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COMPARATIVE STUDIES OF MEASUREMENT METHODS OF THE COOLING EFFICIENCY OF FABRICS WITH PHASE-CHANGE MATERIALS, DEPENDING ON THE USED TYPE OF THE THERMAL SIMULATORS

ABSTRACT OF DOCTORAL THESIS

During physical activity as well as at rest, the human body produces heat which under conditions of the thermal comfort, should be totally given back to the environment. Due to difficulties in heat exchange, the accumulation of heat in the human body can cause an increase in the internal body temperature. One of the concepts developed for the purpose of protection of the human body, is using clothing elements with Phase Change Materials (PCM), which allow to absorb the heat from the human body allowing to cool it down. This happens when the phase changes from solid to liquid.

Literature analysis has shown an increasing interest in the use of heat transfer characteristics by fabrics containing phase-change materials (PCMs). However, in the science literature, the results of studies of the effectiveness of fabrics with PCM are not clear. Currently, studies are conducted on a variety of research equipment (thermal simulators) and using a variety of test procedures. The lack of a unified research methodology and selected effectiveness indicators for fabrics with PCM, makes it impossible to directly compare the results of available research studies.

The main goal of the PhD thesis was the assessment of the cooling effectiveness of fabrics containing phase-change materials, obtained in studies with different thermal simulators. Furthermore, developed a test procedure which allowed to standardize the results obtained from different simulators.

Two fabrics with PCM were selected for the study, differing mainly in the value of enthalpy of phase change and the reference material without cooling elements. Preliminary measurements were performed to measure their basic properties such as enthalpy of phase change (ΔH), water contact angle (DSA) and density of PCMs application in the fabrics. The analyzes of available methods of measuring the effectiveness of fabric

with PCM were carried out including: the constant value of the heat loss from the thermal simulators, the constant surface temperature and application of simulation of physiological response (using a physiological model). The studies using one-segment Torso simulator allowed to propose one research method, which could be used on all other thermal simulators. The suggested research method assumes constant temperature of the measurement surface.

Principal studies (both in non-isothermal and isothermal conditions) were conducted in a variety of experimental systems on four typical thermal simulators: the hot plate (skin model), two full-size thermal manikins (Diana, Newton) and also one-segment Torso simulator. In the case of the hot plate and Torso, the test fabrics covered the entire measuring surface, whereas in the case of the thermal manikins, they were on the back segments (the best fit to the surface). The measurement surface area for these thermal simulators ranged from 0,04 m^2 to 0,43 m^2. To eliminate the variable associated with the surface area of the fabrics with PCM, the values of the heat loss were converted to measuring surface area (heat flux W/m^2) for each simulator.

Two indicators have been proposed to evaluate the effectiveness of fabric with PCMs: the amount of accumulated heat (calculated from the response of thermal simulators, using the Matlab® program with the Spline Toolbox) and their operating time. Depending on the used thermal simulator, different values of the measured effectiveness of fabric with PCM were obtained. It has been shown that the value of the effectiveness test results with the use of thermal manikins was lower and with Torso was higher than for the hot plate (skin model).

The structural and technological factors (like the power of the simulator, the mode surface temperature control, the frequency of data recording as well as the degree of fitting of the test sample fabrics to the measuring surface of the simulator), as well as, the human factor were indicated as the possible factors that cause the observed differences.

On the basic of the comparative analysis involving both theoretical calculation and obtained results, the hot plate (skin model) was identified as a reference device. Furthermore, the degree of divergence between the results obtained on the reference device and the other simulators (used in the studies) was determined.

Moreover, the research with human subjects (case study) was performed and compared with the results obtained in the studies with thermal simulators. During the study, the changes

of skin temperature or the temperature of outer surface of fabric with PCM were analyzed. The results of the study with human subjects concurred with the determined operating (cooling) time of fabric with PCMs observed in studies with thermal simulators.

The obtained results confirmed the accuracy of the suggested research procedure for testing fabrics with PCMs using various thermal simulators and using a constant surface temperature. It was also recommended to apply research in non-thermal conditions which allow to obtain better simulation of the real conditions of the practical use of the tested fabrics.

The conducted studies using various thermal simulators and performed analyzes of the obtained results allowed to qualitatively and quantitatively determine the influence of the appropriate measuring systems on the results of the effectiveness of the fabric with PCM. On this basis of the relationship between the amount of accumulated heat in the materials with PCMs and the maximum power rating of the heat simulators was developed.

The obtained results will contribute to the global discussion of the need to normalize the research procedure, a problem which is very important both for research and practical purposes.