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USE A SMARTPHONE APP FOR PREDICTING HUMAN THERMAL RESPONSES IN HOT ENVIRONMENT

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The object of this study is to predict of human thermophysiological state in hot environment to prevent heat stress or heat stroke. A key issue is the need to design effective tools for heat stroke risk assessment taking into account environmental conditions, physical activity, characteristics of human clothing and protective equipment.

A mobile application has been developed, which, unlike existing analogs, provides users with data on the safe time of human under selected environmental conditions. The mobile application uses the method of mathematical modeling to predict important indicators of human thermophysiological state: body temperature, sweat evaporation, body water loss. The mathematical model takes into account the generation of metabolic heat, the transfer of heat inside the body, and the heat exchange of a human with the environment.

This paper reports the results of using a mobile application for predicting human thermal responses under hot environmental conditions. With the help of the application, it was possible to determine the time of a human's safe stay depending on the intensity of his/her activity and the characteristics of his/her clothing. It is shown that walking at a speed of 6 km/h in a military uniform is safe for 1 hour at an air temperature of 36 °C. Running at a speed of 8 km/h under such conditions becomes risky already after 15 minutes due to overheating of the human body.

The developed information technology is designed to warn about heat stress or heat stroke of people who are under hot conditions in order to preserve their health and work capacity. The received predicting data should be considered as one of the theoretical measures to prevent human heat stress under hot environmental conditions

Keywords: model, physical activity, heat stress, extreme environment, health risk

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1. Introduction

More than 3 billion people on the planet are vulnerable to the effects of global warming [1]. The increase in temperature has led to an increase in cases of heat stress and related diseases [2]. Although the human body adapts to certain changes in temperature, conditions often arise that pose a real threat to human health. For example, during the abnormally hot weather in Japan in July 2023, when daytime temperatures reached 39 °C for a week, 8,189 people were hospitalized for heatstroke. According to the data of the Japanese Agency for Combating Fires and Natural Disasters, this number doubled from the corresponding period of the previous year [3].

Climatic changes affect the nature and speed of human thermoregulatory responses, which are aimed at counteracting heat stress, heat stress, or heat stroke. Heat stress is especially risky for people who are forced to work outdoors. Thus, during the Sydney Marathon on September 17, 2023, about 26 participants were admitted to the hospital, and another 40 needed medical assistance due to heat stress [4]. The main reason was the air temperature of 32 °C, atypical for the beginning of spring.

Careful selection of clothing is also critically important to prevent overheating and dehydration of the human body under hot environmental conditions. This problem arises not only in everyday life but also during sports competitions or military activities.

In order to prevent heat stress under hot conditions, mathematical models of energy processes of heat exchange and thermoregulation of a human in the open air [5, 6] and indoors [7] are used. Taking into account environmental conditions, the level of physical activity and thermophysical characteristics of clothing is a necessary task.

The significant spread of mobile devices makes it expedient to develop and implement mobile applications in the field of health care. The combination of mobile devices with modern mathematical models of human physiological systems makes it possible to make timely decisions regarding the prevention of human health risks depending on physical activity and clothing.

2. Literature review and problem statement

Mobile and web applications combined with fitness bracelets and smart watches make it possible to monitor human physiological indicators and environmental conditions to assess heat stress [8]. They are used to track the intensity of physical activity, heart rate, water needs and consumption, calories burned, blood oxygen content, and others. The issues of integration of these data with information about weather conditions for a comprehensive assessment of a human's functional state remain unresolved. The reason for this is the technical limitations of wearable devices for measuring meteorological data. A possible solution is the collection and analysis of information from various sources – mobile devices, external sensors, and weather services.

This is the approach used in work [9] to assess the influence of ambient temperature on human thermal comfort in real time using a smart watch. It has been shown that it is possible to predict the internal temperature of a human's body based on heart rate, wrist skin temperature, and air temperature. However, issues related to the assessment of physiological reserves and preventive warning regarding the possible risks of overheating and dehydration of the human body remained unresolved. The reason for this may be the limited capabilities of smart watches for comprehensive analysis of human thermal stress. An option to overcome these difficulties may be a combination of a smart watch and external sensors with mathematical models of human thermoregulation.

Work [10] reports the results of research on methods for assessing human heat stress for the purpose of preventing diseases and injuries in industry, military activities, professional sports, and during active recreation. It is shown that in order to predict the consequences of a human's stay under hot conditions, it is necessary to take into account all aspects of heat generation in the body and all ways of heat exchange between a human and the environment. However, issues related to the comprehensive consideration of various factors that affect heat stress, such as environmental conditions, physical activity, and clothing, remain unresolved.

The reason for this may be objective difficulties associated with a large number of variables involved in the processes of heat exchange and thermoregulation of a human. An option to overcome these difficulties can be the use of mathematical models according to the ISO 7933 standard [11]. This standard provides an opportunity to assess the influence of the environment, clothing, and physical activity on thermal responses and to determine the maximum time of a human's safe stay under these conditions.

HuTAS, PHS, and ClimApp applications for predicting the thermophysiological state of a human were developed using mathematical models according to ISO 7933.

The web application HuTAS (Human Thermal Audit Simulator) [12] allows one to view the dynamics of the temperature of internal organs, changes in perspiration and general moisture loss by the human body. The generation and removal of heat into the environment during 8 hours of physical activity is shown. Among the results of the application is the UTCI index (Universal Thermal Climate Index) [13].

The PHS (Predicted Heat Strain Ca) mobile application was developed by the University of Queensland [14]. This application uses the PHS mathematical model to predict the internal body temperature and total water loss of the human body under different environmental conditions and with different physical activities. The PHS mobile application is available under the IOS operating system.

The mobile application ClimApp [15] provides warnings about the threat of heat stress during indoor and outdoor activities. The application is based on a mathematical model of human thermoregulation. Indoor conditions are set manually, and climatic conditions are provided by weather services. The authors of the application developed the heat stress index "ClimApp Index". It takes into account temperature and air humidity, wind speed, intensity of solar radiation, human clothing, and level of physical activity [16]. The result of the simulation is the 12-hour changes in the ClimApp Index and UTCI indices.

Available mobile and web applications for predicting human functional status show changes in core body temperature, total water loss, and heat stress indices over a long period of time. However, the question of the safe time of a human's stay under extreme hot conditions, taking into account the intensity of physical activity and the biophysical characteristics of clothing, remained unresolved. Thus, it is appropriate to conduct a study aimed at assessing a human's physiological reserves and determining the safe time of his/her stay under hot environmental conditions.

3. The aim and objectives of the study

The purpose of our study is to evaluate the influence of a hot environment, protective clothing, and physical activity on human thermal responses using a mobile application for Android OS. The use of a mobile application will provide an opportunity to avoid the risks of heatstroke and determine the safe time of a human's stay under the selected conditions.

To achieve the goal, the following tasks were set:

– to develop a mobile application based on a mathematical model of human thermal responses under hot environmental conditions;

– to perform a theoretical study of the human condition under hot environmental conditions with different physical activity using the developed mobile application.

4. Materials and methods

4. 1. Information technology architecture

The object of our research is information technology for predicting the human condition under hot environmental conditions. The developed technology has a client-server architecture. The client part of this technology consists of the Health Risk Prediction mobile application, which makes it possible to input, initially monitor, and transmit data to the server, and then receive and display the results on the smartphone screen. The mobile application is developed in the Java programming language for the Android OS operating system. This operating system is actively developing and is the most common among smartphone manufacturers and users. According to the statistics website, 70 % of users chose Android mobile devices [17].

The cloud-based server part of this technology consists of a data flow management program, a mathematical model, and a database. The server part is written using the Java programming language. The server handles data received from client applications, namely the authorization process, saving changes to human data, modeling and saving predicting results.

The server allows simultaneous processing of requests from a significant number of clients. The server hosts a MySQL database for registering and saving human data of customers.

The most important part of information technology is the mathematics of human thermal responses under hot environmental conditions. The model is implemented in the form of a computer module written in the object-oriented programming language C++. The principle of modular construction of information technology makes it possible to divide a complex system into subsystems of different levels with numerous initial variables and parameters, which simplifies scaling and integration of new models in the future.

4. 2. Mathematical model of human thermal responses under hot environmental condition

The main hypothesis of the study assumes that prediction of the human condition can be performed using a dynamic mathematical model of human thermal responses implemented in a mobile application [18–23]. This scientific approach provides a quantitative assessment of complex physiological processes of thermoregulation and heat exchange in the human body.

The dynamic mathematical model consists of passive and active parts of human thermoregulation.

Passive part. The method of multicompartmental modeling is based on the division of the human body into compartments, each of which corresponds to a part of the body, an organ, or a group of organs or tissues. The compartment has a cylindrical shape to describe body parts and a spherical shape to describe processes in the human head. The division of the system into elementary units is carried out taking into account the main functions of the site. An elementary unit (compartment) has properties inherent to the entire organism: a source of energy, generation and transfer of heat, interaction with neighboring compartments and the surrounding environment. The set of compartments and the establishment of connections between them determines the nature of the approximation of the anatomical shape of the human body and the physiological processes occurring in it. The degree of approximation of models is determined by the tasks of using modeling.

The model takes into account dynamic temperature changes and physiological responses of a human during physical activity in hot air conditions.

Heat generation, heat transfer, and heat exchange with the environment:

$$c_{ij}m_{ij}\frac{dT_{ij}}{dt}=M_{ij}+M_{ij}^{a}+Q_{ij-1}^{k}-Q_{ij}^{k}-Q_{ij}^{b}-$$
$$-Q^{rw}\pm C\pm R-E\Big|_{i=\overline{1,N};\,j=\overline{1,n}}, \qquad (1)$$

$$V_b\rho_b c_b\frac{dT_b}{dt}=\sum_{i=1}^{N}\sum_{j=1}^{n}w_{ij}\rho_b c_b T_{ij}-W\rho_b c_b T_b-$$
$$-\tilde{V}\rho_{air}r\left(y_{ex}-y_{in}\right)-\tilde{V}\rho_{air}c_{air}\left(T_b-T_{air}\right), \qquad (2)$$

where *T* is temperature, °C; *t* – hours; *c* – specific heat capacity, kcal/(kg·°C); *m* – mass, kg; *M* –metabolic rate, W; *Q* – heat flow, W; *V* – volume, l; ρ – density, kg/m^3; *w* – blood flow, l/h, *W* – cardiac output, l/h; *C* – convection, W; *R* – radiation, W; *E* – evaporation, W; $\tilde{V}$ – pulmonary ventilation rate, l/h; *r* – specific heat of vaporization, kcal/kg; *y* – moisture content (mass amount of water vapor in the air, relative to the mass of dry air). Indices: *b* – blood; *a* – physical activity; *k* – conduction; *air* – air; *rw* – heat loss by respiration; *ex* – exhaled air; *in* – inhaled air; *i* – body part number; *j* – compartment number; *N* is the number of cylinders; *n* is the number of layers in the cylinder.

Active part. During a human's stay under hot conditions, two main thermoregulatory responses occur, which should ensure effective heat transfer to the environment, namely: a change in blood flow in the skin and sweat evaporation from the skin surface [23]:

$$W_s=W_s^{*}-k_{br}^{w}\left(T_{br}^{*}-T_{br}\right)-k_s^{w}\left(T_s^{*}-T_s\right), \qquad (3)$$

$$E=E^{*}-k_{br}^{e}\left(T_{br}^{*}-T_{br}\right)-k_s^{e}\left(T_s^{*}-T_s\right),\ \text{if } T_{br}\geq T_{th}, \qquad (4)$$

where *W* is blood flow, l/h; *k* – sensitivity coefficient of the thermoregulation center to changes in brain and skin temperature; *E* – evaporation of liquid from the surface of the body, W; T_{th} is the threshold of the thermoregulatory center, which is assumed to be 37.3 °C in the model. Indices: * – initial value; *w* – blood flow; *e* – evaporation; *br* – brain; *s* is skin.

In general, the model operates with more than 500 parameters, constants, and variables that characterize the processes of heat generation and regulation in the human body during a stay under hot environmental conditions.

4. 3. Validation of the model for human thermal responses

The validation of the mathematical model of human thermal responses was confirmed by comparing the simulation results with the measurement data given in [24], which reports the results of a study in which the internal temperature of a human during physical exertion was measured using a radio capsule. 14 volunteers participated in the study. They exercised in a special chamber maintained at 35.5 °C and 54 % relative humidity for 45 min on a treadmill in running clothes.

The mathematical model of human thermal responses made it possible to reproduce the conditions of the research given in paper [24]. The simulation results are in good agreement with the internal temperature dynamics measured by the radio capsule (Fig. 1).

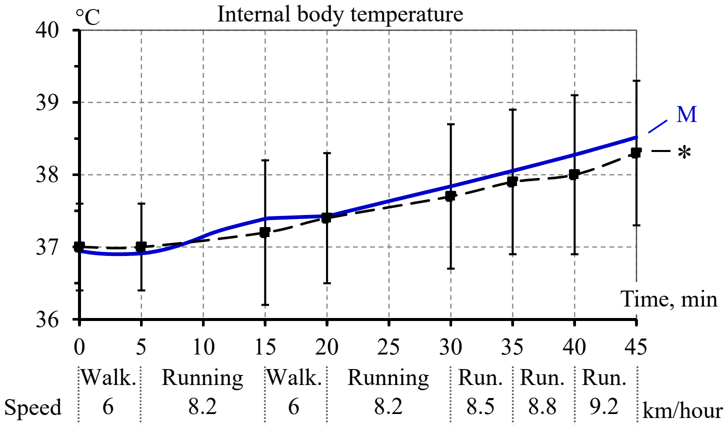


Fig. 1. Internal body temperature: M — simulation results, * — measured data [24]

Table 1 gives a comparison of the simulation results and the average values of the measured internal body temperature specified in [24] at the end of each stage of physical exercise.

The Theil index is close to zero, which indicates the similarity of calculated and measured data. The Student's t-test value of 1.854 is less than the critical value of 2.37 for degrees of freedom 7 and the significance level of 0.05, so the differences between calculated and measured data are not statistically significant.

Table 1

Comparative analysis of simulation results and measured data

Time, min.	Internal body temperature, °C		Temperature difference, °C
	Modeling results	Measured data [24] – Mean Value±VCR	
0	36.942	37±0.6	–0.058
5	36.912	37±0.6	–0.088
15	37.391	37.2±1	0.191
20	37.428	37.4±0.9	0.028
30	37.84	37.7±1	0.140
35	38.052	37.9±1	0.152
40	38.274	38±1.1	0.274
45	38.518	38.3±1	0.218
Average			0.107
Standard deviation, °C			0.163
Student's t-test			1.854
Theil index			0.0031

4. 4. Connection of a smartphone with a mathematical model

Users of the mobile application can conduct research on a mathematical model of human thermal responses under hot environmental conditions. The smartphone communicates with the server through a telecommunications network using a network socket on the server side. The server program waits for client sockets to connect and responds to client requests.

Four types of requests are implemented:

1) checking the connection between the client and the server;

2) user authentication and registration;

3) management of human data;

4) inputting data for modeling.

The answers to these requests are:

1) confirmation or non-confirmation of server availability;

2) confirmation or non-confirmation of user authorization/registration;

3) confirmation or non-confirmation of changes to human data;

4) display of simulation results.

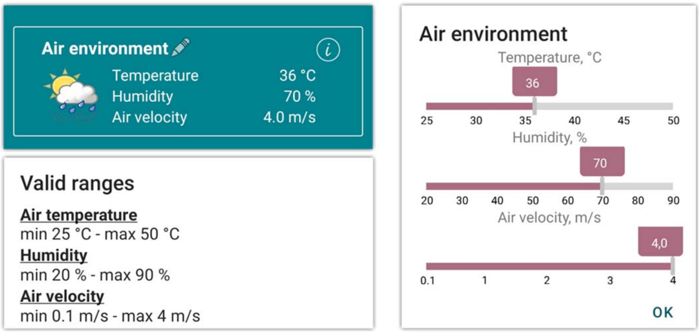
The Transport Control Protocol [25] is used to exchange information between the client and the server. Protection of confidentiality and integrity of messages exchanged between the client and the server over the network is ensured by the Advanced Encryption Standard 128 [26]. The client part requires the version of the Android operating system 7.0 and higher to work. The minimum requirements for the operation of the server part are Windows 10, RAM of at least 4 RAM, and additional disk space of 10 GB.

5. Results of predicting the human condition under hot environmental conditions

5. 1. Mobile application

The mobile application predicts a human's thermal responses taking into account environmental conditions, the level of physical activity, and clothing characteristics.

The user inputs environmental conditions, which include temperature in the range from 25 °C to 50 °C, humidity from 20 % to 90 %, and air velocity from 0.1 m/s to 4 m/s, by moving the corresponding sliders (Fig. 2).



Air environment

Temperature 36 °C
Humidity 70 %
Air velocity 4.0 m/s

Valid ranges

Air temperature
min 25 °C - max 50 °C
Humidity
min 20 % - max 90 %
Air velocity
min 0.1 m/s - max 4 m/s

Air environment

Temperature, °C: 36
Humidity, %: 70
Air velocity, m/s: 4,0

Fig. 2. Interface for environmental conditions input

There are several sets of clothes to choose from:

– Mode 1 (T-shirt, shorts, and running shoes);

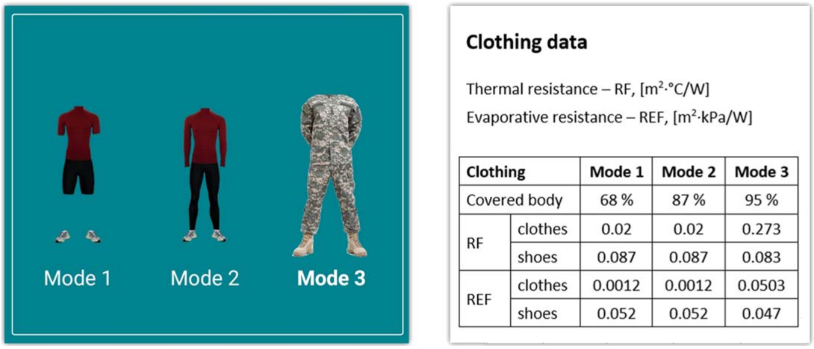
– Mode 2 (long-sleeved T-shirt, pants, and running shoes);

– Mode 3 (military uniform and leather shoes).

Each set of clothing has its specific biophysical characteristics: thermal insulation and evaporation resistance (Fig. 3). Characteristics of clothing for Mode 1 and Mode 2 sets: single-layer knitwear, composition 30 % viscose and 70 % cotton, thermal insulation 0.02 m^2·°C/W, evaporation resistance 0.0012 m^2·kPa/W. Characteristics of running shoes: thermal insulation 0.087 m^2·°C/W, evaporation resistance 0.052 m^2·kPa/W. The characteristics of clothing are selected from the data of the International Organization for Standardization – ISO 7933 (2018) [11]. The military uniform from the Mode 3 set is characterized by thermal insulation of 0.273 m^2·°C/W and evaporation resistance of 0.0503 m^2·kPa/W [19]. Thermal insulation and evaporation resistance of leather shoes are equal to 0.083 m^2·°C/W and 0.047 m^2·kPa/W, respectively. The user can change the characteristics of clothes for each of the sets according to the standard (Fig. 3).

The type, duration, and intensity of physical activity are specified (Fig. 4): walking (253–828 W), running (586–1465 W), exercise (180–1600 W), rest (180 W).

The result of using the application is a conclusion about the safety or danger of a human for the selected time of being in a hot environment during physical activity.

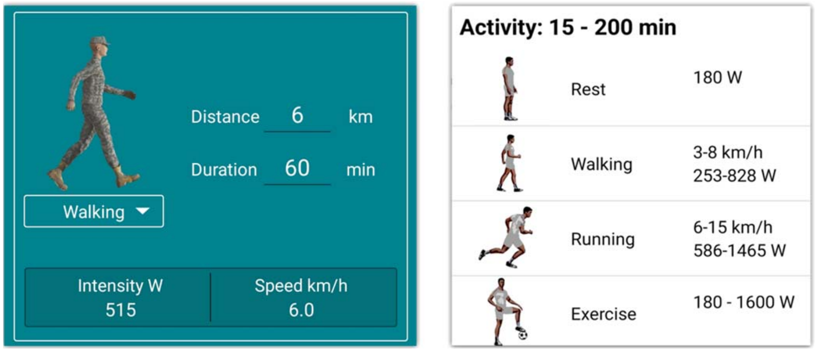


Clothing data

Thermal resistance – RF, [m²·°C/W]
Evaporative resistance – REF, [m²·kPa/W]

Clothing		Mode 1	Mode 2	Mode 3
Covered body		68 %	87 %	95 %
RF	clothes	0.02	0.02	0.273
	shoes	0.087	0.087	0.083
REF	clothes	0.0012	0.0012	0.0503
	shoes	0.052	0.052	0.047

Fig. 3. Interface for cloth input



Distance 6 km
Duration 60 min
Walking
Intensity W 515
Speed km/h 6.0

Activity: 15 - 200 min

Rest	180 W	
Walking	3-8 km/h 253-828 W	
Running	6-15 km/h 586-1465 W	
Exercise	180 - 1600 W	

Fig. 4. Interface for physical activity input

5. 2. Mobile application use to predict human thermal responses in hot environment

Human activities are often happened during intensive physical activity in hot environment [27, 28]. Combined with clothing, this can cause an increase in the body's internal temperature and cause heat stress.

Below are the results of a theoretical prediction of a human's stay under hot conditions: air temperature 36 °C, humidity 30 %, wind speed 3 m/s (Fig. 5, *a*). The conditions were selected according to the actual weather data in Ukraine in the Kherson region in July 2023.

Comparative experiments with different physical activity were conducted:

a) walking, distance 6 km, time 60 minutes, intensity 515 W (Fig. 5, *b*);

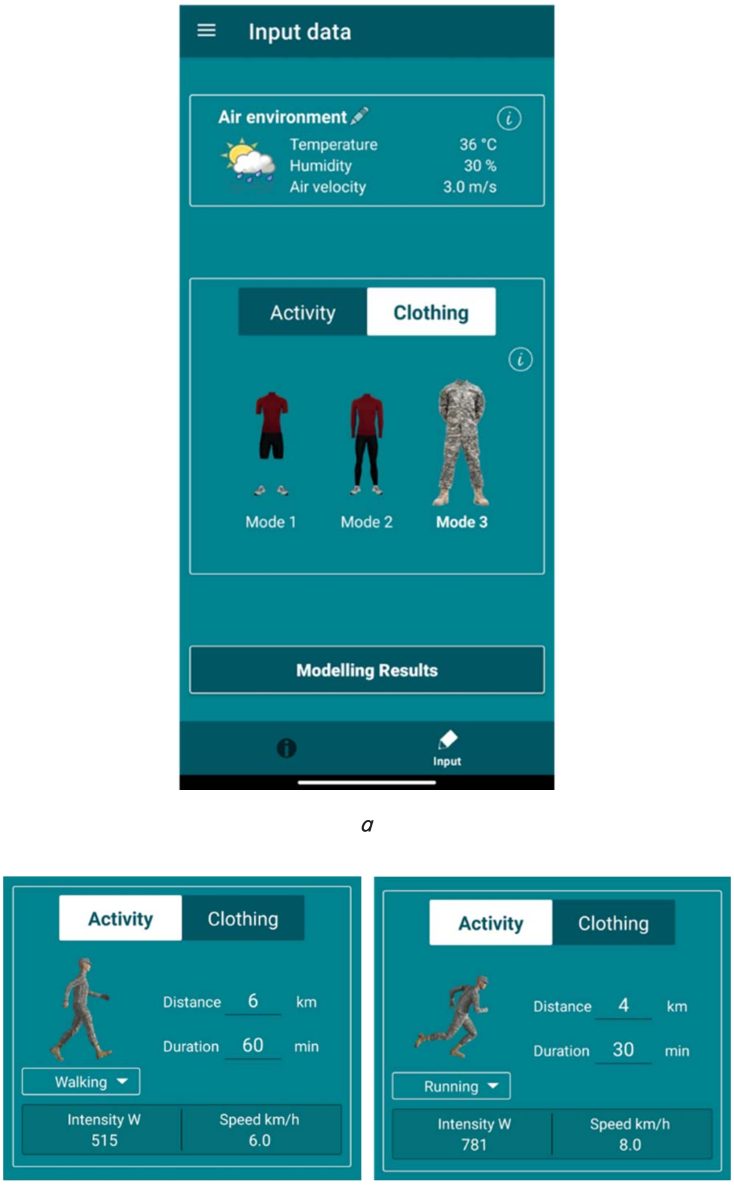
b) running, distance 4 km, time 30 minutes, intensity 781 W (Fig. 5, *c*).

The following characteristics of the military uniform were selected: thermal insulation of fabric 0.273 $m^2·°C/W$, and footwear – 0.083 $m^2·°C/W$, resistance to evaporation of fabric 0.0503 $m^2·kPa/W$, and footwear – 0.047 $m^2·kPa/W$. These characteristics were selected according to research data in [19].

The theoretical prediction showed that with a human activity of 515 W, the internal body temperature gradually rises and reaches 38.2 °C at the 60th minute (Fig. 6, *a*). Under hot environmental conditions, thermal responses of a human occur due to increased blood circulation in the skin and the release of sweat from the body surface [29]. Evaporation of this sweat begins after 8 minutes and ensures removal of additional heat, which is generated during increased physical activity. In this case, moisture loss in 1 hour is 0.8 liters (1.2 % of body weight), thus 340 W of heat is released into the environment (Fig. 6, *b*).

The application provides an opportunity to evaluate the physiological indicators of the cardiovascular system and the water-salt balance system of a human. Under the selected conditions, the cardiac output of a human reaches 711 l/h, the speed of blood movement in skeletal muscles is 162 l/h, the rate of sweat evaporation increases to 505 g/h. The app provides important data on the rate at which sweat flows due to environmental conditions that limit evaporation. Under the selected conditions, this speed reaches 733 g/h towards the end of the activity.

The results of the theoretical study showed that under the same environmental conditions (air temperature 36 °C, humidity 30 %, wind speed 3 m/s), but during running with an intensity of 781 W, the thermophysiological state of a human changes significantly. In just 30 minutes of running, the internal body temperature rises to 39.3 °C (Fig. 7, *a*).



Input data
Air environment
Temperature 36 °C
Humidity 30 %
Air velocity 3.0 m/s

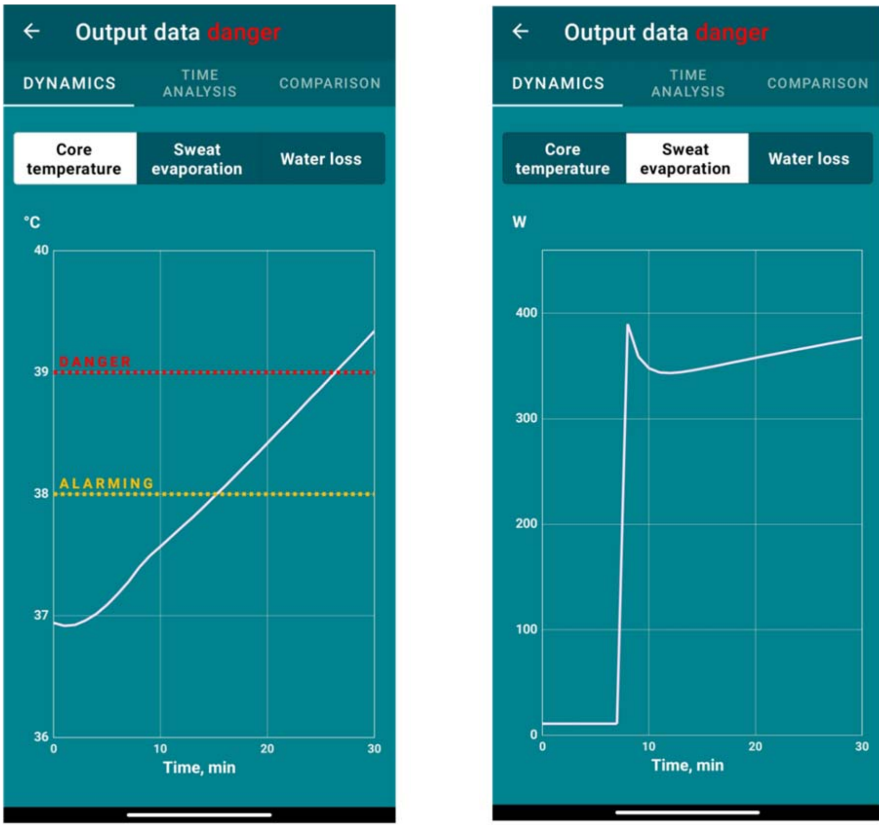
a

Activity
Distance 6 km
Duration 60 min
Walking
Intensity W 515
Speed km/h 6.0

Activity
Distance 4 km
Duration 30 min
Running
Intensity W 781
Speed km/h 8.0

b *c*

Fig. 5. Input data for modeling: *a* — environmental conditions and type of clothing; *b* — walking 515 W; *c* — running 781 W



a *b*

Fig. 6. Prediction of physiological responses during physical activity – 515 W: *a* – internal temperature; *b* – sweat evaporation

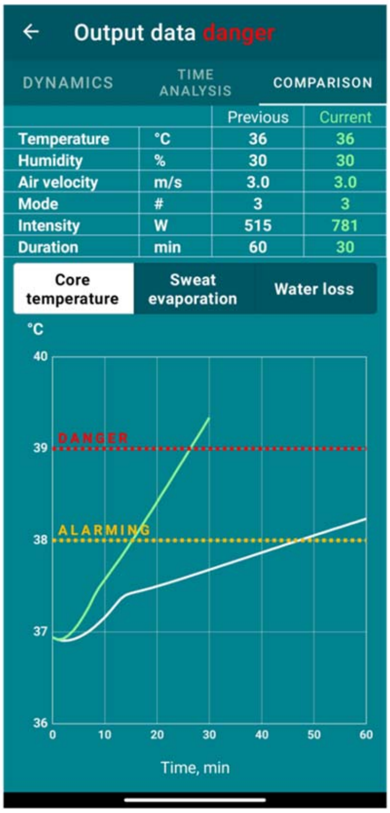
a *b*

Fig. 7. Prediction of physiological responses during physical activity – 781 W: *a* – internal temperature; *b* – sweat evaporation

The application issues a warning about the danger of further running under the selected conditions, as there is a risk of heat stroke. During running, the speed of blood movement in the skeletal muscles is 246 l/h, the cardiac output of a human increases to 1007 l/h. The rate of sweat evaporation increases to 559 g/h, which removes 377 W of heat into the environment (Fig. 7, *b*). The sweat flow rate reaches 1737 g/h at the end of the activity. Moisture loss in 30 minutes of running is 0.7 liters.

The simulation results showed that under selected environmental conditions and a moderate level of activity (515 W), an increase in body temperature for one hour does not pose a threat to human health while at high physical intensity (781 W) overheating occurs, which can lead to heat stroke.

The screen form "Comparison" serves to compare the current experiment with the previous one. For convenience, a table of input data of two experiments that are compared is given above the plots (Fig. 8).

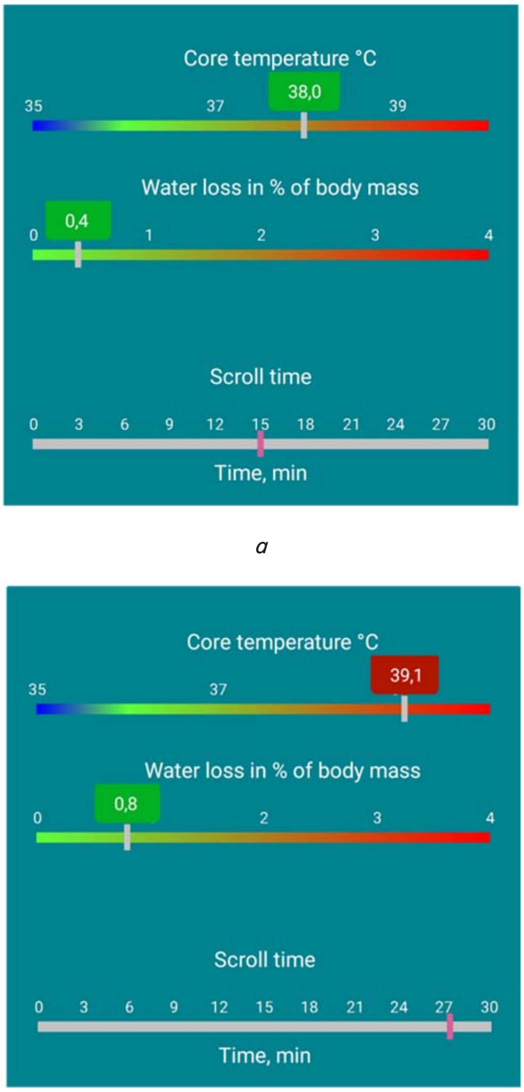


		Previous	Current
Temperature	°C	36	36
Humidity	%	30	30
Air velocity	m/s	3.0	3.0
Mode	#	3	3
Intensity	W	515	781
Duration	min	60	30

Fig. 8. Dynamics of human internal temperature at moderate activity (white line) and at high activity (green line)

The application provides an opportunity to determine the time of safe stay under the given conditions. By moving the slider on the "Scroll time" scale (Fig. 9), the user can assess the risks of heat stress based on the internal temperature and water loss by the human body. On the "Temperature" scale, the safe range of a human's temperature is marked in green (Fig. 9, *a*), red – the risk of heat stroke (Fig. 9, *b*).

Loss of water up to 3 % of body weight does not pose a threat to health [30, 31]. Green color on the "Water loss" scale indicates permissible water losses, and red – the risk of dehydration.



a

b

Fig. 9. Predicting the duration of a human's safe stay while performing a task with an intensity of 781 W:
a — safe; b — dangerous

6. Discussion of results of predicting human thermal responses under hot air conditions

Preliminary predicting of a human's condition under extreme environmental conditions is possible owing to the application of a comprehensive approach using the latest achievements in the field of mathematical modeling of human thermal responses and modern mobile information technologies.

The mobile application makes it possible to determine a safe time for performing physical activity under hot environmental conditions, taking into account the characteristics of clothing (Fig. 3, 4). This is possible owing to the use of a mathematical model of human thermoregulation – formulas (1) to (4), which makes it possible to quantitatively assess a human's physiological reserves. The user receives a warning about the danger of further stay under the selected conditions (Fig. 7). The application informs about the risks of overheating and dehydration of the body (Fig. 9), which is an advantage compared to existing mobile applications.

With the help of the application, it was possible to determine that walking at a speed of 6 km/h for 60 minutes is safe for a human under the selected environmental conditions (Fig. 7). Running at a speed of 8 km/h is safe only for 15 minutes (Fig. 9, *a*). The application showed that water losses during this period do not pose a threat to human health.

A number of limitations and assumptions were adopted during the development of the mobile application. The dynamics of the processes are limited to two hours in order not to take into account the changes in the human body associated with the consumption of food and drinks. Also, the limitations of the study include the established ranges of temperature, humidity, and air movement speed (Fig. 2), the intensity of human physical activity (Fig. 4), and the specified number of clothing sets (Fig. 3).

Disadvantages of the study include the peculiarities of the formation of clothing sets (Fig. 3). This is due to the insufficient number of biophysical characteristics of the fabrics used to manufacture clothing for extreme environmental conditions. The emergence of new standards for clothing will complement the capabilities of the application.

Prospects for the development of the research are the improvement of the mobile application by taking into account more variables of the human thermoregulation model [19–21], which are currently not implemented in the application. Important areas of further work are the integration of the mobile application with external sensors and wearable devices to automate the collection of data on the current state of a human and environmental conditions.

7. Conclusions

1. The Health Risk Prediction mobile application for Android OS has been developed to predict human thermal responses under hot environmental conditions, taking into account the level of physical activity and thermophysical characteristics of clothing. The application is based on a mathematical model of human thermal responses, which makes it possible to obtain a theoretical prediction of the dynamics of internal body temperature, sweat evaporation, and total water loss. Analysis of important indicators for human thermoregulation provides an opportunity to predict the risks of heat stress and quantitatively assess the reserves of the human body.

2. The application possibilities of predicting and assessing the risks of heat stress, taking into account the characteristics of clothing, and determining the safe time of stay under hot conditions depending on the intensity of physical activity, are shown. The simulation results showed that walking at a speed of 6 km/h in a military uniform is safe for 1 hour at an air temperature of 36 °C. Running at a speed of 8 km/h under these conditions becomes risky already after 15 minutes due to overheating of the human body. The received predicting data should be considered as one of the theoretical measures to prevent human heat stress under hot environmental conditions.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, human, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

All data are available in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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