Mansoura Engineering Journal

Volume 17 | Issue 4 Article 10

12-1-2021

Warmth Property of Clothing Assembly - Part III: Theoretical Approach for Calculating the Warmth Parameters of Clothing Assembly.

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Recommended Citation

Abou-Taleb, Hemdan and Abd El-Hady, Nehad (2021) "Warmth Property of Clothing Assembly - Part III: Theoretical Approach for Calculating the Warmth Parameters of Clothing Assembly.," *Mansoura Engineering Journal*: Vol. 17 : Iss. 4 , Article 10.
Available at: https://doi.org/10.21608/bfemu.2021.188751

Mansoura Engineering Journal (MEJ), Vol. 17, No.4,Dec. 1992.

WARMTH PROPERTY OF CLOTHING ASSEMBLY
Part III : Theoretical Approach For Calculating The Warmth Parameters Of Clothing Assembly

خاصية الدفء لاقمشة الملبوسات
الجزء الثالث : اتجاه رياضى لحساب متغيرات الدفء لاقمشة الملبوسات

By

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الخلاصه :البحث الحالى هو دراسه لامكانيه التنبوء بمتغيرات الدفء لاقمشه الملبوسات · وقد امكن التوصل الى عدة معادلات رياضيه للتنبوء بمقاومة نفاذية الهواء والمقاومه الحراريه لاقمشة الملبوسات · لتطبيق المعادلات النظريه التى امكن التوصل اليها امكن اختيار ثلاث حالات لبس شائعة الاستعمال فى فصل الشتاء· النتائج المحسوبه بواسطه المعادلات النظريه وجد انها قريبه الى حد كبير من النتائج المعمليه المقاسه· ايضا امكن استنتاج معادلة معمليه لتناسب النتائج المقاسه للمقاومه الحراريه لاقمشه الملبوسات مستخدما طريقه تحليل الانحدار المتعدد· وهذة الطريقه تربط المقاومه الحراريه لاقمشه الملبوسات مع وزن المتر المربع والسمك ومقاومه الهواء خلال اقمشه الملبوسات·
وهذة العلاقه المعطيه يمكن بها التنبوء بالمقاومه الحراريه لاقمشة الملبوسات بدقه·

ABSTRACT - the present work deals with the theoretical prediction of warmth parameters of clothing assembly. Theoretical expressions are derived for calculating both air flow resistance and thermal resistance of clothing assembly. Three different cases which represent the most common wearing cases in winter season were selected for applying the theoretical expressions. The derived relations were found to be fairly close to those observed experimentally. Also an empirical relationship is fitted to the measured thermal resistance data of clothing assembly using stepwise multiple regression analysis.The regression analysis relates the thermal resistance of the clothing assembly to the parametes of weight per unit area, thickness and air resistance. This empirical relationship is shown to predict the thermal resistance of clothing assembly accurately.

NOMENCLATURE

V	Air velocity through each layer of clothing assembly,m/Sec
t	Fabric or clothing assembly thickness, m
μ	Dynamic viscosity of air, $\mu = 1.855\times10^{-5}$ (N.Sec)/m^2
$\Delta P = (Pa-Pb)$	Air pressure drop, N/m^2
Pa,Pb	Pressure values on both the upper and lower surfaces of the clothing assembly, N/m^2
B	Permeability coefficient of single layer,m^2
B_t	Permeability coefficient of clothing assembly, m^2
F	Rate of air flow, m^3/Sec
A	Area of tested specimen of clothing assembly, m^2
$\acute{R}$	Air resistance of single layer, (N.Sec)/m^3
$\acute{R}_t$	Air resistance of clothing assembly, (N.Sec)/m^3
q	Heat flux density, watt/m^2
Q	Heat flux, watt

Ta,Tb	Degree of temperature of air and body respectivelly, C°
Ka	Thermal conductivity of air layers, ka=0.02 watt (m.C°)
S	Air spacing between fabric layers, m
Ra	Thermal resistance of all the air layers, $(m^2.C°)$/watt
Rt	Total thermal resistance of clothing assembly, $(m^2C°)$/watt
Ro	Outside air film resistance, $(m^2.C°)$/watt
Ko	Thermal conductivity of the overall system, watt/(m.c°)
n	Number of layers

1.INTRODUCTION

One of the most effective properties related to the clothing assembly is the warmth property [1]. The air flow resistance and thermal resistance are two important physical criteria involved in warmth of clothing assembly. Different wearing cases of clothing assembly can be used in winter season to protect the human body against the atmospheric conditions.The type and arrangement of components of clothing assembly affect to a great extent the warmth parameters of the clothing assembly such as air resistance and thermal resistance. Thermal insulation properties of clothing assembly are dependent on number of layers contained in clothing assembly, thickness of each layer and thickness of clothing assembly (including the thickness of air layers), fibre composition and air permeability of clothing assembly also the outer conditions such as degree of temperature, air moisture and wind speed. Because clothing is basically concerned with minimizing the thermal stresses, warm or cold, imposed on man by the environment, there is good reason to measure the thermal insulation of single layers of clothing materials, as well as multiple layers assembled more or less as in clothing during use [2].

Mc Adams [3] found that, at the higher wind speed the air will be circulated in the pores of the fabric causing a greater heat loss which in turn decreases the value of fabric thermal insulation. This circulation depends upon the pore volume, shape and orientation inside the textile structure. Therefore, the fabric of higher air permeability is a good insulator in the still air conditions, while it becomes of poor insulating value in a wind condition, i.e. in a moving surrounding air.

Previous work [4-8] in the literature on the subject of thermal insulation has been only concerned with determining warmth parameters of single layers experimentally and theoretically. And very little work has been done on the prediction of warmth parameters of clothing assembly. The purpose of this paper is to fill this gap and to relate the observed performance of the clothing assembly to its components.

2. MATHEMATICAL PREDICTION OF WARMTH PARAMETERS OF CLOTHING ASSEMBLY

2.1 Air Flow Resistance :

From Darcy's law [9], the mean velocity V, m/Sec, across a porous medium with a thickness t, metre, for a viscous fluid whose dynamic viscosity is μ, $(N\cdot Sec)/m^2$, under a pressure drop ΔP. N/m^2, is

$$V = (B.\,\Delta P)/\mu.t \quad , m/Sec \qquad ...(1)$$

Where B is a permeability coefficient, m^2, indicating more or less facility for fluid to flow through the porous medium.

Scheidegger [10] verified empirically that Darcy's law is valid for the small values of (V) of a more general law :

$$\Delta P = cV + dV^2 \qquad \ldots(2)$$

where ΔP-pressure drop, N/m^2; and
c,d-constants depend upon the parameters of fabric construction.

For tight fabrics Equation (2) may be simplified by cancelling out (dV^2):

Then, $V = \Delta p/c$, m/Sec ...(3)

where $C = \mu . t/B$

Equation (3) can be rewritten as follows :

$$V = (B \Delta P)/\mu . t \quad , m/Sce \qquad \ldots(4)$$

Hence, the effect of air gap thickness on air permeability is very small [2], therefore it can be neglicted. Then rate of air flow (F) through multi-layer fabrics as shown in Fig. (1) can be calculated as follows :

$$F = A.Bt.\ \Delta P/(\mu . x),\ m^3/Sec \qquad \ldots(5)$$

or

$$F = A.Bt.\ (Pa-Pb)\ /(\mu . x),\ m^3/Sec \qquad \ldots(6)$$

where $X = \sum_{i=1}^{n} t_i$ - total thickness of n multi-layers of fabrics , m ;

μ-dynamic viscosity of air, $(N.Sec)/m^2$;

Bt-permeability coefficient of total layers, m^2;

A-area of tested specimen of clothing assembly, m^2; and

Pa,Pb-pressure values on both the upper and lower surfaces of the clothing assembly, N/m^2.

If the pressure values between each fabric layer and the adjacent one are: $P_1, P2, P3, \cdots P_{n-1}$

$$F = \frac{A.B_1.(Pa-P_1)}{\mu . t_1} = \frac{A.B2.\ (P_1-P2)}{\mu . t2} = \frac{A.B3\ (P2-P3)}{\mu . t3} = \ldots\ldots = \frac{A.Bn\ (Pn-Pb)}{\mu . tn}$$

$$(Pa-Pb) = (Pa-P_1) + (P_1-P2) + (P2-P3) + \ldots + (Pn-Pb) \qquad \ldots(7)$$

By substituting in Equation (7) from Equations (5,6), yields:

$$\frac{F.\mu . X}{A.Bt} = \frac{P.\mu . t_1}{A.B_1} + \frac{F.\mu . t2}{A.B2} + \frac{F.\mu . t3}{A.B3} + \ldots + \frac{F.\mu . tn}{A.Bn}$$

or

$$\frac{X}{Bt} = \frac{t_1}{B_1} + \frac{t2}{B2} + \frac{t3}{B3} + \ldots + \frac{tn}{Bn} \qquad \ldots(8)$$

$$\text{Then , } Bt = \frac{X}{\sum_{i=1}^{n} \left(\frac{ti}{Bi}\right)} \qquad \ldots(9)$$

By substituting in Equation (5) from Equation (9), gives

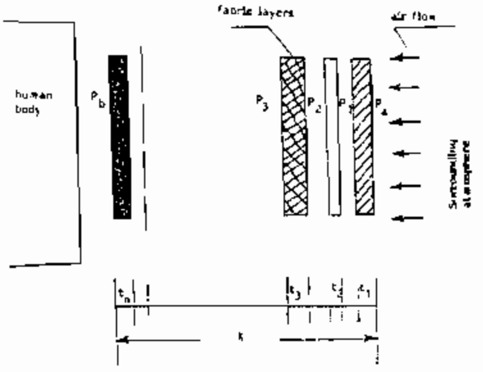

Fig. (1) A simple model for studying air flow through clothing assembly

$$F = \frac{A.\ \Delta P}{\mu \sum_{i=1}^{n} (\frac{ti}{Bi})} \quad , m^3 / Sec \qquad ...(10)$$

Hence, air resistance ($\acute{R}$) = 1/ (air permeability)

$$\text{Terefore} \ , \acute{R} = \frac{\Delta P \ (N/m^2) \ . \ A \ (m^2)}{F \ (m^3/ \ Sec)} \quad , \quad (N.Sec)/m^3 \qquad ...(11)$$

From Equations (10,11) air resistance of clothing assembly ($\acute{R}t$) can be calculated as follows :

$$\acute{R}t = \mu . \sum_{i=1}^{n} (\frac{ti}{Bi}) \quad , (N.Sec) /m^3 \qquad ...(12)$$

2.2 Thermal Resistance :

Studying the heat transfer by conduction from the body to the surrounding atmosphere through clothing assemblies could be made by considering the model shown in Fig. (2) [4,7]. Assuming that no moisture transfer through clothing assembly ; and no heat transfer by radiation and convection, due to the small air thickness between the fabric layers which decrease the amount of heat transfer by convection and it is negligable.

If the body temperature is greater than the surrounding atmosphere like shown in winter season or in the cold regions, the heat will flow from the body to the surrounding atmosphere as shown in Fig. (2). And for the steady state flow, the rate of heat flow is considered to be "constant" . Therefore, the heat flow through an area (A) is the same for each section of clothing assembly and may be represented as follows :

$$q = Q/A = \frac{Ko. \ (Tb-Ta)}{X} \qquad ...(13)$$

$$Q/A = \frac{(Tb-Ta)}{(X \ /Ko)} = \Delta T/Rt \qquad ...(14)$$

where X - the overall thickness of air and fabric layers

$$X = \sum_{i=1}^{n} ti + \sum_{i=1}^{n} Si$$

If the common temperatures between each fabric layer and the adjacent air layer are :

$T_1, T'_1, T2, T'2, \ldots T'n-1, Tn$ for the layers 1, 2, 3, . . . , n respectively, one obtain:

$$Q = \frac{ka\ A\ (Tb-T1)}{S_1}$$

$$= \frac{K_1\ A\ (T_1-T'_1)}{t_1}$$

$$= \frac{Ka\ A\ (T'_1-T2)}{S2}$$

$$= \frac{K2\ A\ (T2-T'2)}{t2}$$

$$= \ldots\ldots\ldots\ldots\ldots$$

$$Q = \frac{Ka\ A\ (T'\,n_{-1} - Tn)}{Sn}$$

$$= \frac{Kn\ A\ (Tn - Ta)}{tn} \qquad \ldots (15)$$

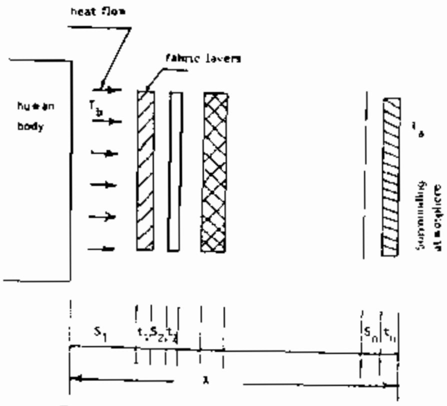

Fig. (2) A simple model for studying heat flow through clothing assembly.

$$\text{Then,}(Tb-Ta)=(Tb-T_1)+(T_1-T'_1)+(T'_1-T2)+\ldots+(T'n-1-Tn)+(Tn-Ta) \qquad \ldots(16)$$

By substituting in Equation (16) from Equations (13,15) yields :

$$\frac{Q.X}{Ko.A} = \frac{Q.S_1}{Ka.A} + \frac{Q.t_1}{K_1.A} + \frac{Q.S2}{Ka.A} + \frac{Qt2}{K2.A} + \ldots + \ldots + \ldots + \frac{Q\ Sn}{Ka.A} + \frac{Q.tn}{Kn.A} + \frac{Q.Ro}{A}$$

$$\frac{Q.X}{Ko.A} = \frac{Q.S_1}{Ka.A} + \frac{Q.S2}{Ka.A} + \ldots + \frac{Q\ Sn}{Ka.A} + \frac{Q.t_1}{K_1.A} + \frac{Q\ t2}{K2.A} + \ldots + \frac{Q\ tn}{Kn.A} + \frac{Q.Ro}{A} \qquad \ldots(17)$$

Dividing by (Q/A) Equation (17) can be rewitten as follows :

$$\frac{X}{Ko} = \frac{S_1}{Ka} + \frac{S2}{Ka} + \ldots + \frac{Sn}{Ka} + \frac{t_1}{K_1} + \frac{t2}{K2} + \ldots + \frac{tn}{Kn} + Ro \qquad \ldots(18)$$

Equation (18) can be rearranged as follows :

$$\frac{X}{Ko} = \sum_{i=1}^{n} \frac{S_i}{Ka} + \sum_{i=1}^{n} \frac{T_i}{K_i} + Ro$$

Or

$$X \quad . \quad n \quad t_i$$

From Equations (14,19), total thermal resistance of clothing assembly (Rt) can be calculated as follows :

$$Rt = (A.\ \Delta T)\ Q = Ra + \sum_{i=1}^{n} \frac{t_i}{k_i} + Ro \qquad ...(20)$$

According to the above assumptions (Ro) can be neglected and Equation (20) can be rewritten as follows :

$$Rt = \sum_{i=1}^{n} \frac{t_i}{k_i} + Ra \qquad ...(21)$$

where $Ra = \dfrac{\sum_{i=1}^{n} S_i}{Ka}$ = the thermal resistance of all the air layers of clothing assembly.

This theoretical expression(Eq.21)has been checked for three common wearing cases of clothing assembly. It was found experimentally that :

(Ra) for the first case (3 components)= $3X23.3X10^{-4} = 70X10^{-4}$ (m^2.C°)/watt

(Ra) for the second case (5 components) = $5X8X10^{-4} = 40X10^{-4}$ (m^2.C°)/watt

(Ra) for the third case (6 components)= $6X6.6X10^{-4} = 39.6X10^{-4}$ (m^2.C°)/watt

3. EXPERIMENTAL WORK

3.1 Materials

Three wearing cases (models) of clothing assembly were selected and described as follows :

The 1 st wearing case is consisted of three components e.g. under wear, shirt fabric and knitted outer wear;

The 2 nd wearing case is consisted of five components e.g. under wear, shirt fabric and jacket (lining, gasket and suit fabric) ; and

The 3 rd wearing case is consisted of six components e.g. under wear, shirt fabric, knitted outer wear and jacket (lining, gasket and suit fabric).

Two common types of each component of clothing assembly were chosen as the following:

- Under wear is either Jil (J) or Tricona (T);
- Shirt fabric is either poplin of kafr El-Dawar (K) or poplin of El-Mahalla El-Kuba(M);
- Knitted outer wear is either half cardigan (H) or double jersey (D);
- Lining fabric is either polyester (P) or Viscose (V);
- Gasket fabric is either with stick (S) or without Stick (W);
- Suit fabric is 50/50 (5W), 70/30 (7W) and 100/0 (10 W) % wool /polyester.

A few details on the components characteristics are given in Table 1 (a & b).

Table 1 : Characteristics of Components of Clothing Assembly

a) Under wear and knitted outer wear

Characteristics	Under wear		Knitted outer wear	
	T	J	H	D
Weight, g/m 2	218	182	546	437
Thickness at 5 g/cm^2,10^{3}m	1.03383	0.757	5.175	3.925
Density, g/cm ^{3}	0.2109	0.2404	0.1055	0.1113
Fabric bulk, cm^3/g	4.7424	4.1603	9.4780	8.9817
Porosity, %	86.3	84.4	91.0	90.5
Wales /cm	12	24	1.83	2.64
Coarses /cm	13	17	4.89	8.8
Yarn count, Ne	30	35	28/2	28/2
Loop length, mm	3.8	2.4	22	18.6
Structure	interlock	rib	half cardigan	double jersey
Material	cotton	cotton	acrylic	acrylic

b) Shirt, lining, gasket and suit fabrics

characteristics	Shirt		Lining		Gasket		Suit fabric		
	K	M	P	V	W	S	5 W	7 W	10W
Weight, g/m2	105	98	75	95	400	185	165	219	285
Thickness at 70 g/cm^2,10^{3}m	0.2075	0.195	0.20	0.19	0.968	0.413	0.255	0.320	0.716
Density, g/cm3	0.406	0.379	0.344	0.450	0.386	0.358	0.427	0.373	0.371
Fabric bulk, cm^3/g	2.46	2.64	2.91	2.22	2.59	2.79	2.34	2.68	2.69
Porosity, %	73.6	75.4	77.7	70.8	74.9	76.7	68.3	72.0	71.6
Ends /cm	30	38	25	40	10	23	21	20	17
Picks /cm	28	24	15	17	17	26	20	20	20
Warp count, Ne	80/2	28/1	33	33	2.5	36	28.7/2	29.5/2	16.7/2
Weft count, Ne	70/2	30/1	30	30	8	24	32/2	21.2/2	20/2
Material	cotton	cotton	polyes.	viscose	cotton	cotton	50/50 warp 50/50 weft	30/70 warp 70/30 weft	100/0 warp 100/0 weft

3.2 Testing Methods

3.2.1 Air resistance

Air resistance values were measured with a Shirley air permeability instrument at an air pressure difference of 49 pascals (5 mm of water).

3.2.2 Thermal resistance

Intrinsic thermal conductivity $(\acute{K})$ and thermal resistance (R) values were measured on a heat transport apparatus described in part (I) of this series.

All tests were carried out on conditioned samples as specified by ASTM standard D 1776-74 [11] in a standard conditioning room (65±2 % relative humidity, 21±2 C°).

The results of warmth parameters of the individual layers of the components of clothing assembly are given in Table (2).

Table 2 : Warmth Parameters of Components of Clothing Assemblies

Type of component (Symble)	Permeability Coefficient, m^2 (B)	Air Resistance, $(N.Sec)/m^3$ $(\acute{R})$	Thermal Conductivity, watt/(m.C°) $(\acute{K})$	Thermal Resistance, $10.(m^2.C^\circ)/watt$ (R)
T	$7.23267X10^{-11}$	265.15	0.17747	58.297
J	$9.78026X10^{-11}$	143.61	0.15380	49.321
K	$4.61012X10^{-12}$	1039.46	0.06558	39.822
M	$7.01558X10^{-11}$	68.44	0.06656	39.630
H	$1.70021X10^{-9}$	56.46	0.27367	189.850
D	$1.17230X10^{-9}$	62.11	0.23646	166.082
P	$4.95531X10^{-11}$	81.72	0.06153	35.562
V	$3.21666X10^{-11}$	121.78	0.07297	29.260
W	$4.08701X10^{-11}$	470.52	0.16885	61.702
S	$8.25613X10^{-12}$	1160.86	0.118557	43.938
5W	$2.77386X10^{-11}$	258.25	0.08850	44.444
7W	$7.40879X10^{-12}$	1470.15	0.10275	57.777
10W	$1.29473X10^{-11}$	1099.15	0.12543	61.207

4. RESUTS AND DISCUSSION

The practical application of the previous Equations (12 & 21) could be obtained by using the results of the experimental work. Three different cases which represent the most common wearing cases were used and the results of warmth parameters are given in Table 3 (a,b&c).

Table 3 : Warmth Parameters of Clothing Assembly

(a) The 1 st wearing case

No.	Components	Weight, g/m^2	Thickness, at 5 g/cm^2, mm	Air resistance, (N.Sec) $/m^3$		Thermal resistance, $10^4.(m^2.°C)$/watt		
				measured	calculated Eq.(12)	measured	calculated Eq.(21)	calculated Eq.(22)
1	T+K+H	869	6.533	1222.9	1156.5	385.1	358.0	379.0
2	T+K+D	760	5.350	1253.2	1162.2	324.9	334.2	330.0
3	T+M+H	862	6.740	304.2	373.2	352.5	357.8	380.8
4	T+M+D	753	5.233	303.6	378.8	325.8	334.0	320.6
5	J+K+H	833	6.133	1150.2	1035.0	369.1	349.0	362.1
6	J+K+D	724	5.067	1170.9	1040.6	326.4	325.2	317.1
7	J+M+H	826	6.267	288.4	251.6	357.0	348.8	361.7
8	J+M+D	717	5.067	285.1	257.3	327.3	325.0	312.0

(b) The 2 nd wearing case

No	Components	Weight, g/m^2	Thickness at $5g/cm^2$, m m	Air resistance, $(N.Sec)/m^3$		Thermal resistance, $10^4.(m^2.°C)$/watt		
				measured	calc. Eq.(12)	measured	calculated E q(21)	calculated E q.(22)
1	J+M+V+S+5W	725	2.360	1530.4	1736.1	201.5	246.6	226.5
2	T+M+V+W+10W	1096	3.467	2047.6	2008.2	330.5	290.1	296.6
3	J+K+V+W+10W	1067	3.250	2770.5	2670.0	293.0	281.3	290.6
4	T+K+V+S+5W	768	2.587	2373.5	2641.0	228.7	255.8	242.0
5	J+M+P+W+5W	920	2.883	1088.0	1005.7	270.3	270.7	257.7
6	T+M+P+S+10W	861	3.000	2535.0	2658.4	269.7	278.6	264.4
7	J+K+P+S+10W	832	2.733	3450.4	3320.3	270.2	269.9	257.6
8	T+K+P+W+5W	963	3.217	2014.4	1910.6	266.7	279.8	277.3

(c) The 3rd wearing case

No	components	weight, g/m^2	Thickness, at $5g/cm^2$ mm	Air resistance $(N.Sec)/m^3$		Thermal resistance, $10^{-4}(m^2.c^{\circ})$/watt		
				measur.	calcu. Eq.(12)	measured	calculated	
							Eq.(21)	Eq.(22)
1	J+M+D+P+W+10W	1477	6.950	2404.2	2030.2	398.4	462.5	447.7
2	T+M+D+V+S+10W	1318	6.757	2307.3	2760.6	414.4	438.4	428.0
3	J+K+D+V+W+5W	1384	6.550	1987.4	1891.2	364.5	430.6	424.5
4	T+K+D+P+S+5W	1185	6.350	2419.7	2663.0	411.0	428.1	404.0
5	J+M+H+P+S+5W	1251	7.193	1572.3	1752.5	453.2	442.7	433.8
6	T+M+H+V+W+5W	1522	8.000	1419.6	1223.7	522.2	463.1	482.2
7	J+K+H+V+S+10W	1398	7.533	3029.6	3416.8	478.0	453.4	464.5
8	T+K+H+P+W+10W	1629	7.440	2587.8	2807.9	497.9	486.4	477.5

The comparison between both calculated and measured values has been possible. The good agreement shown by Table 3 (a,b,c) supports the validity of the derived Equations (12) and (21). Figures (3&4) show both measured and calculated values for the tested wearing cases. It can be seen that the theoretical relations obtained in the work discussed in this paper can be therefore considered to agree fairly close with the obtained experimental results.

Figures 5,6 and 7 show the variation of thermal resistance of clothing assembly with weight per unit area, thickness and air resistance respectively. In general the thermal resistance increases with weight per unit area, thickness and air resistance. There is a considerable amount of scatter, which may be referred to the interaction effect of other clothes parameters. Since, in plotting these figures, no attempt was made to keep the other parameters constant.

To examine the interaction of thermal resistance of clothing assembly and its parameters, an equation relating the thermal resistance of clothing assembly to the variables of weight per unit area, thickness and air resistance was fitted to the experimental data using stepwise multiple regression analysis [12,13]. Stepwise multiple regression analysis can be looked as an extension of straight line regression analysis, involving only one independent variable where there are any number of independent variables. As with stright line regression, the basic approach for determining the best estimate of a stepwise multiple regression equation is the least squares approach, which is the method of fitting a line to a set of data points in such a way that the sum of squares of error has its smallest value [14]. The results of the stepwise multiple regression analysis are

$$R_t X 10^{-4} = 80.280 + 7.980 X 10^{-2} M + 34.147\ t + 5.104 X 10^{-3} \acute{R}t \qquad ...(22)$$

where M = weight per unit area of clothing assembly (g/m^2), t = thickness of clothing assembly at $5g/cm^2$ (mm), $\acute{R}t$ = air resistance of clothing assembly ($N.Sec.m^{-3}$), Rt= = thermal resistance of clothing assembly ($m^2.c^{\circ}$)/watt. The correlation coefficient = 0.96. The fitted regression equation was used to predict the thermal resistance per each wearing case of clothing assembly. Figure 4 shows the comparison between the measured and predicted thermal resistance. As can be seen, the points fall on a straight line roughly normally distributed with no bias, indicating that the empirical Equation 22 provides a good fit to the experimental data. As such, the empirical relation can be useful to a manufacturer who can relate the mass and thickness of the fabrics

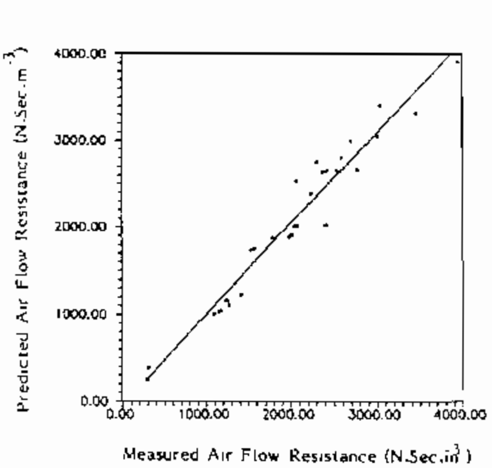

FIG.3.COMPARISON BETWEEN MEASURED AND PREDICTED AIR RESISTANCE

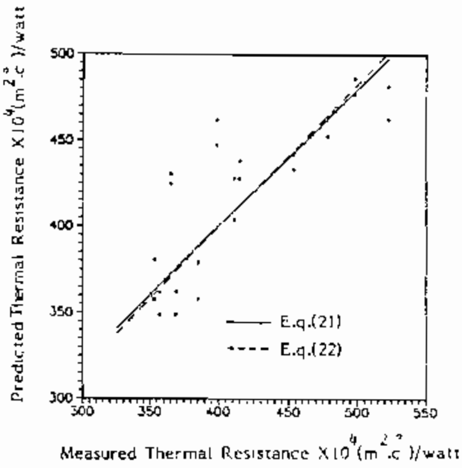

FIG.4.COMPARISON BETWEEN MEASURED AND PREDICTED THERMAL RESISTANCE

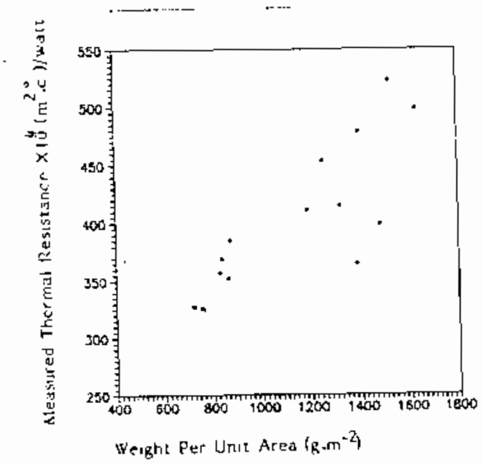

FIG.5.INFLUNCE OF WEIGHT PER UNIT AREA OF CLOTHING ASSEMBLY ON THE THERMAL RESISTANCE

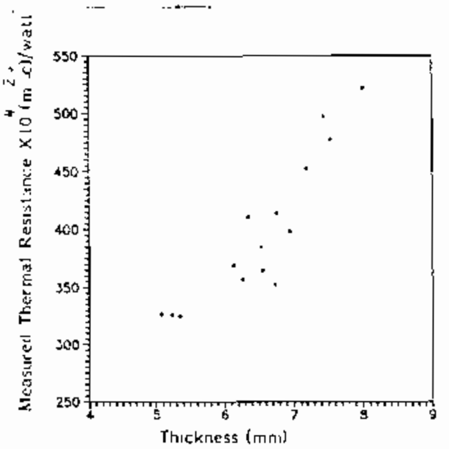

FIG.6.INFLUENCE OF THICKNESS OF CLOTHING ASSEMBLY ON THE THERMAL RESISTANCE

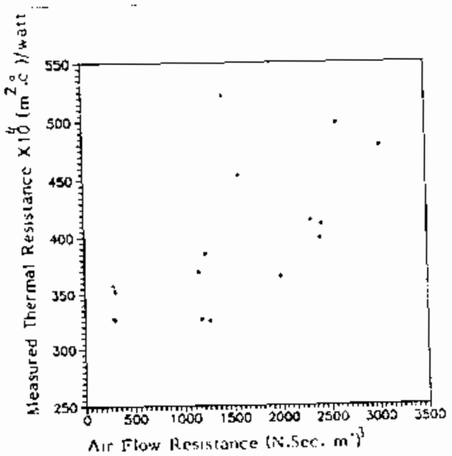

FIG.7.INFLUNCE OF AIR FLOW RESISTANCE OF CLOTHING ASSEMBLY ON THE THERMAL RESISTANCE

5. CONCLUSIONS

From the above analysis the following conclusion can be drawn:

1. The comparison between both calculated and measured values of warmth parameters was then possible. The good agreement shown by Table (3) and Figures (3&4) supports the validity of the derived equations at least within the range of type and arrangement of components of clothing assembly used in winter season.
2. The thermal resistance of clothing assembly is dependent on its weight per unit area, thickness and air resistance. On the basis of the empirical equation fitted to the data, a considerable amount of variation in thermal resistance can be achieved by increasing weight per unit area, thickness and decreasing the size of the air channels within the components of clothing assembly through which air flows.

REFERENCES

1- Kaswell R.E., "Textile Fibres, Yarns and Fabrics". A Book Published By Reinhold Publishing Corporation, New York (1953).

2- Sklenekov V.P.,Afanaceva R.F. and Mashkova E.N., Assessment of Textile Materials. Moscow, 1985. (in Russian).

3- Mc Adams H.W."Heat Transmission", A Book Published by Mc Graw-Hill Book Co. Inc. New.York.

4- El-Okeily M.E.,M.Sc. Thesis, Alexandria University, 1973.

5- Abou-Taleb H.A."Measurement of Thermal Conductivity of Fabrics", Mansoura Engineering Journal (MEJ), Vol.12, No.1, June 1987,P.82-90.

6- Kolesnekov P.A., Thermal Insulation Properties of Clothes, Moscow, 1965. (in Russian).

7- Kolesekov P.A., Principles of Design of Thermal Insulated Clothes, Moscow, 1971. (in Russian).

8- Umbach K.Ubergangs-Phänomene Von Wärme und Feuchte Zwischen Textilschichten, Melliand Textilberichte, 1980, No.5,S.466-469.

9- Darcy H.,Les Fontaines Publiques de la ville de Dijon-Dalmont, Paris, 1856.

10- Scheidegger A.E.,"The Physics of Flow Through Porous Media", University of Toronto Press, 1957.(in Russian).

11- American Society for testing and Materials (ASTM) Standard, Part 32; 1980.

12- Draper N.R. and Smith H.,"Applied Regression Analysis", John Wiley and Sons, New York, 1981, PP. 307.

13- Mosteller F. and Tukey J.W., "Data Analysis and Regression", Addison-Wesley Publishing Company, London, 1977, pp.387.

14- Adler H.L. and Roessler E.B.,"Probability and Statistics", W.H. Freeman and Company, London, 1964.