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THERMOELECTRIC CONDITIONER WITH UNIFORMLY DISTRIBUTED MODULES FOR A HUMAN

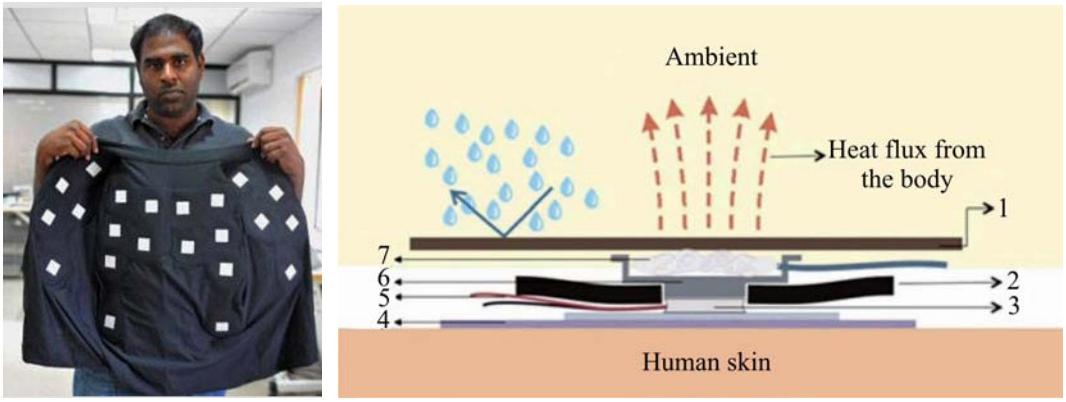
The results of computations of a thermoelectric (TE) conditioner with the uniformly distributed modules design are presented in this paper. The physical, mathematical and computer models of the TE conditioner were developed. Its efficiency for different thermal resistance values and conditions for its exploitation were determined.

Key words: thermoelectric module, computer simulation, clothing TE conditioning.

Introduction

General characteristics of the problem. When humans undergo various ambient temperature conditions they often suffer either from overheating or overcooling that influences their physiological state but negatively [1]. It firstly concerns the people who have to remain under such conditions for a long period of time because of their professional duties. To this group military servants, hot shop workers, sportsmen and alike belong in particular.

The problem of provision a human with comfortable functioning under different conditions can be solved, though, by creating some special TE conditioners for clothing. In [2] their detailed classification is given and the most prospective physical models of such conditioners to be implemented are highlighted. Of special interest are TE conditioners for clothing where thermoelectric cooling and heating are used [3]. It is connected with their advantages, such as cooling and heating provision, reliability, environmental friendliness (harmful cooling agents absence), high efficiency and low mass dimensions [4, 5].



a) b)

Fig. 1. Appearance a) and physical model b) of a thermoelectric conditioner for the Dhama Innovations clothing [7]: 1 – heat-scattering fabric; 2 – insulation; 3 – thermoelectric modules; 4 – heat-conducting fabric; 5 – wires; 6 – heat concentrators; 7 – heat-conducting material.

The simplest and most demonstrative model of a thermoelectric conditioner for humans is a model with thermoelectric modules uniformly distributed over the surface of the clothing. However, as the modules sizes are significantly smaller than the heat-exchanging surface, heat supplies and heat diffusers should be used in such conditioners. [4] (Fig. 1). As it is clear from Fig. 1*a*, a TE conditioner contains 22 TE modules, whereas the schematic from Fig. 1*b* makes it clear that heat supplies and heat diffusing plates are used in it. Unfortunately, no energy characteristics of such a conditioner are given in [4, 6]. Therefore, computer research to determine the efficiency of such a model, being the objective of the present work, was performed.

Consequently, *the objective of the present work* is to examine the possibilities of implementation of a TE conditioner for the clothing with the uniformly distributed modules by way of computer simulation of its design.

Physical model of a thermoelectric conditioner for clothing

A physical model, presented in Fig. 2, was applied to compute an individual conditioner for a bullet-proof vest.

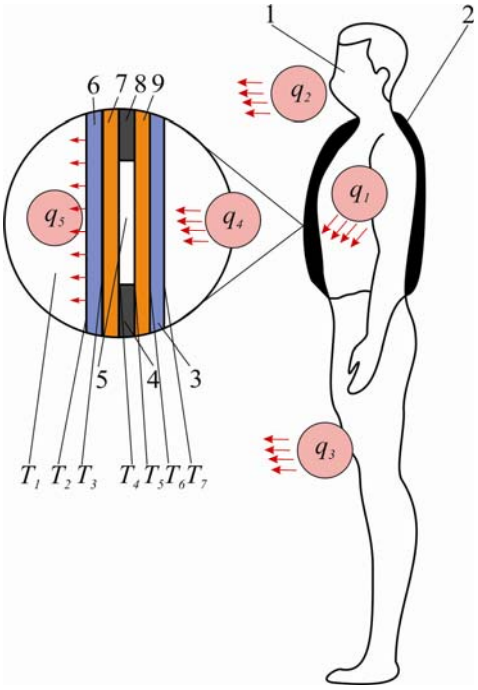


Fig. 2. Physical model of a thermoelectric conditioner for clothing with uniformly distributed modules: 1 – human body; 2 – vest with a conditioner; 3 – fabric, conducting heat from human body, and heat collector 9; 4, 8 – heat-insulation layers; 5 – thermoelectric module; 6 – fabric, conducting heat into the ambient, 7 – heat-conducting plate

It is built on the basis of the model depicted in Fig. 1*b* and presents a human body 1 that emits a heat flux q_1. Depending on the state the body is in (rest, physical loads of varying intensity, etc.) it produces a heat flux from 100 to 800 W [7]. This flux is rejected into the ambient with the help of thermal regulation mechanisms (thermal conductivity, convection, emittance and water evaporation (from skin and mucosal tunics)) via breathing (q_2), thermal insulation (clothing) (q_4) and unprotected parts of the human organism (q_3). Due to the ambient conditions and thermal resistance of the clothing, the said mechanisms add different percentage to the heat exchange (Fig. 3) [8].

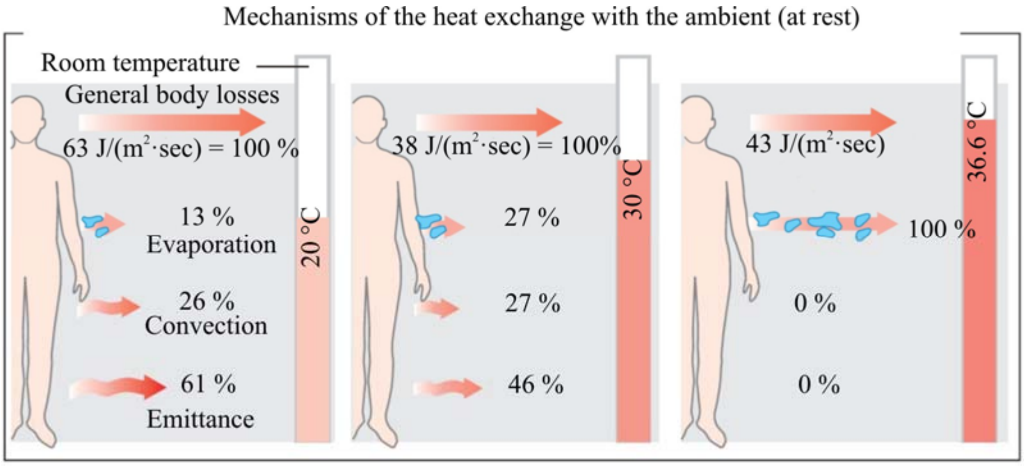


Fig. 3. Typical dependence of the correlation between human heat exchange mechanisms on the ambient temperature [7].

A vest with the TE conditioner 2 is put on the body wearing the underwear 3, through which the heat flux q_4 is transferred to the heat collector 9, and, subsequently, to TE modules 5. The part of the collector surface that is not covered with TE modules is thermally insulated 4, 8. The heat flux from the TE modules q_5 is rejected into the ambient via a metallic heat conducting plate 7 and fabric 6. It is clear that the heat resistance of the material of the vest influences the energy characteristics of the TE conditioner and thermal conditions inside it. Therefore, the computation of the TE conditioner energy characteristics due to the thermal resistance of the vest material and ambient conditions present a significant problem to solve.

Mathematical and computer models of a thermoelectric conditioner for a bullet-proof vest

The system of computation of TE conditioner energy characteristics as a function of physical model elements parameters is defined from the heat balance equation:

$$\begin{cases} Q_c = \chi_1 (T_7 - T_6) \\ Q_c = \chi_2 (T_6 - T_5) \end{cases}, \tag{1}$$

$$\begin{cases} Q_h = \chi_3 (T_3 - T_4), \\ Q_h = \chi_4 (T_2 - T_3), , \\ Q_h = hS (T_1 - T_2), \end{cases} \tag{2}$$

$$Q_h = Q_c + W_{TE}. \tag{3}$$

Here χ_1 is the thermal resistance of the vest material 6, χ_2 is the thermal resistance of the plate 7, χ_3 is the thermal resistance of the of the material 9, χ_4 is the thermal resistance of the material 3, Q_c is the cooling capacity of the TE conditioner, Q_h is its heating capacity, W_{TE} is the electric power of TE power supply 5, h is the heat-transfer coefficient, S is the area from which heat transfer is performed.

Taking into consideration (1) – (3), the following expression for the TE conditioner coefficient of performance (COP) is obtained:

$$\varepsilon = \frac{Q_c}{W_{TE}} = \frac{\alpha I (T_c + Q_c N_1) - 0.5 I^2 R - \lambda (T_h - T_c - (Q_h N_2 + Q_c N_1))}{W_{TE}}, \tag{4}$$

where $N_1 = \frac{(\chi_1 + \chi_2)}{\chi_1 \chi_2}$, $N_2 = \frac{(\chi_3 + \chi_4 + hS)}{\chi_3 \chi_4 hS}$, I – current strength, R – electric resistance, α – Seebeck coefficient of thermoelement, λ – thermal conductivity coefficient of thermoelement.

The heating coefficient for such a case will have the form of:

$$\mu = \frac{Q_h}{W_{TE}} = \frac{\alpha I (T_h + Q_h N_2) + 0.5 I^2 R - \lambda (T_h - T_c - (Q_h N_2 + Q_c N_1))}{W_{TE}}. \quad (5)$$

The computer methods of object-oriented simulation together with numeric methods for determination of the purpose-oriented functions, namely, COP and heating coefficient of the TE conditioner, were applied for computing in the present work. These functions are nonlinear and depend on the totality of parameters which are expressed implicitly with the help of the plurality of empiric equalities. Therefore, there exists no possibility of applying any methods of determining either the first or second order extremum (due to impossibility of the derivatives definition). To ensure the search for the optimal COP value, the non-gradient method of the zero order, namely, the modified Hooke-Jeeves method, was applied [9].

A system of non-linear equations (1 – 3) is being solved in each iteration of the main cycle of the programme, and cooling capacity is determined. The approximating polynoms coefficients which help determine the empirical correlations between the physical parameters of the optimization problem are computed in the programme. The details of the modelling technique are given in [10].

Simulation results

Hence, the initial parameters of the model are the following: thermal power to be rejected from a human body through TE modules, the power itself being the function of the ambient temperature (Fig. 3), and the organism physiological state (the value of human heat emittance of $Q = 100$ W is used that corresponds to the state of a human at rest); the ambient temperature of $T_1 = 20, 30, 36.6, 40$ ºC; the external surface area of the vest to provide heat-exchange of $S = 0.5$ m^2; *Bi-Te* TE heat converters parameters [11] are 20 × 20 mm with the crystal size of 2.0 × 2.0 × 1.5 mm and the number of TE modules being equal to 50 pcs.

As a result of modelling, the dependence of the electric power required for provision of the human body constant temperature ($T = 36.6$ ºC) on the ambient temperature and heat resistance of the vest materials (Fig. 4) was computed.

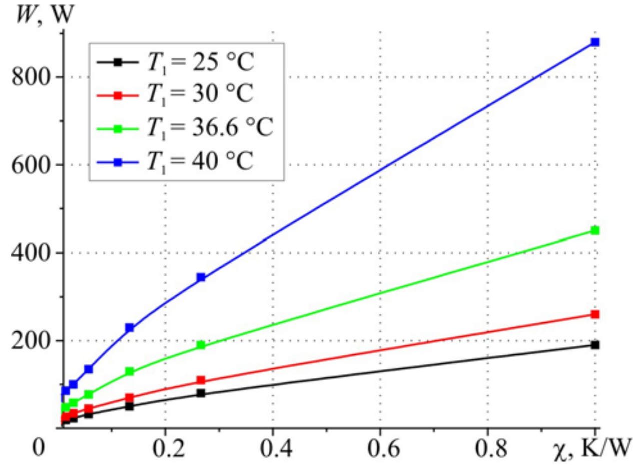


Fig. 4. Electric power of thermoelectric modules as a function of thermal resistance of the vest fabrics and for different ambient temperatures.

As it is evident from Fig. 4, the power required for provision of the human body constant temperature ($T = 36.6$ ºC) is strongly dependent on the heat resistance of the clothing fabric. For example, to supply the TE conditioner with the vest fabric heat resistance of about $\chi = 0.4$ K/W, which corresponds to the use of cotton-based fabrics (thermal conductivity coefficient $\kappa \approx 0.05$ W/m·K) and at the ambient temperature of $T_1 = 36.6$ ºC, which corresponds to the human body surface normal temperature, the power of $W = 250$ W is required. If the thermal resistance of the vest is reduced fivefold, which corresponds to the use of the fabric with the increased thermal conductivity ($\kappa \approx 0.01$ W/m·K) [12], it leads to the increase in its efficiency by the factor of 2.5 and decrease in TE modules power down to $W = 100$ W.

However, from the research performed it is clear that the model of a TE conditioner with uniformly distributed modules for humans is not efficient enough and requires further improvements, especially by way of intensifying of the heat exchange by blowing with air fans, etc. Moreover, to diminish energy expenditures when using individual conditioners for humans, the search for and development of novel materials with the increased thermal conductivity remains essential.

Conclusions

1. The possibility of development of a thermoelectric conditioner for humans based on the model with the uniformly distributed modules was confirmed but its application is not efficient enough and requires further improvements. The dependence of the electric power needed for provision of the human body constant temperature ($T = 36.6$ ºC) on the ambient temperature and the vest fabric thermal resistance was computed.
2. The dependence of the electric power necessary for the human body constant temperature ($T = 36.6$ ºC) provision on the ambient temperature and the vest fabric thermal resistance was computed.
3. It was determined that the electric power of $W = 250$ W is required to supply the conditioner for humans at the thermal resistance of about $\chi = 0.4$ K/W, which corresponds to the use of cotton-based fabric, whereas the ambient temperature is $T_1 = 36.6$ ºC.
4. If the thermal resistance of the vest is reduced fivefold, which corresponds to the use of the fabric with the increased thermal conductivity ($\kappa \approx 0.01$ W/m·K) [11], it leads to the increase in its efficiency by the factor of 2.5.

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