Substantiation of the Project of an Environment Protection Thermal Protective Product for Disabled People Taking into Account the Impact of Environmental Factors of the Natural and Technical Environment

L G Babenko¹, M D Molev², N Yu Savelyeva³

¹Assistant, «Construction and technosphere safety», Institute of service and business (branch) of Don state technical university in town Shakhty Rostov region, Russia
²Professor, «Construction and technosphere safety», Institute of service and business (branch) of Don state technical university in town Shakhty Rostov region, Russia
³Associate professor, «Construction, Technology and Design», Institute of service and business (branch) of Don state technical university in town Shakhty Rostov region, Russia

E-mail: liana-babenko@mail.ru

Abstract. The article presents the research results of the impact of various environmental factors on the design parameters of heat-protective products for the disabled. It is shown that the assessment of the environmental friendliness and safety of this type of clothing must be considered in the framework of the complex dynamic system «external environment – clothing – people». Detailed attention is paid to the research of the effects of thermo-physical factors on human body of people with limited motor capabilities in negative ambient temperatures. Based on the results of the analysis, a working hypothesis of research has been put forward and confirmed. It was established that the design of a heat-protective product must be carried out taking into account the individual characteristics of the body, which are manifested in the complex elements interaction of the subsystems of the specified system. In the framework of this thesis, the analysis of the relationship of factors is carried out and parametric assessment of the adaptation of the disabled people to temperature variations is given. To justify the choice of material types and structural elements of the product, a mathematical model of heat transfer processes has been developed to provide a qualitative forecast of the thermal state of the human body.

1. Introduction

In modern science, theoretical and experimental studies, which are clearly characterized by the interdisciplinary direction, are successfully developing. The posed problem and the results of the research work described in this article can be attributed to the integrated area of scientific disciplines «Techno-sphere safety», «Human ecology» and «Design of garments». The starting point of the research is the steadily increasing attention of Russian leadership and civil society to the formation of ecologically safe and comfortable living environment for the population on the territory of the country. One of the issues to be constantly monitored by government and public bodies is the creation of the...
so-called «barrier-free environment» for disabled people. So, a special government program was developed, according to which people with limited mobility should be provided with modern rehabilitation products with appropriate characteristics such as functionality, safety, reliable operation and high quality [1]. The authors consider the design and manufacture of comfortable and functional clothing, including clothing for negative ambient temperatures, the most important aspect in the framework of involving disabled people in active life.

The posed problem determines the solution of a number of technical, technological and environmental issues, such as the environmental friendliness of the used materials, heat transfer between the space inside of the heat-insulating product and the surrounding environment. The conceptual diagram of the heat transfer process is shown in Fig. 1.

**Figure 1.** The block diagram of the interaction of human heat transfer with the surrounding environment: HPP – heat-protective product; arrows indicate the direction of exchange flows

A detailed analysis of scientific and technical publications on a range of issues related to the design of heat-protective clothing shows that the amount of conducted research papers is limited. Mostly specialists study the technology of making clothes, the choice of fabric, accessories, comfort, etc. Design issues intended for people with particular disabilities are pointed out in details in scientific publications of Korobtseva N.A., Kozlova E.V., Manukyan K.A. and other scientists involved in research of these aspects. A lot of works is devoted to the design of special clothing for people with limited motor capabilities, as well as to the study of the properties of materials used in the design of rehabilitation products [2-10].

A detailed analytical assessment of all aspects of the problem under study shows that insufficient attention is paid to the issue of heat transfer. Certain issues of people’s thermal protection are considered by Russian scientists Bekmurzaev L. A., Brink I. Yu., Lebedeva, E. O. and some other researchers [11-13]. These authors do not fully take into account factors that primarily affect the microclimate in the so-called «under clothing area» for people with movement impairments. The well-known multi-factorial nature and specificity of environmental risks caused by low temperature and other physical fields in the system «external environment – clothes – people» makes scientists and specialists develop scientifically based complex solutions.

Based on the results of the analysis, the authors of the article consider that it is possible to present the main materials of experimental and theoretical research on the issue of heat transfer, which is directly related to the safety and ecology of human clothing.

**2. Problem statement, hypothesis and research methodology**

The purpose of the presented research work (RW) is a scientific and technical justification of the environmental and safety of the project of heat-protective products for people with motor disabilities. The list of main tasks to achieve the goal should be included the following scientific positions:

– analysis of the relationship of the main factors affecting the state of human environmental comfort;
– assessment of the human’s body adaptation to the deviation of the temperature factor;
– forming a mathematical description of the heat transfer process.

The working hypothesis of research can be expressed in the form of the following thesis. We offer a scientific position: «The design of a heat-protective product, based on the results of the analysis of
the interaction factors and the impact of the internal and external environment on the human body, will ensure comfortable states for people with motor disabilities».

In the course of research work assessing interacted environmental and thermo-physical factors in the system under consideration, the authors came to the conclusion that research work should be based on the following basic provisions:

– analytical and measuring procedures should be carried out with the involvement of a system analysis (SA) of factors and structural elements;
– the object of research is a specific complicated well organized dynamic system «man – environment – heat-protective product»;
– the research subject is the impact of environmental factors on the human body and their sources;
– the research should be carried out by means of a complex of theoretical and experimental methods determining the verification of the hypothesis.

The choice of SA is determined by the requirements of the basic postulates of mathematics and the prognostics theory, which state that the level of the research method should correspond to the complexity of the object (process) under study. In accordance with the status of the research object, a system analysis was selected to provide the highest level of reliability in assessing all physical, environmental, and geometric parameters of the structure under study [14-19].

The research algorithm can be expressed as follows:

– the analysis of environmental factors of under clothing area;
– assessment of disabled people's adaptation to temperature changes;
– mathematical modelling of heat transfer processes.

It is also necessary to point out an important statement of methodological character, namely: the analysis of publications on the research theme led the authors to a fundamental conclusion, according to which a person, the environment and a heat-protective product (clothing) is a single complex system constantly changing in time and space. In the framework of this scientific concept, all the logical relationships of the elements and the processes including their thermo-physical nature should be considered.

3. Results of theoretical and experimental research

In accordance with the stated results of scientific and methodological research, the research tasks were solved. First, the impact of environmental factors on the individual was considered. A complex of environmental and thermo-physical factors can have different effects on a person depending on the level and state of the human body. The so-called «thermal comfort» is considered to be a key factor to a large extent. This is a complex concept to characterize a person’s sensation due to the interaction between the microclimate, the material (fabric) of the heat-protective product and the psycho-physiological state of the body [20].

Thus, the urgent task of clothing designers is the selection of permissible temperature conditions for the disabled for designing heat-insulating products at low ambient temperatures. In the framework of this work, it is necessary to determine a parameter called «physiological zero» to characterize a small temperature range within which there are no thermal sensations.

For these purposes, experimental studies were conducted with the participation of people with various diseases caused by disorders of the musculoskeletal system. All parameters of the experiment were recorded in the initial state of the test subjects in a sitting position, during the experiment at a comfortable room temperature of 24°C, relative humidity (60-65%) and air mobility of not more than 0.1 m/s. To conduct a qualitative experiment, a method for performing research has been developed. Based on the initial results for determining the average surface temperature of the skin of the subjects’ lower extremities, the results of graphs for each defined local area are constructed. The example of such graph is shown in Fig. 2.
Figure 2. The example of a graph of the average surface temperature of human skin.

To determine the reliability of the obtained data and define the required number of tests, statistical processing of the primary experimental data was carried out. The sample size at a confidence level of 0.95 and an acceptable error of 5% was 50 people.

As a result of the analysis of the obtained data, it was found out that the average temperature of the skin surface of the hypo-dynamic system of the lower extremities of healthy people exceeds to 2.2°C in comparison to similar measurements of the disabled.

The complexity of the considered heat exchange process and the inability to take into account the variety of factors in the system under consideration, the introduction of the following restrictions was necessary:

– the lower extremities of a person are considered to be integral part of the whole body, receiving part of the heat from the total heat production;
– comfortable thermal condition of the lower extremities is characterized by the surface temperature of the skin of various parts of the legs;
– cooling of each leg area is considered at the first stage, when the person's well-being is normal, and the thermoregulatory functions are not strained. The skin temperature is not lower than critical, which allows maintaining heat generation at a certain average level;
– clothing that protects the main parts of the human body (trunk, arms) corresponds to the meteorological conditions in which the person is located;
– when using a heat-protective product in winter, evaporation of sweat is not significant in the thermoregulation of the lower extremities, therefore, it is not taken into account when constructing a mathematical model of heat transfer.

According to the results of the analysis, it was concluded that the temperature of the skin of the lower extremities of disabled people, when they feel thermal comfort, is close to the temperature of a healthy person who is situated in a street in winter pants.

Taking into account these limitations, a mathematical description of the heat transfer process in the foot area was performed.

We point out that in order to protect the feet from the cold; heating elements (plates) are provided in the design of the heat-protective products. The heat transfer process in this area can be described by means of using the boundary-value problem for a multilayer plate, including the foot itself, a woolen sock, a heating element and a package of heat-protective materials of a heat-protective product (1):

\[
\frac{\partial T_i}{\partial t} = a_i \frac{\partial^2 T_i}{\partial x_i^2} + \frac{q_v(x_i, t)}{c_i \rho_i}, l_{i-1} \leq x_i \leq l_i, l_0 = 0, i = 1, 2 \ldots n. \tag{1}
\]

The solution of the problem (2) is given in the form of an eigenfunction expansion of the corresponding homogeneous problem by the Fourier method. The Initial conditions are 

\[T_i(x_i, 0) = f_i(x_i).\]
Omitting the intermediate calculations (1), we find the temperature of the i-th layer \( i = 1,2,\ldots n \)

\[
T_i(x_i, t) = \Theta_i(x_i, t) + T_C = \sum_{k=1}^{\infty} \left( \int_0^t Q_k(t) e^{\mu_k x_i t} dt + L_k \right) e^{-\mu_k x_i t} \frac{M_{ik}}{\sqrt{\alpha_i}} + A_{ik} \sin \left( \frac{\mu_k x_i}{\sqrt{\alpha_i}} \right) + T_C \quad (2)
\]

Where \( t \) – is the time, \( h \); \( T_i \) – is the temperature of i-th layer, °C; \( T_C \) – is ambient temperature, °C; \( T_i - T_C = \Theta_i, i = 1,2 \ldots n; \sum_{k=1}^{\infty} \left( \int_0^t Q_k(t) e^{\mu_k x_i t} dt + L_k \right) e^{-\mu_k x_i t} \frac{M_{ik}}{\sqrt{\alpha_i}} \) – coefficients of a number of Fourier; \( \cos \frac{\mu_k x_i}{\sqrt{\alpha_i}} + A_{ik} \sin \left( \frac{\mu_k x_i}{\sqrt{\alpha_i}} \right) \) – custom edge task functions; \( x_i \) – point coordinate of i-th layer; \( M_{ik} \) – eigenvalues.

The resulting control is a mathematical model for predicting the thermal state of disabled people wearing heat-protective products with local heating elements. The described method is quite justifiably and objectively predicted the so-called thermal comfort of a person with limited motor capabilities – temperature criteria.

4. Conclusion
Application of physical and mathematical apparatus, ecology and prognostics to the study of processes taking place in the system of «external environment-clothing-man» allowed us:

– to analyze the factors affecting the microclimate of the under clothing area;
– to assess the adaptation of people with disabilities to temperature changes;
– to perform mathematical modeling of heat transfer processes. It is important to indicate that socio-economic efficiency of this development is confirmed by the practice of using heat-protective products in real conditions. [21].

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