EXTRAPOLATION METHOD IN TEMPERATURE MEASUREMENT ON CLOTHING LAYERS

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Abstract
One of the most important thermal insulation clothing features is the clothing internal surface temperature. This parameter is more determinate than underclothing temperature which depended on the various dimension and air condition. In this paper the authors proposed an extrapolation method of estimate the internal surface temperature of clothing in the constant thermal state. It was conducted verification research of this method on a physical model. The critical analysis of the method is presented in this paper.
Key words: measurement, underclothing temperature, extrapolation

1. Introduction

The new textile technology based on materials enginering and computer science make arrise possible new multifunction textiles. This kind of textiles can be used to construction textronics clothing. Some kind of textronic clothing can monitoring human physologiccal parameters f.e. skin temperature.

From the point of view of heat exchange, we may consider textronic clothing as permeable barriers of small thickness, and a specially formed surface [1]. It is assumed in this study that clothing does not contact directly the human skin with its whole surface, which results in the need to consider the existence of air channels in the layer between skin and clothing in which the phenomena of convection and heat radiation occur. Skin and underclothing temeprature measurement in normal service conditions is difficulte to realization. The temperature sensors should have small dimensions and should be stable fix. They can't disturb temperature in place of measurement and not contact with the skin or the inner layer of clothing.

The underclothing temperature is the average air temperature of gap between human skin and inner layer of clothing. During normal clothing exploatation the dimensions of underclothin gap changed. The temperature sensor should have constant position towards human body or inner layer of clothing. During the clothing movement of human body the sensor contact with skin [2], this the typical condition of exploatation. Authors defined estimation temperature value of inner clothing layer in constant state using extrapolation method [3]. Proposed method is the alternative fot the direct measurement method using traditional temperature sensors.

2. Experiment

The research conducted on physical model presented in figure 1, where d – fabric thickness, s_i – the thicknes of air gap. The thermocouples of the K type (6) cooperating with the AMD 90 (1) thermometer was characterized by a measurement accuracy of 0,1 ºC. The thermocouples arranged betwen textile fabric layers. An inacurracy of measurement was 0,1 % reading ± 0,7 °C. Heaters temperature (4) measured with resolution 0,1 °C using multimeters (2), connected with diode temperatures sensors (7). Heaters suply from stable voltage source (3). The power of the heating plate was measured with an accuracy of 0,1 W. The ambient temperature, t_a was measured using a resistance thermometer Temp Master 100 with inacurracy of 0,01 °C. The relative moisture of the air was measured with an inaccuracy of 1% RH using capacitive sensors with measure range 5%-95%.

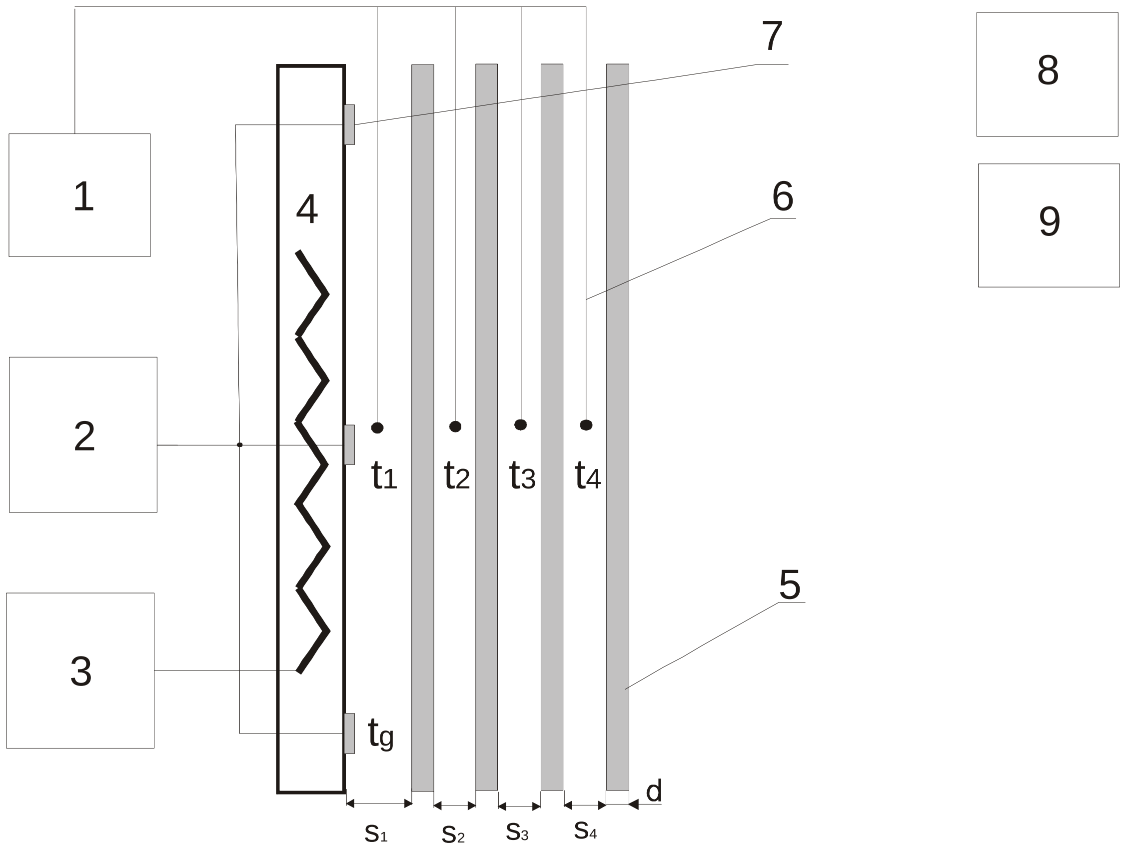

Figure 1. The simplification scheme of measurement stand, 1 – the thermocouples TMD 90; 2 –multi meter CHY 21G; 3 – Power suply, Meratronik Type P 315S; 4 – heater; 5 – wool woven; 6 – thermocouples t_1, t_2, t_3, t_4 type K; 7 – temperature sensors t_g BAS 16; 8- Temp Master 100; 9 – RH meter; d – fabric thickness, s_i – the thicknes of air gap (i = 1, 2, 3, 4).

In the research used woven fabric with plain wave. Basic physical properties of the material used is shown in table 1. The surface mass of the specimens studied was calculated according to the standard PN-85/P-04613, by means of formula:

$$M_p = \frac{m}{l_s \cdot s_p}, \ \frac{\mathrm{g}}{\mathrm{m}^2} \tag{1}$$

where: m – the specimen mass, g; s_p – the specimen width, m; l_s – the specimen length, m.
For measuring the mass of specimens of dimensions 0,1 m by 0,1 m an OHAUS laboratory balance, model TS 400S was used, whose accuracy of measurement was 0,01 g. The equivalent density of the material studied was calculated according to the standard PN-85/P-04688, by means of formula:

$$G_p = \frac{\bar{m}}{\bar{l} \cdot \bar{s} \cdot \bar{d}} \cdot 10^6, \ \frac{\mathrm{kg}}{\mathrm{m}^3} \tag{2}$$

Table 1. The wool woven parameters

Thickness d mm	Apparent density G_p kg/m^3	Amount of yarns density		Twis		Mass M_p g/m^2
		Unit/dm				
		warp	weft	warp	weft	
1,86	184	60	50	139	141	293

In addition, the number of threads of the weft and the warp was calculated according to the standard PN-80/P04637, by means of formula:

$$N_{0(W)} = \frac{\sum_{i=1}^{n} n_i}{\sum_{i=1}^{n} l_i} \cdot 100 \text{, unit/dm} \tag{3}$$

where: N_o – the mean number of the warp threads, piece/dm; N_w – the mean number of the weft, piece/dm; n_i – the number of threads of the warp and weft in the i-th specimen, pieces; l_i – the length of the i-th specimen, mm; n – the number of the specimens. 10 measurements of the number of threads of the warp and the weft were performed. The mean results both for the number of threads and the remaining parameters are shown in table 1.

The research method

The extrapolation method of estimate the internal surface temperature of clothing based on Newton equation for constant thermal flow :

$$q=-\lambda \, grad \, t \tag{4}$$

or after transmition for layer d

$$\Delta t=qR_c \tag{5}$$

where :

q – heat flux density , Wm^{-2};
λ – the thermal conduction coeficient, $Wm^{-1}K^{-1}$;
t – temperature, ºC;
R_c – thermal resistanceof the textile layer d, $Kw^{-1}m^{-2}$;
Δt – the temperature drop on the textile layers, ºC.

In constant state of the flux density q, the temperature drop on the textile layer is propotional to their thermal resistance (5). The homogenous textile packet obtain linear temperature drop. In the physical model of textile layers (figure 1), where the layers ware losley packing each other, appear air gaps. These air gaps caused arrise additional thermal resistances.
The edges of the specimens were sewn together with cotton thread so that the particular edges of the textile packet would adhere to each other more closely.
For physiscal model parameters conducted the drop temperature calculations acording to formula 5. The heat transfer phenomena in air gap between human skin and clothing layer can be described only by conduction properties of air in the cases when Grashof number G_r is smaller than 2000 [4].
In our model the temperature drop wasn’t proceed through the stright line (the dashed line, figure 2), but through broken line (solid line, figure 2), where t_{pe} – extrapolation underclothing temperature, t_{we} – extrapolation temperature of inner clothing layer, t_{po} – counted underclothing temperature, t_{wr} – counted temperature of inner clothing layer [5].
However treat the thermal resistance of textile layer as a sum of layer and neighbouring air gap thermal resistence t_2, t_3, t_4, (figure 2) measured on surface of layers, it can be extrapolated the stright line [6]. The thickness of air gaps between textile layers 2, 3, 4 are the same. For veryfication proposal method, authors also measured the heater temperature t_g.

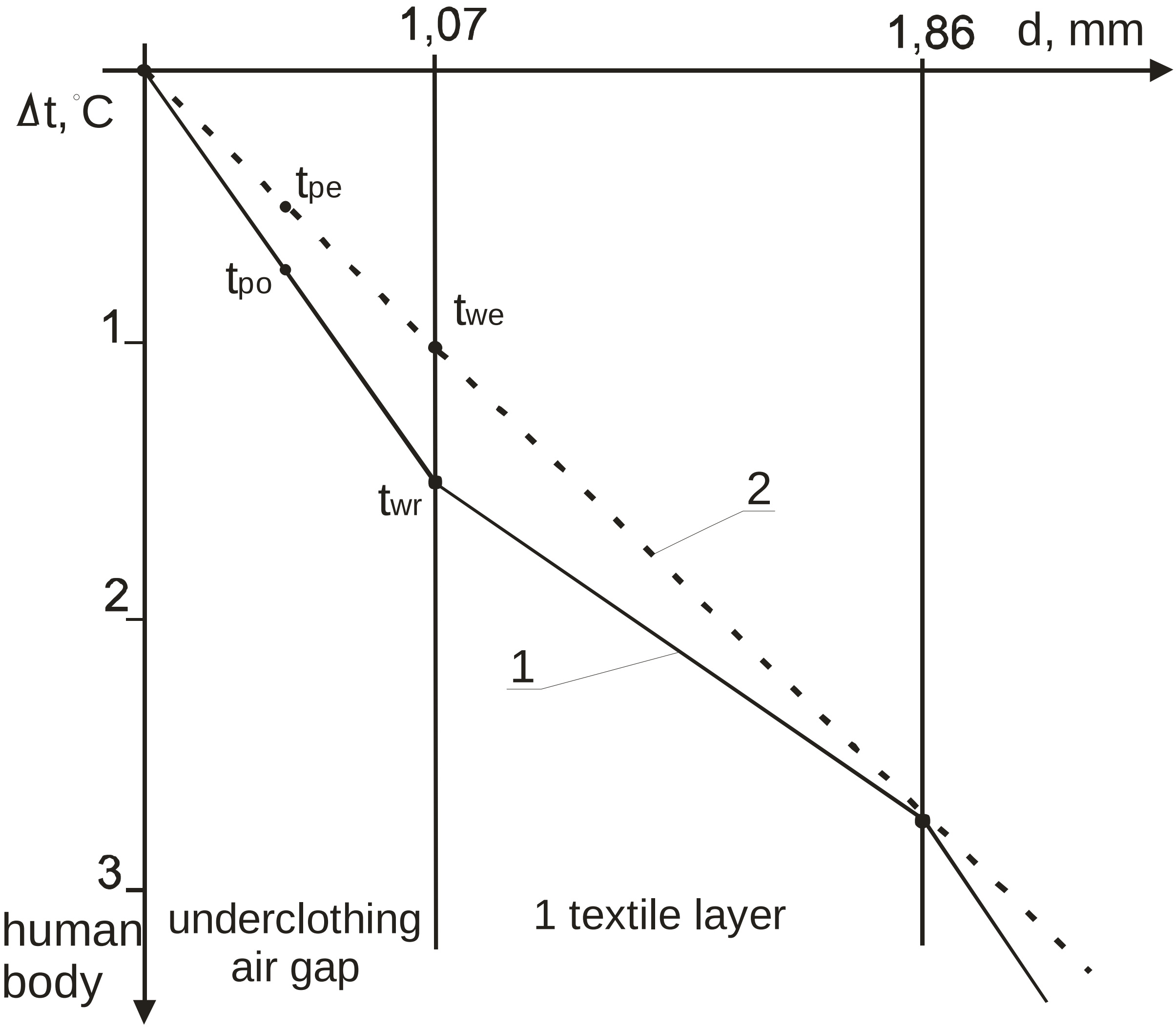

Figure 2. The drop extrapolation and counted temperature comparison in underclothing layer; for 32,5 ºC heater temperature.

Received results

On the measurement stand figure 1, ware recording the constant temperature between the textile layers. Authors have done two series, with 14 measurement each for three variants of heater temperature. The value of heater temperature selected in physological skin temperature range of changes, from rest state to effort state. The average received results for three value of source temperature presents table 2. The example of extrapolation present figure 3.

Table 2. The average value of measurement results for research cases

Lp	t_g	t_1	t_2	t_3	t_4	t_a	RH
	ºC						%
1	32,7	29,3	28,8	25,4	24,6	24,5	25
2	36,8	36,2	35,5	30,5	28,5	24,5	25
3	41,0	40,4	39,6	33,1	30,4	24,5	25

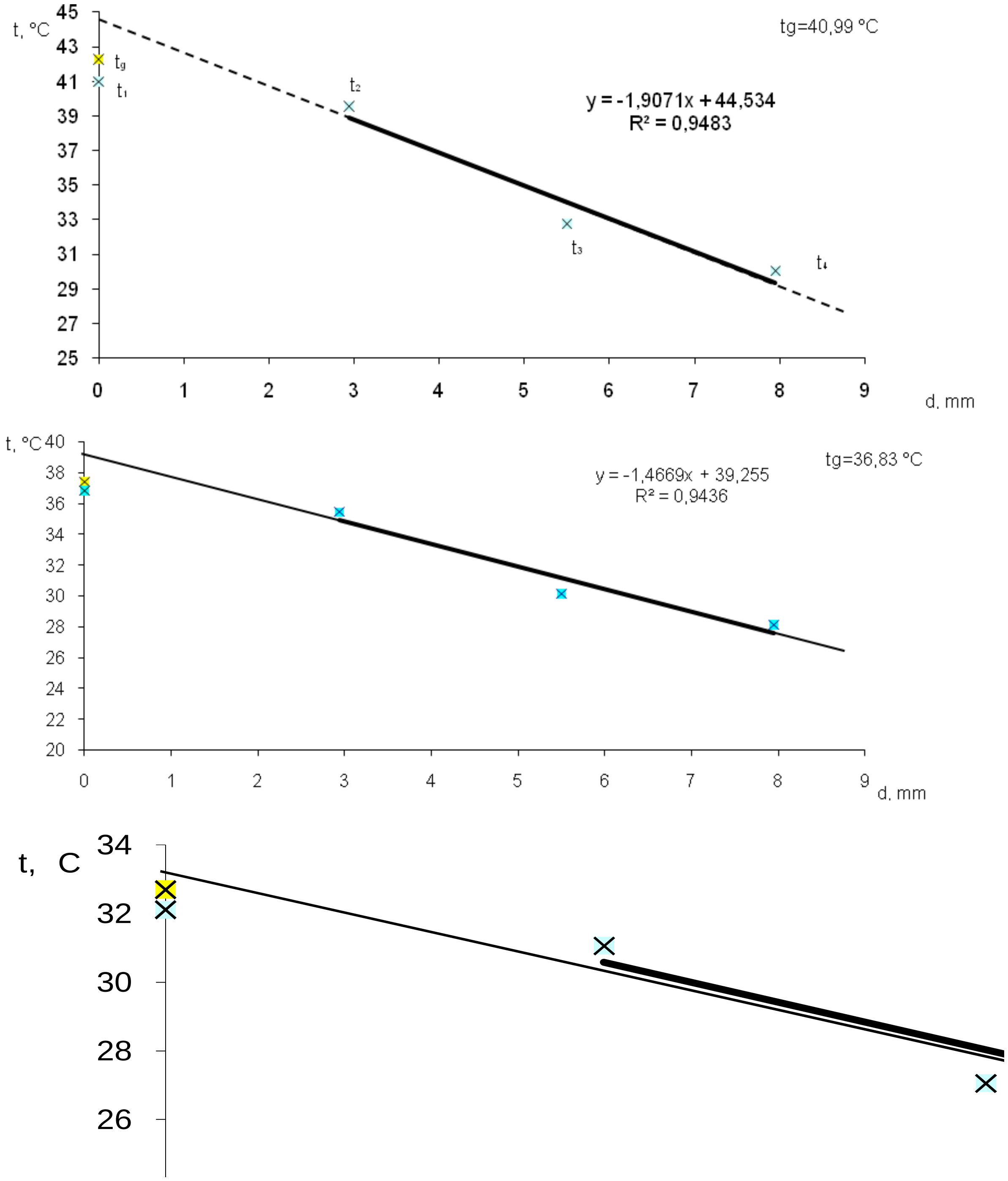

Figure 3. The average temperature measurement results between the clothing layers, for heater temperatures 40,99 °C, 36,8 °C, 32,69 °C.

The comparison between extrapolate value and measurement present table 3. Table 4, 5 and 6 present counted value of standard uncertainness type A and B, complex uncertainness, for received measurement value, counted for significance level 0,05. During the B type uncertainness measurement assumed uniform value.

Table 3. The extrapolation and measurement temperature value for research cases

Lp	Extrapolation temperature, °C			Measurement heater temperature, °C	The maximal error of extrapolation, °C
	heater	underclothing	Inner textile layer		
1	33,5	33,0	32,4	32,7	0,98
2	39,3	38,5	37,7	36,8	1,04
3	44,5	44,0	42,5	41,0	1,29

Table 4. The uncertainty type A and B for three research conditions

lp	U_{A1}	U_{A2}	U_{A3}	U_{A4}	U_B
1	0,60	0,60	0,63	0,51	0,05
2	0,04	0,28	0,03	0,03	0,05
3	0,03	0,03	0,04	0,04	0,05

Table 5. The uncertainty for three variants of measurements

lp	U_{c1}	U_{c2}	U_{c3}	U_{c4}
1	0,64	0,64	0,67	0,55
2	0,23	0,35	0,23	0,23
3	0,23	0,23	0,23	0,23

Table 6. The complex uncertainty for three variants of measurements

lp	U1	U2	U3	U4
1	1,27	1,29	1,33	1,11
2	0,45	0,71	0,45	0,45
3	0,45	0,45	0,45	0,45

Conclusions

The method of direct measurement of underclothing temperature is not satisfy. The measurement with 1,5 °C accuracy in this layer is realy hard to realization. The initial research show that maximal error of temperature extrapolation is equal 1,29 °C. Based on this, authors assumed that maximal error of underclothing extrapolation temperature isn't larger. The propsed method of extrapolation could be alternative for estimate the temperature inderclothing layer in the constant thermal state. Limit of the method is exiting minimum three identical layers in textile packet

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