AD-750 830

ASSESSMENT OF THE THERMAL RESISTANCE OF CLOTHING

Yu. F. Voinov, et al

Defence Research Information Centre
Orpington, England

October 1972

DISTRIBUTED BY:

NTIS
National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

BR 30290

AD 750830

ASSESSMENT OF THE THERMAL RESISTANCE OF CLOTHING

Yu.F. Voinov and K.V. Karlina

Technologiya Legkoi Promyshlennosti, 1 (1972) 80-84
(from Russian)

DRIC Transl. No. 2920 October 1972

Translated by Dr. B.F. Toms

I

DRIC TRANSLATION No. 2920

ASSESSMENT OF THE THERMAL RESISTANCE OF CLOTHING

Yu.F. Voinov and K.V. Karlina

Technologiya Legkoi Promyshlennosti, 1 (1972) 80-84

The extremely complex process of heat exchange between the human body and the external environment is associated with a whole number of thermophysical and physiological effects. These problems have been studied in a considerable number of works which have been reviewed in detail in the monograph[1]. Nevertheless certain aspects of heat transfer through clothing have as yet received insufficient attention. For example, in[2] it is stated that the relationship between the thickness of clothing and its thermal resistance is exponential. Furthermore, it was shown in this study that the thermal resistance of clothing in the region of the head, hands and feet reaches a certain limit when the clothing is 23 mm thick, and that further increase of thickness does not produce a corresponding increase in the thermal resistance. At the same time it is known that the thermal resistance of a multilayer wall of small curvature is a linear function of its thickness without extrema.

To explain the findings of[2] as a consequence of physiological redistribution of heat flows over the surface of the body is not sufficiently convincing since the body surface temperature changes very little with physiological regulation of heat exchange. At the same time the temperature difference between the body surface and the environment does not depend significantly on the body surface temperature, and as a result of this when the temperature of the environment is constant heat flow from the surface of the body is mainly determined only by the thermal resistance of clothing.

A more convincing explanation of these discrepancies may be found by analyzing the components of the thermal resistance of clothing.

The thermal resistance of a multilayer suit of heat-resistant clothing may be considered to consist of three components:

$$R_{cl} = R_{\alpha} + \Sigma R_m + \Sigma R_a \qquad (1)$$

where R_α, ΣR_m and ΣR_a are the thermal resistances respectively to heat emission from the surface of the clothing, of the materials and of the air layers between the layers of the fabrics.

$$R_\alpha = \frac{1}{\alpha_r + \alpha_c} \qquad (2)$$

where α_r and α_c are the coefficients of heat transfer due to radiation and convection respectively.

To calculate the coefficient of heat transfer by radiation we shall use the familiar expression

$$\alpha_r = \varepsilon C_o \frac{\left(\frac{T_{c \cdot s}}{100}\right)^4 \left(\frac{T_e}{100}\right)^4}{T_{c \cdot s} - T_e} \qquad (3)$$

where ε is the blackness of the surface; for clothing $\varepsilon = 0.95$;

$C_o = 5.7\ W/m^2 \cdot {}^oK^4$ is the coefficient of radiation;

$T_{c \cdot s}$ is the temperature of the surface of the clothing, ^oK;

T_e is the temperature of the environment.

When the difference between the temperature of the surface of the clothing and the environmental temperature is small, by simple transformations we gat from (3)

$$\alpha_r = 0.215 \left(\frac{T_e}{100}\right)^3 \qquad (4)$$

The computational error here compared with formula (3) does not exceed 10% when $T_{c \cdot s} - T_e \leq 20^oK$.

To calculate the convective heat exchange at the surface of the clothing under conditions of free convection[3] suggests the criterion equation

$$Nu = C(GrPr)^n \qquad (5)$$

where the constants C and n are determined from Table 1.

Table 1 - Parameters C and n for difference values of GrPr

GrPr / Constant	10^{-4}-10^{-3}	10^{-3}-$5\cdot10^{2}$	$5\cdot10^{2}$-$2\cdot10^{7}$	$2\cdot10^{7}$-10^{13}
C	0.50	1.18	0.54	0.135
n	0	1/8	1/4	1/3

When $GrPr = \frac{g d_H^3 \beta_m \Delta T}{\nu^2} Pr = 6.3 \cdot 10^9 - 7.3 \cdot 10^{11}$ from Equation (5) we get

$$\alpha_c = 0.135\lambda \sqrt[3]{\frac{g\beta_m (t_{c\cdot s} - t_e)}{\nu^2} Pr} \tag{6}$$

The heat flow from the surface of the clothing is defined by the equation

$$q = (\alpha_r + \alpha_c)(t_{c\cdot s} - t_e) \tag{7}$$

and heat flow through the clothing by

$$q = \frac{1}{R_{cl}} (t_c - t_e) \tag{8}$$

where t_c is the human body surface temperature, °C;

R_{cl} is the overall thermal resistance of the suit of clothing.

From Equations (7) and (8) we find

$$t_{c\cdot s} = \frac{t_c - t_e}{R_{cl}(\alpha_r + \alpha_c)} + t_e \tag{9}$$

By solving the system of Equations (4), (6) and (9) for a body surface temperature of 31°C we find the thermal resistance of heat emission from the surface of the clothing with different thermal resistances of clothing and environmental temperatures. The results of calculation are shown in Table 2.

Table 2 - Thermal resistances to heat emission with different values of R_{cl} and t_e

Indices	t_e °C	R_{cl}, m^2 . deg/W					
		0.2	0.4	0.6	0.8	0.9	0.93
α_r	- 10	3.92	3.92				
α_c		4.94	4.06				
$R\alpha$		0.133	0.125				
$t_{c \cdot s}$		10.5	2.85				
α_r	- 30			3.09	3.09	3.09	3.09
α_c				4.42	4.09	3.95	3.92
$R\alpha$				0.133	0.139	0.142	0.143
$t_{c \cdot s}$				- 16.45	- 19.38	- 20.35	- 20.65

One may readily see that in calculating the thermal resistance of clothing the influence of the curvature of the surface of the clothing can be ignored. Then the overall thermal resistance of the layers of fabric is

$$\Sigma R_m = \frac{\delta_m}{\lambda_m} \tag{10}$$

where δ_m is the total thickness of the fabrics in the suit of clothing;

λ_m is the effective coefficient of thermal conductivity of the suit of clothing.

From the data in[1] (Table 59, p. 196), λ_m for different parcels of clothing varies from 0.046 to 0.065 W/m · deg with a mean value λ_m = 0.055 W/m · deg.

The thermal resistance of the air layers may be estimated from data from the technique worked out by the Central Scientific Research Institute of the Clothing Industry (TsNIIShP) and approved by the Ministry of Light Industry of the USSR.

When determining the thickness of fabrics in a suit of clothing required to ensure a given thermal resistance, the technique recommends the use of the graph shown in the diagram (Curve 1).

Having determined from the graph the thermal resistance of the clothing for different thicknesses of fabrics in the suit, by using the data calculated from Equation (10) and the data in Table 2 we can find the thermal resistance of the air layers for different thicknesses of fabrics in the suit:

$$\Sigma R_a = R_{cl} - R_\alpha - \Sigma R_m \qquad (11)$$

The results of calculation are shown in Table 3.

Table 3 - Values of thermal resistances R_α, R_m and R_a with different values of R_{cl}

Indices	R_{cl}, $m^2 \cdot deg/W$					
	0.2	0.4	0.6	0.8	0.9	0.93
δ, mm	1.3	4.4	8.8	16.2	24	36
R_α $m^2 \cdot deg/W$	0.113	0.125	0.133	0.139	0.142	0.143
R_α %	57	31	22	17	16	15
ΣR_m $m^2 \cdot deg/W$	0.024	0.080	0.160	0.295	0.437	0.654
ΣR_m %	12	20	27	37	49	71
ΣR_a $m^2 \cdot deg/W$	0.063	0.195	0.307	0.366	0.321	0.133
ΣR_a %	31	49	51	46	36	14

The relations between the components of the thermal resistance of the clothing are shown in the diagram.

CONCLUSIONS

In the thermal resistance of clothing a substantial part may be played by any of the components of the thermal resistance depending on the thickness of the clothing and the magnitude of its overall thermal resistance.

The thermal resistance of the air layers in existing heat-resistant clothing with a thickness of 1.3 to 24 mm and thermal resistance of 0.2 to 0.9 m^2, deg/W comes to 31-51% R_{cl}.

The magnitude of the thermal resistance of the air layers chiefly depends on the thickness of the clothing. As the thickness increases the thermal resistance at first increases, reaching a maximum, and then it decreases. This indicates that the thickness of the air layers in modern clothing is unstable and is non-linearly dependent on the thickness of the fabrics in the clothing. This results in a non-linear dependence of the thermal resistance of the clothing.

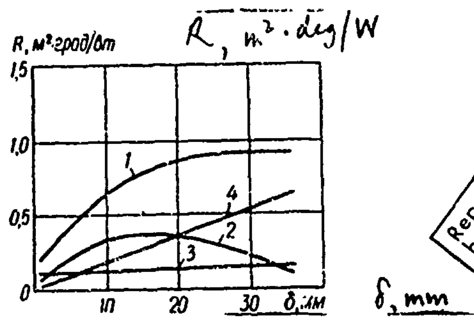
In present-day clothing the air layers are not used efficiently enough. With the right approach to design it should be possible to achieve about 50% of the required thermal resistance of clothing from the air layers. It should thus be possible to reduce the amount of materials used in present-day heat resistant clothing with consequent saving in costs.

REFERENCES

(1) P.A. Kolesnikov: Heat-resistant properties of clothing. IL (1965).

(2) R.F. Afanas'yeva: Scientific research transactions of the Central Scientific Research Institute of the Clothing Industry, 15 (1970).

(3) G.N. Dul'nev: Scientific research transactions of the Central Scientific Research Institute of the Clothing Industry, 16 (1970).



The dependence of thermal resistances on the overall thickness of fabrics in a suit of clothing:

1 - thermal resistance of clothing; 2 - of air layers;
3 - to heat emission from the surface; 4 - of the materials

R, $m^2 \cdot$ deg/W δ, mm