L.I. Anatychuk[1,2], R.G. Giba[1], R.R. Kobylyanskii[1,2]

[1] Institute of Thermoelectricity NAS and MES of Ukraine, 1, Nauky Str., 58029, Ukraine;
[2] Yu. Fedkovych Chernivtsi National University, 2, Kotsyubinsky Str.,
Chernivtsi, 58000, Ukraine

SOME PECULIARITIES OF USING MEDICAL HEAT METERS IN THE INVESTIGATION OF LOCAL HUMAN HEAT RELEASE

This paper presents the results of computer simulation and experimental research on the effect of thermal insulation and spatial orientation of thermoelectric heat meter on its readings in the investigation of local human heat release. It has been proved experimentally that the presence of thermal insulation on thermoelectric heat meter does not always cause a decrease in its readings. In some cases it leads to their increase, since thermal insulation serves as a peculiar heat exchanger.
Key words: computer simulation, thermoelectric heat meter, medical thermal insulation, local human heat release.

Introduction

General characterization of the problem. Semiconductor thermoelectric heat meters are known to show good promise for the investigation of local human heat release [1-13]. They combine miniature size, fast response and parameter stability in a wide range of operating temperatures and are consistent with state-of-the art recording equipment [14, 15]. The use of such heat meters yields high locality and accuracy of heat measurements. This, in turn, affords an opportunity to obtain information on the characteristics of objects under study and analyze them in detail with the purpose of early detection of inflammatory processes in human body. However, the impact of different factors on the readings of thermoelectric heat meters remains an important issue.

Analysis of the literature. Effect produced by such heat meters on the object under investigation was studied analytically in [2], and for the case of living objects by means of computer simulation in [16, 17]. It was established that the influence of thermoelectric heat meter on measurement of human heat release can be minimized on condition of equality of heat exchange coefficients α_1, α_2 and radiation coefficients ε_1, ε_2 of heat meter and human skin surface, respectively. Also by means of computer simulation in [18] the effect of thermal insulation on thermoelectric heat meter readings was studied under real-service conditions. Besides, of paramount importance in the investigation of human heat release is heat meter spatial orientation, the method of its attachment to the surface of area under study and heat meter thermal insulation thickness increase that can affect considerably the thermoelectric heat meter readings.

Therefore, the purpose of this work is creation of improved computer model to determine the effect of thermal insulation and spatial orientation of thermoelectric heat meter on its readings, as well as experimental proof of the results obtained in the investigation of local human heat release.

Computer simulation results

To determine the effect of thermal insulation on thermoelectric heat meter readings, the model of biological tissue elaborated in [18] having on its surface thermoelectric heat meter with medical thermal insulation has been improved. Physical model improvement consists in approximating the shape and arrangement of medical thermal insulation to the real situation (Fig. 1). To construct an improved three-dimensional computer model, Comsol Multiphysics software package was employed [19], allowing simulation of thermophysical processes in human body biological tissue with account of blood circulation and metabolism. Calculation of temperature and heat flux density distributions in the biological tissue, thermoelectric heat meter and thermal insulation was done by finite element method (Fig. 2).

Computer simulation was used to obtain the distribution of temperature and heat flux density lines in the biological tissue of human body and thermoelectric heat meter (Fig. 3 – 5), as well as to construct isothermal surfaces in the biological tissue (Fig. 6) with regard to boundary effects in a three-dimensional computer model.

To determine temperature difference between thermoelectric heat meter surfaces, averaging of the resulting temperature distributions on the upper and lower heat meter surfaces was performed, since such distributions are nonuniform.

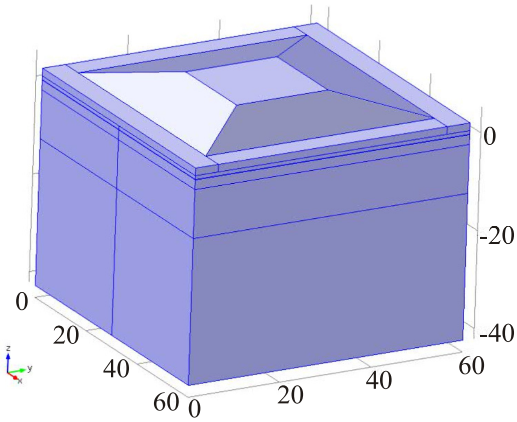

Fig. 1. Improved model of biological tissue having on its top thermoelectric heat meter with medical thermal insulation.

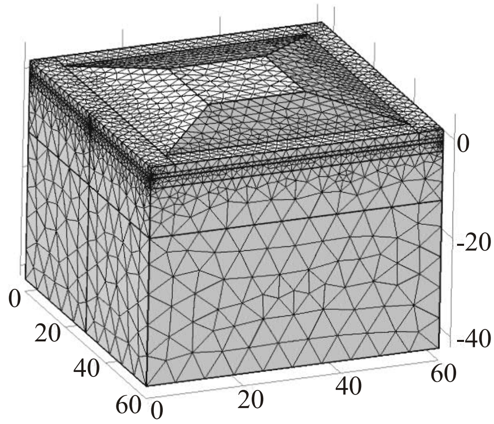

Fig. 2. Finite element method network.

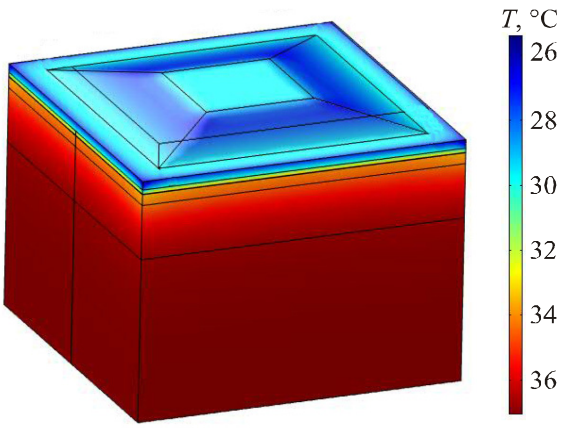

Fig. 3. Temperature distribution in biological tissue having on its top thermoelectric heat meter with medical thermal insulation.

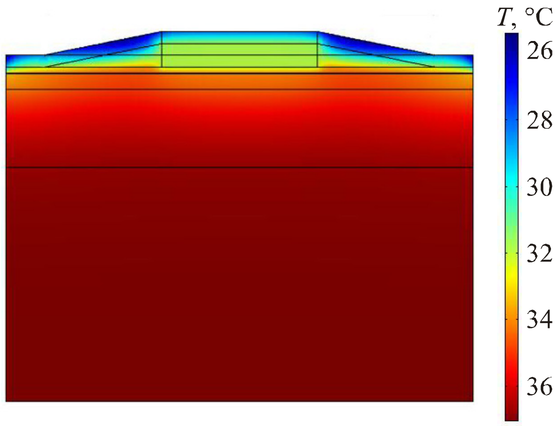

Fig. 4. Temperature distribution in the cut of biological tissue having on its top thermoelectric heat meter with medical thermal insulation.

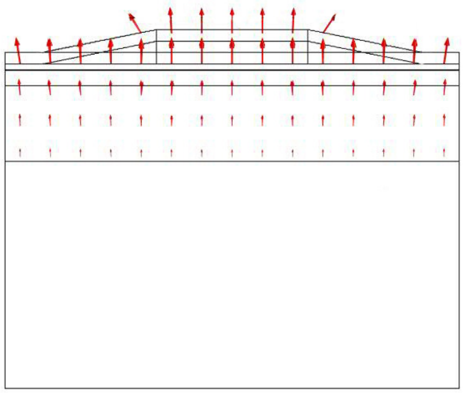

Fig. 5. Distribution of heat flux density lines in biological tissue having on its top thermoelectric heat meter with thermal insulation.

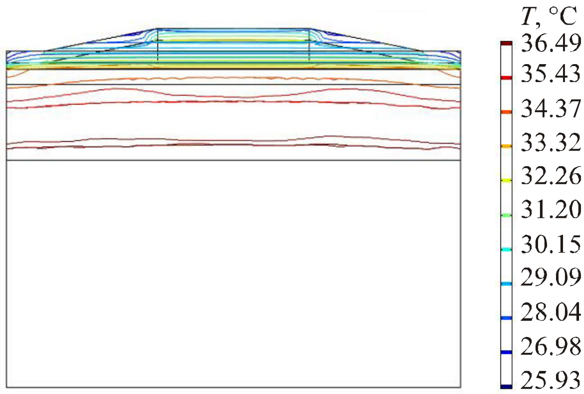

Fig. 6. Isothermal surfaces in biological tissue having on its top thermoelectric heat meter with medical thermal insulation.

Computer simulation was used to determine the effect of thermal insulation on thermoelectric heat meter readings under real-service conditions. Dependence of temperature difference on thermoelectric heat meter on the thickness of heat meter thermal insulation (the number of external bandage layers N_{extern}) was determined with different thickness of thermal insulation between the biological tissue and heat meter (the number of internal bandage layers N_{intern}) (Fig. 7).

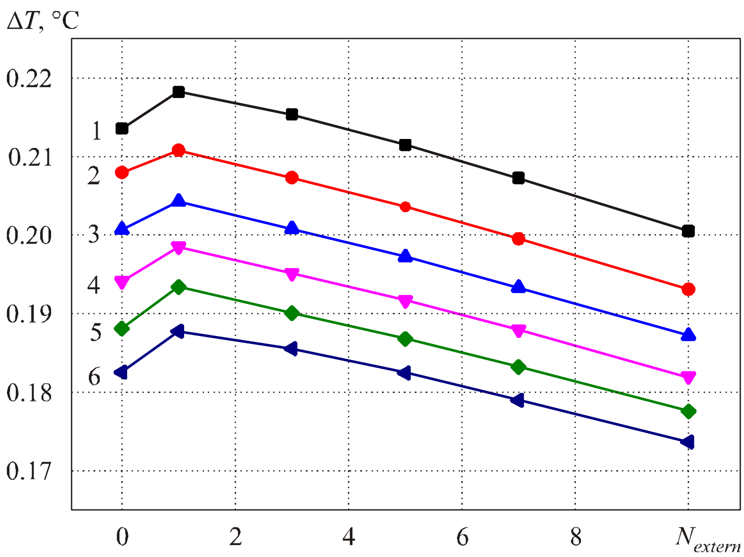

Fig. 7. Dependences of temperature difference on thermoelectric heat meter on the thickness of heat meter thermal insulation (the number of external bandage layers N_{extern}) with different thickness of thermal insulation between the biological tissue and heat meter (the number of internal bandage layers N_{intern}).
1 – N_{intern} = 0; 2 – N_{intern} = 1; 3 – N_{intern} = 2; 4 – N_{intern} = 3; 5 – N_{intern} = 4; 6 – N_{intern} = 5.

From Fig. 7 it is seen that increase in the thickness of thermal insulation between the biological tissue and thermoelectric heat meter definitely leads to a reduction of temperature difference between heat meter surfaces. However, increased thickness of heat meter external insulation does not always decrease its readings, and in some cases leads to their increase, since thermal insulation serves as a peculiar heat exchanger. This, in turn, must be taken into account when measuring local human heat release by creating identical conditions of repeated measurements.

Experimental studies of the effect of thermal insulation on thermoelectric heat meter readings

To determine the effect of thermal insulation on thermoelectric heat meter readings, a series of experimental measurements of local human heat fluxes was performed with different number of external N_{extern} and internal N_{intern} bandage layers. Measurement was performed on the area of human left hand at body temperature T_{body} = 36.6 °C and ambient temperature T_{room} = 20 °C with a horizontal arrangement of heat meter on the surface of area under study (Fig. 8).

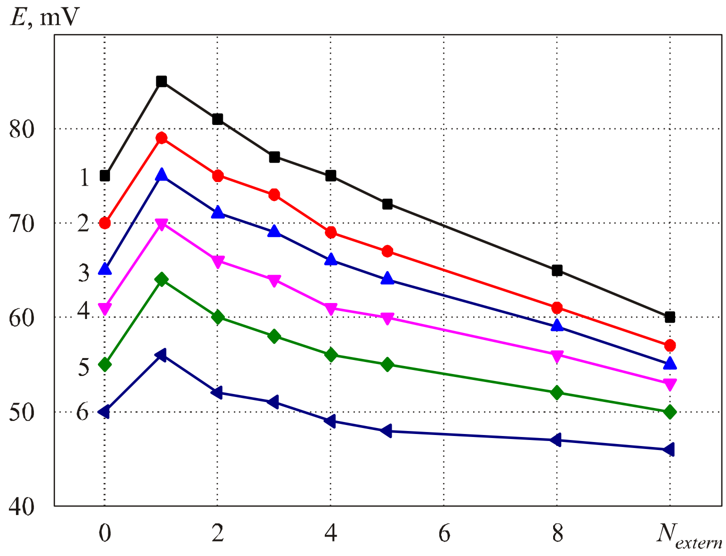

Fig. 8. Dependences of thermoelectric heat meter readings on thermal insulation thickness (the number of external N_{extern} and internal N_{intern} bandage layers) with a horizontal heat meter arrangement (φ = 0°) on the surface of human body area under investigation: N_{extern} – the number of bandage layers on thermoelectric heat meter, N_{intern} – the number of bandage layers between the skin and heat meter surface. 1 – N_{intern} = 0; 2 – N_{intern} = 1; 3 – N_{intern} = 2; 4 – N_{intern} = 3; 5 – N_{intern} = 4; 6 – N_{intern} = 5.

Thus, it has been established that the presence of thermal insulation on the biological tissue and thermoelectric heat meter does affect heat meter readings. From Fig. 8 it is seen that a small number of external layers of medical thermal insulation (N_{extern} = 1 ÷ 4) leads to increase in thermoelectric heat meter readings by 15 %, and further increase in thermal insulation (the number of external and internal bandage layers) reduces its readings by 40 % as compared to the case when thermal insulation is absent. Thus, the obtained results of experimental research confirm the assumption that thermal medical insulation serves as a peculiar heat exchanger and in some cases leads to increase in heat meter readings.

Table 1

Dependence of thermoelectric heat meter readings on the type of thermal insulation

№	Measurement conditions	*E*, mV
1.	N_{intern} = 0, N_{extern} = 0	75
2.	Ordinary jacket	65
3.	Knitted jacket	39
4.	Continental quilt	25

Also investigated was the influence of thermal insulation type on thermoelectric heat meter readings, that is, the cases of heat meter surface without thermal insulation, with clothing or continental quilt (Table 1). The measured data are represented in Fig. 9.

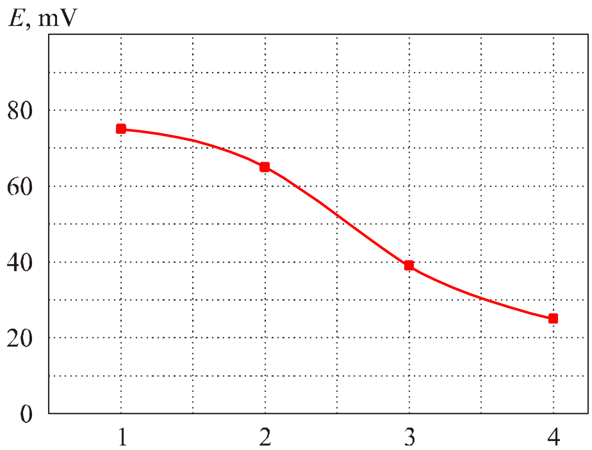

Fig. 9. Dependence of thermoelectric heat meter readings on the type of thermal insulation with investigation of local human heat release: 1 – no thermal insulation on heat meter surface, 2 – ordinary jacket, 3 – knitted jacket, 4 – continental quilt.

From Fig. 9 it is seen that the presence of thermal insulation on the surface of thermoelectric heat meter has a great impact on its readings which can decrease several times as compared to the case when thermal insulation is absent. This fact must be taken into account by creating identical conditions when measuring local heat fluxes of human body.

Dependence of thermoelectric heat meter readings on its spatial orientation

To determine the effect of spatial orientation of thermoelectric heat meter on its readings, a series of experimental measurements of heat fluxes from the respective area of human left hand was performed (T_{body} = 36.7 °C, T_{room} = 20 °C). The measured data are represented in Table 2 and Fig. 10, respectively, where φ is inclination angle of the hand with thermoelectric heat meter.

From Fig. 10 it is seen that with increasing the inclination angle of the left hand with a thermoelectric heat meter, its readings are reduced by 12 % with the number of bandage layers $N_{extern} = N_{intern} = 1$ and accordingly by 46 % with further increase in the number of bandage layers $N_{extern} = N_{intern} = 5$.

Table 2

Dependence of thermoelectric heat meter readings on its spatial orientation

φ, °	$N_{intern} = 1$ $N_{extern} = 1$	$N_{intern} = 2$ $N_{extern} = 2$	$N_{intern} = 3$ $N_{extern} = 3$	$N_{intern} = 4$ $N_{extern} = 4$	$N_{intern} = 5$ $N_{extern} = 5$
0	79	71	64	57	48
45	74	66	58	52	46
90	70	61	54	49	45

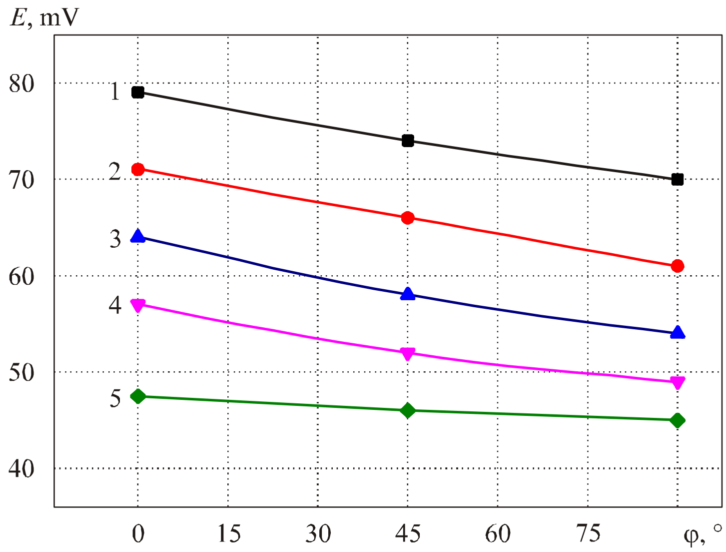

Fig. 10. Dependences of thermoelectric heat meter readings on its spatial orientation on the surface of human body area under investigation: N_{extern} – the number of bandage layers on thermoelectric heat meter, N_{intern} – the number of bandage layers between the skin and heat meter surface. 1 – N_{intern} = 1; 2 – N_{intern} = 2; 3 – N_{intern} = 3; 4 – N_{intern} = 4; 5 – N_{intern} = 5.

Thus, peculiarities of using medical heat meters in the investigation of local human heat release have been established. It has been found that spatial orientation of thermoelectric heat meter has a great impact on its readings which can vary up to 15 % depending on the thickness of medical thermal insulation on the heat meter surface.

Conclusions

1. Computer simulation results have been proved experimentally. It has been established that the presence of medical thermal insulation on thermoelectric heat meter does not always decrease its readings. In some cases it leads to their increase, since thermal insulation serves as a peculiar heat exchanger. However, further increase in the thickness of medical thermal insulation definitely leads to a decrease in heat meter readings about to 40 % as compared to the case when thermal insulation is absent.
2. It has been established that depending on spatial orientation of thermoelectric heat meter on human body area under investigation, heat meter readings can vary up to 15 %. This fact must be taken into account by creating identical conditions when measuring local human heat release.

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