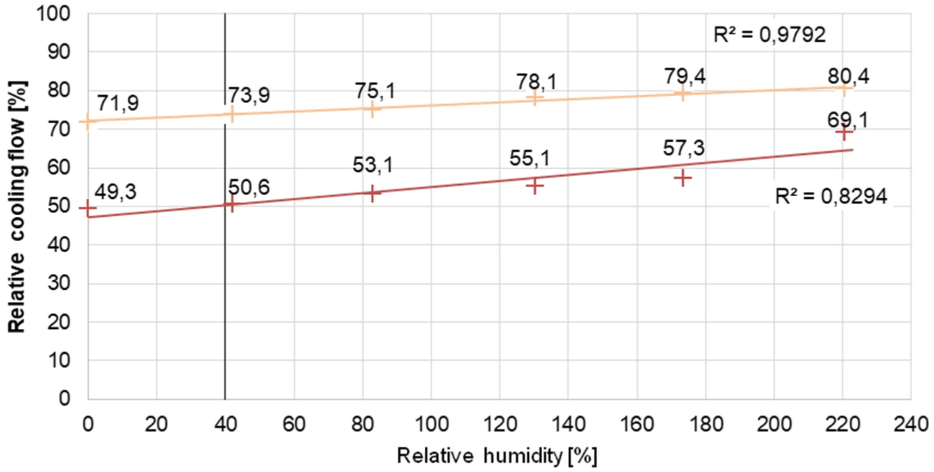

Figure 3 The effect of the sample relative humidity on the relative cooling flow released from the sample No. 5 (PES Thermocool). The higher levels were determined for the air flow parallel with the ribs. Height of the ribs 5 mm, distance 15 mm

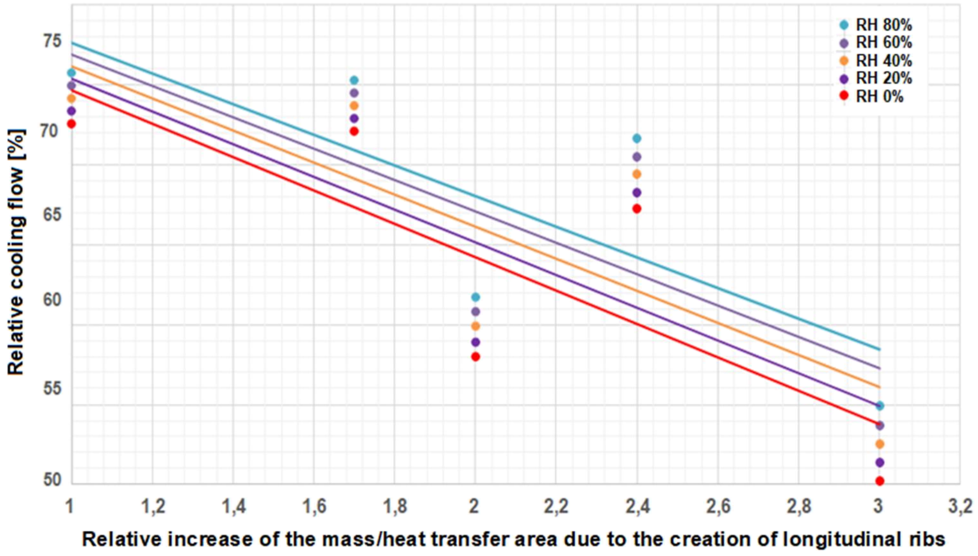

Figure 4 The effect of fabric relative humidity and heat transfer area on the relative cooling flow of the most efficient fabric No. 5 from the Themocool fibres, when the air passes along the ribs (better case)

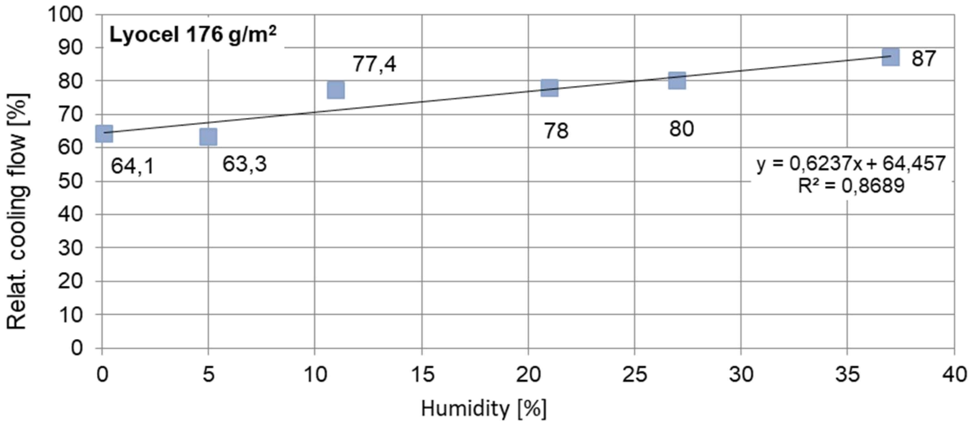

Figure 5 The effect of the fabric relative humidity on the relative cooling flow of the most efficient smooth Lyocel fabric

3.1 Cooling effect of selected smooth fabrics in wet state

Five thin woven fabrics in a plain structure made of cotton (square mass 163 and 95 g/m^2), Lyocel viscose (square mass 175 and 96 g/m^2), PES (square mass 92 g/m^2) and PA nanofibre layer (square mass 5.3 g/m^2) were stepwise wetted and relative cooling flow generated by evaporation water from their surface in the PERMETEST instrument was registered. The 100% relative cooling flow was caused by evaporation of water from the porous surface which simulates human skin.

The objective of this study was the determination of a fabric with the highest cooling effect in wet state, which should be used for design of a comfortable sport dress. As the reference value of the relative moisture *U* of the fabric was 40%, which presents the moisture level when the increased friction between a skin and a fabric starts to cause sensorial discomfort.

The highest relative cooling flow 90% was observed when testing the Lyocel fabric with the square mass 176 g/m^2. The lowest cooling flow 63% was registered for the cotton fabric with the square mass 163 g/m^2. Other fabrics provided the cooling flow in the range from 72 to 79%.

4 CONCLUSION

In the paper, the cooling ability of 6 various knitted fabrics with 4 different surface ribs subject to air flow was investigated. The stepwise wetted samples were inserted into the PERMETEST Skin model with ribs oriented parallelly and perpendicularly to the air flow and the relative cooling flow was recorded. This relative heat flow was then converted (calibrated) into the real cooling flow.

It was found that at low air velocity the ribs did not provide the expected enhanced cooling effect. In the last part of the study the cooling effect of thin wetted woven fabrics was investigated. The highest level was observed for the relatively thick Lyocel woven fabric.

5 REFERENCES

1. Hes L., Dolezal I.: A new portable computer-controlled skin model for fast determination of water vapour and thermal resistance of fabrics, Asian Textile Conf. (ATC 7), New Delhi, 2003
2. Bogusławska-Bączek M., Hes L.: The Effective water vapour permeability of wet wool fabric and blended fabrics, Fibres & Textiles in Eastern Europe 21(1), 2013, pp. 67-17
3. Slancova M.: Knits with enhanced cooling (in Czech), MSc Thesis, TU Liberec, 2018
4. Karakoc Y.: Cooling efficiency of selected fabrics, Research Report, TU Liberec, 2017