EVALUATION OF THERMAL PROPERTIES OF TEXTILE STRUCTURES UNDER FAST FLOWING AIR CONDITIONS

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Abstract: *The subject of this article is the evaluation of thermophysiological comfort of clothing under influence of flowing air. For this purpose a special device has been created, which is capable of generating an air flow of variable velocities. Under these conditions the values characterizing thermal insulating properties of the textile material sample are recorded on a human arm model which is placed in the wind tunnel.*

Keywords: *thermophysiological comfort, thermal insulation, aerodynamic tunnel, fast flowing air.*

1 INTRODUCTION

Nowadays, consumers evaluate not only the visual aspect of clothing, but also its functional properties. As the protection against cold is inherently essential among the basic functional properties, the thermal insulation capability is one of the most important qualities. Therefore, these properties are repeatedly investigated and requested. Thermal comfort is often defined as that condition of mind which expresses satisfaction with the thermal environment. It depends on the heat transfer between the body and the environment [1]. Thermal insulating properties of fabrics can be evaluated by several methods and devices. The individual methods differ from another in terms of measurement, measured values, sample size and for example ambient climatic conditions.

Methods for evaluation of thermal insulation properties are governed by international standards and can be described by basic physical quantities. Internationally recognized methods for evaluation are for example The Sweating Guarded Hotplate, which describes thermal properties using heat resistance R_{ct} [$m^2.K.W^{-1}$], or FOX 314, which describes heat insulating properties using thermal conductivity λ [$W.m^{-1}.K^{-1}$] and thermal resistance R [$m^2.K.W^{-1}$], [2-4]. When searching thoroughly, we can find many other methods and devices for evaluation of thermoisulation of clothing, but all of them observe static ambient conditions. To maintain objectivity when evaluating thermal insulation properties under realistic conditions, it is important to observe as many parameters as possible from a real environment. No one has ever been able to combine all aspects. However, there are many scientific groups that have dealt with partial problems.

The evaluation of materials designed to isolate the human body in extremely cold conditions is therefore more interesting when done at temperatures close to zero or below zero than under normal climatic conditions.

If we deal with performance verification of thermal insulation fillings that are used for outer clothes for cold environments, it is necessary to test thermal properties of batting materials (down and three sophisticated battings) under conditions approaching real weather conditions in Central Europe, where these materials are intended for usage [5]. It has been found, that the thermal insulation of clothes is also very closely related to water vapor permeability [1, 3, 6, 7].

It can be verified that movement of air influences the rate of heat loss from the human body. A moderate breeze can increase the rate of cooling so much that a cool day seems bitterly cold. The concept of "wind chill" was already proven in 1939 to describe the combined effects of wind and temperature. Siple and Passel (1945) later conducted experiments and obtained an equation to predict the rate of cooling as a function of temperature and wind speed [8]. Certain differences were also found when assessing thermal insulation properties at different positions such as siting, walking, etc. This is, of course, also dependent on the precise fit of the garment used [9]. Recent research has been carried out mostly using different models of body parts and also methods using air flow. However, the flow rate it is not possible to change during the measurement [5, 7, 10-12].

The purpose of this paper is the evaluation of thermophysiological comfort of clothing under influence of flowing air. For measuring a special wind tunnel was used, where the intensity of wind can be changed during the measurement without interfering with other set conditions.

2 MEASURING DEVICE

2.1 Description of the measuring device

As can be seen in Figure 1, the measuring system consists of two basic components, the aerodynamic tunnel and the human arm model.

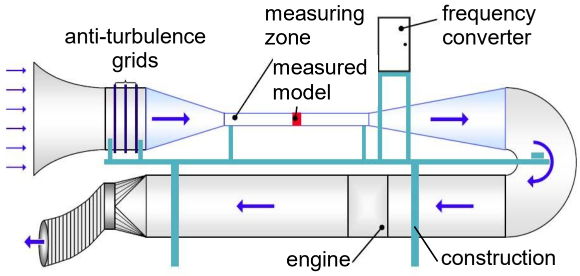

Figure 1 Diagram of the measuring device

The wind tunnel is five meters long. The measurement is carried out in the upper section of the tunnel, which is one meter long, where the required measurement conditions are set and the air flow is adjusted. In the middle of the measuring zone a cylindrical measuring module, representing the human arm, is placed. The model is composed of a heated cylinder, surface of which simulates the surface temperature of the human arm. Around the measured model the sensors are placed at regular intervals to detect the thermal resistance of the fabric.

2.2 Adjusting measurement conditions

The device is controlled by a program built in the LabVIEW programming environment. Thanks to flexibility of the program it is possible to set several important parameters of the air flow specification in the wind tunnel even in course of measurement, which is unique for our model.

The air flow rate is continually controlled and adjusted to maintain the desired value thus obtain more accurate data.

2.3 Model of human arm

The human arm model has a form of cylinder (diameter is 8 cm). In its core is a heater that heats the surface to the temperature of the human body skin. The temperature on the surface of cylinder is 32±0.5°C. Around the cylinder are eight uniformly distributed alphameters (A0-A7). Alphameter is a heat flow density sensor [W/m^2] that can measure the thermal insulation properties of the measured materials. The alphameter A0 is located directly against the air flow (on the windward side of the measured model), alphameter A4 is located on the other side of the cylinder (on the leeward side of the model). The other sensors are distributed at angles of 45 degrees, see Figure 2.

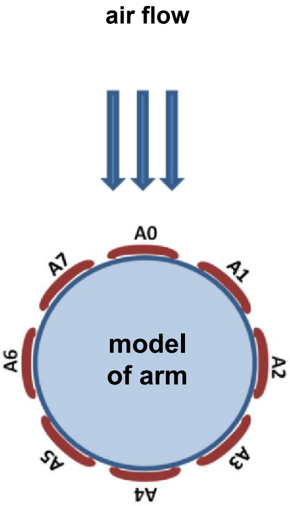

Figure 2 Human arm model with alphameters A0-A7

2.4 Air flow in aerodynamic tunnel

The air flow, which viscosity is very low, becomes quickly turbulent at higher speeds, and such a character is also exposed to a swollen (or flowed) human body.

Within the measurement, an experiment was performed for airflow visualization and human arm model wrapping, as shown in Figure 3. Special smoke was used to visualize the air flowing.

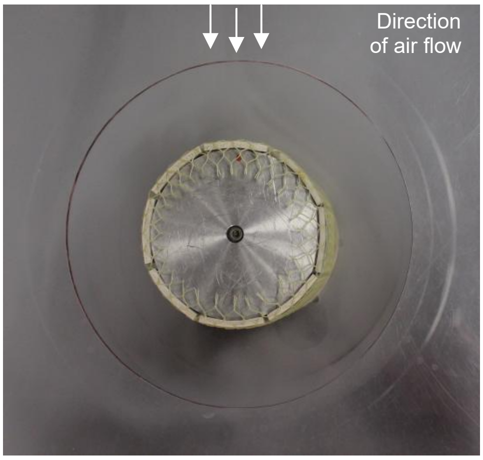

Figure 3 Visualization of air flow in velocity 10 m/s

Figure 3 shows the direction of air flow that affects the individual heat air density sensors. In front of the arm model and on its sides, it is apparent that the air flow is linear at the beginning. By contrast, the A3, A4 and A5 sensors are affected by the turbulence occurring behind the measured model.

3 MATERIALS

Four different types of fabrics were used in experiment. The first one is cotton woven fabric, designed as the working clothes. The material is highly air permeable. The second fabric is fleece knit fabric as a second layer of clothing. Air permeable of this fabric is also high. Third and fourth fabrics are used as outer layers of garments. Their air permeability is insignificant. Table 1 presents the specification of used fabrics.

Table 1 Specification of used fabrics

Sample	Fabric structure	Raw material	Weight $[g/m^2]$
M1	Woven fabric	100% CO	240
M2	Fleece fabric	100% PES	300
M3	Neoshell barrier fabric	100% PAD; 100% PES	129
M4	Softshell Power Shield barrier fabric	50%PES, 38% PAD, 2% Spandex;100% PES	292

4 METHODS

Thermal insulation properties of our group of textile fabrics were measured on the human arm model in the wind tunnel. The airflow intensity in the wind tunnel was changing during the measurement. It was possible to discern differences in heat loss depending on the angle position in the air flow. The positions of the individual sensors in Figures 4, 5 and 6 correspond to the real positions on the model.

Figure 4 shows the variation of the heat flux on the sample M2 at different velocities of the flowing air.

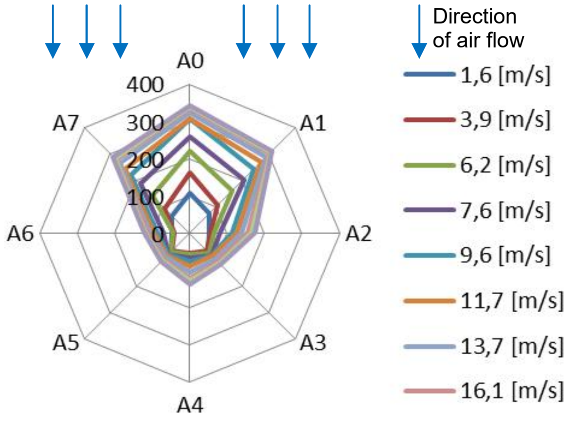

Figure 4 Measuring the variation of the heat flow on the sample M2 at different velocities of the flowing air

Figure 4 shows the difference in the behavior of the heat flux on one material at different velocities of the flowing air. In contrast, Figures 5 and 6 show the difference in thermal insulation properties of all used materials (M1-M4). While Figure 5 was measured at low speed of air flow (2 m/s), Figure 6 was measured at high speed of air flow (18 m/s). It can be deduced from Figures 5 and 6 that while at lower airflow rates the differences in heat loss are not noticeable, at higher speeds, these differences are striking. Behavior of fabrics with a membrane and without differs significantly.

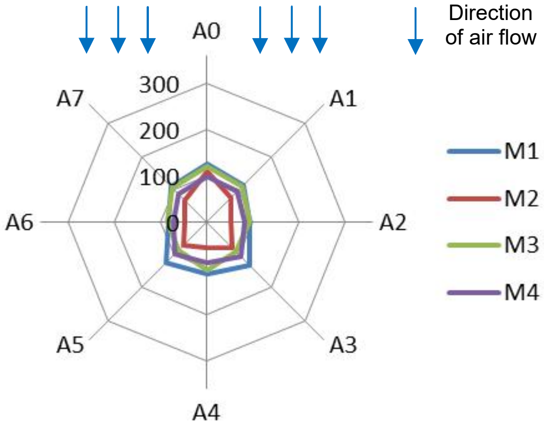

Figure 5 Heat flux at airflow velocity 2 m/s

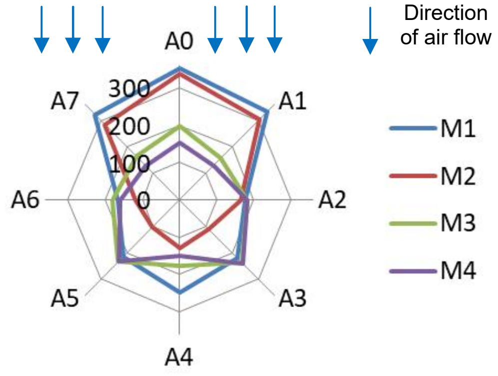

Figure 6 Heat flux at airflow velocity 18 m/s

Figure 7 shows the influence of velocity on the heat flux on the windward side of the measured model.

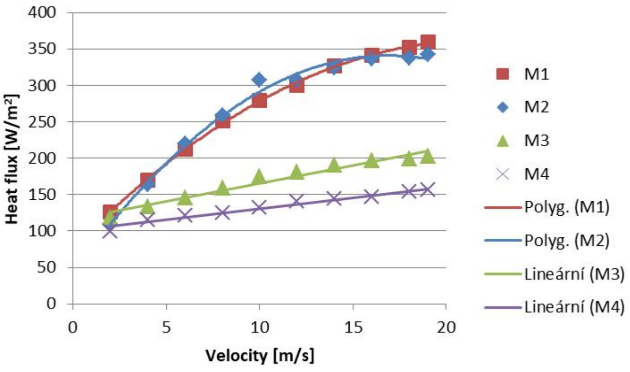

Figure 7 The influence of velocity on the heat flux for windward side (A0)

It can be seen from the Figure 7 that while fabric M1 and M2 behave with polynomial dependence, the values of heat flux and velocity for M3 and M4 show almost linear dependence. For samples M1 and M2 with increasing velocity the sensed heat flux increases much more significantly than the M3 and M4 values. This means that M3 and M4 have passed much less heat away from the arm model to the surroundings. Thus, the body is much less cooled than with M1 and M2 materials even at high airflow. This difference can be explained by the fact that while M3 and M4 materials are designed to protect the body against weather conditions (third layer), the material M1 is intended for the first layer of clothing and the M2 material for the second layer of clothing. Neither M1 nor M2 material does have any wind barrier to keep its breathability as high as possible. The difference between the M3 and M4 materials is due to the fact that the M4 material has an additional thermal insulating layer, whereas the M3 material is only a barrier fabric.

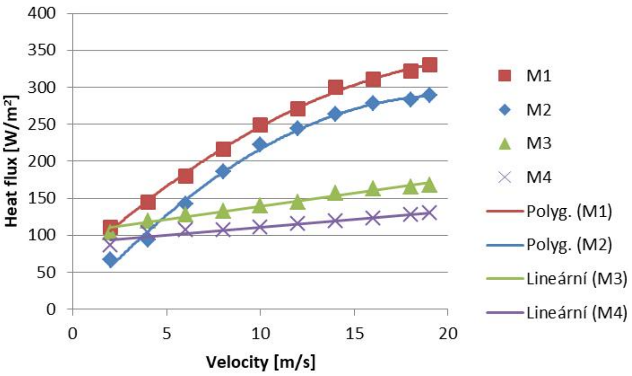

Figure 8 The influence of velocity on the heat flux for alphamether (A7)

As can be seen on Figure 8 the heat flux sensors A1 and A7, which are the first next to the windward sensor (45 degrees), show almost the same course of measurement as the direct windward sensor A0.

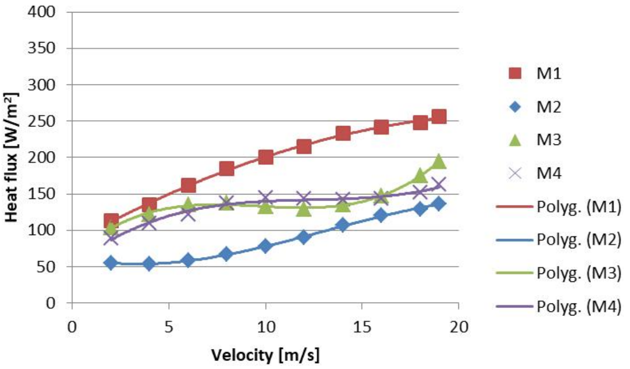

Figure 9 The influence of velocity on the heat flux for leeward side (alphamether A4)

To the contrary, the leeward side of the model (Figure 9) does not show any linear dependence at all. It is apparent on this side of the model that mainly with the barrier textiles (M3 and M4) turbulence caused on the leeward side of the cylinder influences the insulating properties significantly (as was already mentioned in the above chapter).

5 CONCLUSION

Standard methods for measurement of thermal insulation properties can only simulate the perpendicular direction of airflow to the fabric and only one concrete speed of airflow. Our wind tunnel with the human arm model allows an airflow direction which simulates real conditions when wearing clothes. This device also allows to monitor heat loss changes depending on varying airflow speed and depending on the angle of airflow to the fabric.

6 REFERENCES

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