Aspects of applying theory of human ecology to design safe heat-protective clothing for the disabled people

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Abstract. The article discusses current theoretical and practical issues of scientific research based on the interaction of environmental and technogenic factors in the development of safe heat-protective clothing models for people with restricted motor abilities. In particular, the main results of studying the interaction of elements and objects belonging to the dynamic system «human – habitat – heat-protective clothes» are presented. The purpose of the work was to justify the choice of structural clothing materials with the help of using obtained analytical information on thermal field formation of under clothing space area. The relevance of the described studies is due to the permanently increased demand for special heat-protective products for the disabled and insufficient knowledge of multi factorial environmental processes in spatio-temporal coordinates. The scientific novelty of the presented work consists in solving the problem based on the analysis of the interaction of human lower limbs and heat protective clothing by means of using the author's mathematical model. To carry out the research, modern mathematical methods were used, including system analysis, synthesis of alternatives, modeling, generalization and results verification. The obtained materials develop the theory of applied areas of human ecology. The implementation of the above stated recommendations in the practice of heat protective clothing design contributes to a process of people's socialization with restricted motor abilities.

1 Introduction

According to the 1993 Constitution, the Russian Federation is a socially oriented democratic state. One of the main provisions of the basic law in our country is the right of all citizens to accessible and safe living environment conditions. At the same time, all components of the living environment, including human clothing, must be safe. This key idea of eco-friendly and safe clothing served as the starting point for the research presented below. Based on the theses presented above, the authors consider that it is necessary to express their view on the environmental aspects of creating heat-protective clothes for

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people with disabilities. One of the main reasons for stating the problem is that in Russian society there is a significant and permanent need to involve people with disabilities having limited motor capabilities in the full social life. At the same time, according to official statistics, this group of disabled people in Russia has counted about four hundred thousand citizens.

The second major reason that prompted the authors to carry out scientific research is the need to develop theoretical and practical aspects of designing heat-protective clothing for people with restricted motor capabilities (PRMC).

A lot of scientific and technical works done by domestic and foreign authors on the problem related to the design and construction of special clothing for the disabled have been published in the open press [1-8]. Significant publications determining the main direction of scientific research should include the works of Bekmurzaev L. A., Brink I. Yu., Korobtseva N. A., Savelieva N. Yu., Cherunova I. V., Kromer R., Rossignoly I. and many others. The research works of these scientists make a significant contribution to the development of theoretical and practical issues of designing heat protective clothes.

At the same time, a detailed analysis of existing scientific publications shows that insufficient attention is paid to environmental issues of designing special clothes for the disabled. According to the authors, it is necessary to be guided by an integrated approach to solving the problem based on environmental analysis.

It is known that human ecology is a system of scientific concepts to perform an integrating function, being a general scientific methodology for the study of objective relations in the logical construction chain «human-habitat». In the context of the presentation, it is appropriate to give the classification of the scientific discipline «Human Ecology», as it is shown in Fig.1.

Fig. 1. Main directions of the scientific discipline «Human Ecology».

From the given scheme, it follows that the issues of designing safe and comfortable clothes for the disabled belong to the sphere of applied ecology.

Based on the results of a detailed analysis of the problem, the authors consider it is legitimate to present the results of theoretical and experimental studies in the given work. The main goal is to analyze and justify the eco- physical and thermo- physical characteristics which are typical for people with disabilities.

2 Materials and Methods

The choice of methods and techniques of scientific research significantly depends on the goals, the real environmental and technogenic situation and the desired quality of the interpreted materials. As part of the assessment of environmental and thermo- physical factors accompanying the processes of interaction in the system of «human (PRMC) –

habitat» the authors analyzed the contents of fundamental and applied publications on the problem, regulatory and methodological documents that are available to users of Russian and foreign scientific and technical literature.

In the process of theoretical analysis, a working hypothesis was put forward, according to which an adequate full-scale assessment of the elements of the system under study and their relationships can be obtained only by means of a comprehensive study of the processes and dynamic behavior of environmental-technical (technological) factors. In this case, such basic organizational and technical conditions are pointed out as:

- a systematic approach to organizing measurements and processing the obtained results;
- correspondence of analytical and measuring methods to the complexity of the evaluated object (process or phenomenon);
- implementation of the whole complex of works in a logical sequence is strictly determined by the objectives of the work [9, 10].

Based on the stated fundamental principles, it was decided to use integrated system analysis (ISA), which is described in details in scientific papers [11-13]. At the same time, the use of ISA, according to the indicated publications, provides a detailed objective study of all physical and spatio-temporal parameters of the complex dynamic object under consideration, the model of objects and processes interaction occurring in a real situation can be depicted in Figure 2

Fig. 2. Block scheme of interaction between elements of the «human–habitat–heat-protective clothing» system.

It is quite legitimate to state that the proposed logical scheme is consistent with the laws of physics and the theory of mathematical analysis with sufficient accuracy for practice. Synthesis of alternatives (choice of alternative solutions) when used together with the ISA and methods of long-term forecasting allows developing an optimal solution of the problem, taking into account the following basic elements:

- the most likely forecast for the development of thermo-physical processes;
- material of heat-protective clothes
- design of the adaptive heat protective product.

Mathematical statistical techniques and mathematical process modeling were also used in research work. Statistical methods were used by the authors to process the results of an experiment aimed at determining the degree of influence of materials on the skin temperature of the person’s lower limbs. Special attention was paid to the assessment of thermo-physical factors, because the temperature has a significant impact on other indicators of the local microclimate in the under clothes space area and the state of the PRMC.

Experimental studies were conducted under real microclimatic conditions – at temperatures ranging from minus 15°C to 0°C involving people with disabilities as testers. During laboratory tests, the values of the skin surface temperature of the person’s lower limbs were determined when using a heat protective article with different combinations of insulation materials. At the same time, in addition to quantitative parameters, the qualitative indicator of comfortable health state of PRMC – so-called their «heat perception» was also estimated. The volume of experimental work amounted to thirty-three tests, which, according to the theory of mathematical statistics, is sufficient for the reasonable conclusions based on the results of the analysis [14, 15].

3 Results

As mentioned above, the main goal of the research was to analyze the interaction of environmental and thermal factors in the «human-habitat» system to justify the characteristics of materials and elements of special clothing for disabled people. In order to achieve this goal, an algorithm for selecting the characteristics of a thermal protection product based on the analysis of theoretical materials and experimental results was developed (Fig. 3).

Fig. 3. Algorithm for selecting the characteristics of a heat-protective product.

In the process of substantiating a set of structural characteristics, the analysis of indicators of the impact of environmental factors was made, in particular temperature values, within the under clothing space area with the relevant criteria established by regulatory documents.

To obtain the primary characteristic of the selected packages of materials, the thermal resistance R_T was calculated using reference values of the thermal conductivity coefficients of materials λ . In the case of a single-layer package, the thermal resistance is determined by the formula (1)

$$R_{\tau}=\delta/\lambda, \tag{1}$$

Where δ – is layer thickness, m; λ – coefficient of thermal conductivity, W/m·°C.

The parameter R_{τ} characterizes the heat transfer process in the internal environment (structure) of the material. The heat-protective property in this case is directly dependent on the value of thermal resistance. The thermal values of conductivity coefficients of each of the materials included in the package of heat-protective products (foot bag), as well as the thermal resistance of each material are presented in table 1.

Table 1. Thermal resistance of the studied materials for PRMD clothes.

№	Package material name	Heat resistance, (m ² ·°C /W)
Basic materials		
1	membrane material	0.030
2	Raincoat material «Duspo»	0.024
Gasket (insulation) materials		
1	Sintepon	2.301
2	Tinsulate	0.453
3	Hollofiber-SOFT	0.832
Lining material		
1	Fleece	0.230

The obtained values of thermal resistance in the subgroup «basic materials» are higher for the brand «membrane materials», in the subgroup gasket (insulation) materials, the highest indicator has sintepon. Based on the results of the detailed analysis, a package of materials was selected demonstrating the best thermal protective properties and was constructed from a membrane insulation of «Tinsulate» brand and fleece lining.

For the purpose of scientifically based confirmation of the adopted decisions, the authors applied the mathematical modeling of the thermal state of the disabled people with restricted motor capabilities in the developed design.

The constructed mathematical model predicting the state of the disabled people with restricted motor capabilities in the heat protective products can be described by the formula (2):

$$\begin{aligned} T_i(r_i,t) &= \theta_i(r_i,t) + T_C \\ &= \sum_{k=1}^{\infty} \left(\int_0^t Q_k(t) e^{\mu_k^2 t} dt + L_k \right) e^{-\mu_k^2 t} M_{ik} \\ &\quad + \left(J_0 \left(\frac{\mu_k r_i}{\sqrt{a_i}} \right) + A_{ik} Y_0 \left(\frac{\mu_k r_i}{\sqrt{a_i}} \right) \right) + T_C, \end{aligned} \tag{2}$$

where t – is time, min.; T_i – temperature of the i-th layer, °C; T_C – ambient temperature, °C; J_0, Y_0 – zero-order Bessel functions of the first and second kinds

Using the above pointed formula, we determined the dependence of the skin surface temperature of the person’s lower limbs in heat-protective clothes on the ambient temperature for a specific period of time. The application of this method allows you to

reliably predict the so-called «thermal comfort» of a person with restricted motor capabilities as determining temperature criteria. The conditions, order and results of the analytical procedure are described in details in a previously published article [16]. In the context of the presentation of the question, we demonstrate Figure 4, which shows the predicted dependences of the tested disabled people's skin temperature on the time of using the product at an ambient temperature of minus 15°C.

Fig. 4. Graphs of the dependence of the skin temperature of PRMC on the time of using the product: a – in the area of the knees; b – in the area of the foot.

The forecast curves constructed with the help of the simulation results allow us to determine the so-called «critical point», that is, the freezing point of the lower limbs of the disabled, with sufficient reliability and accuracy in the coordinate system «temperature-time». Comparative analysis showed that the forecasting results are confirmed by experimental data by the conclusions of the analysis [16].

4 Discussion

The application of modern mathematic methods together with the fundamental principles of human ecology to the study of processes taking place in the considered dynamic system «human –habitat– clothes» allowed the authors of the article:

To determine the nature of the interaction of heat-protective products, the environment and people with restricted motor capabilities from the standpoint of ecology and thermal physics;

-to develop an algorithm for selecting heat-protective product characteristics for disabled people with restricted motor capabilities;

-to establish the dependence of the disabled surface skin temperature in heat-protective clothes on the ambient by means of using mathematical modeling

- to make reliable prediction of thermal comfort for people with PRMC.

In the context of the discussion, it is important to indicate that the subsequent practice of using the results of this research work in the design of heat-protective clothing has confirmed the reliability of theoretical conclusions [16].

5 Conclusions

The scientific developments presented in this article allow carrying out the design of heat-protective products for people with motor restrictions based on analytical calculations and modeling that are environmentally sound.

As practice has shown, the use of predictive information obtained by means of modeling data ensures the adoption of the optimal technological solution, the effectiveness of which is 10-15% compared to other methods.

Thus, verification of developed temperature dynamics forecasts with the help of using the described modeling technique showed the validity of the authors' working hypothesis. According to the results of comparative analysis of forecasting and selecting actual materials, the reliability of forecast data is 80%.

In order to further development of theoretical ideas about the interaction of elements and factors in the system «human (PRMC) – habitat – heat –protective product», the authors plan to improve the methodological apparatus of environmental modeling. In particular, the development of a software application package for evaluating results seems to be an urgent issue.

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