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WARMTH PROPERTY OF CLOTHING ASSEMBLY
Part I: Factors Affecting Warmth Property of Clothing Assembly

خاصية الدفء لأقمشة الملبوسات

الجزء الاول : العوامل الموثرة على خاصية الدفء لاقمشة الملبوسات .

By

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الخلاصة : هذا البحث يهتم بدراسة تأثير العوامل الموثرة على خاصية الدفء لأقمشة الملبوسات المختلفة المستخدمة في فصل الشتاء مثل نوع الفانلة الداخلية وقماش القمصان والبلوفر الخارجي وقماش البطانة والحشو وقماش البدلة الخارجي وسمك طبقة الهواء الموجودة بين قماش البطانة وقماش البدلة وعدد الطبقات المستخدمه (حالة اللبس) . وقد أمكن استخدام طريقة تصميم التجارب لايجاد أمثل قيم لهذه العوامل للحصول على أعلى عزل حراري . ومن النتائج اتضح أن القيم المثلى لهذه العوامل عند استخدام حالة اللبس الأولى هي فانلة تريكونا وقميص بوبلين كفر الدوار وبلوفر ذو تركيب نصف كارديجان وعند استخدام حالة اللبس الثانية هي فانلة جيل وبوبلين كفر الدوار وبطانة من البوليستر وحشو لاصق وقماش بدله ١٠٠ ٪ صوف وعند استخدام الحالة الثالثة هي فانلة جيل وبوبلين كفر الدوار وبطانة من البوليستر وفراغ هوائي بسمك ٥ رسم وقماش بدلة ١٠٠ ٪ صوف وعند استخدام الحالة الرابعة هي فانلة جيل وبوبلين كفر الدوار وبلوفر ذو تركيب نصف كارديجان وبطانة من الفسكوز وقماش حشو لاصق وقماش بدلة صوف ١٠٠ ٪ وعند استخدام الحالة الخامسة هي فانلة جيل وبوبلين كفر الدوار وبلوفر ذو تركيب جرسية مزدوج وبطانة من الفسكوز وفراغ هوائي ٥ر١ سم وقماش بدلة صوف ٥٠ ٪ / بولي استر ٥٠ ٪ . أيضا امكن انشاء جهاز جديد لقياس العزل الحراري لاقمشة الملبوسات .

ABSTRACT - The study reported in the work concerns the influence of factors affecting warmth property of different wearing cases of clothing assembly used in winter season in Egypt such as type of under wear, suit fabric, knitted outer wear, lining, gasket and suit fabrics, air gap thickness between lining and suit fabrics and number of layers used in clothing assembly (wearing case). The application of fractional factorial design to optimize the factors affecting warmth property of clothing assembly is demonstrated. The optimum factors (components) when using the 1 st wearing case are Tricona, poplin of Kafr El-Dawar and half cardigan knitted outer wear. And when using the 2 nd one are Jil, poplin of Kafr El-Dawar, polyester lining fabric, sticking gasket and 100% wool suit fabric. And when using the 3 rd one are Jil, poplin of Kafr El-Dawar, polyester lining fabric, 0.5 cm air gap and 100% wool suit fabric. And when using the 4 th one are Jil, poplin of Kafr El-Dawar, half cardigan knitted outer wear, viscose lining fabric, sticking gasket and 100% wool suit fabric. And when using the 5 th one are Jil, poplin of Kafr El-Dawar, double jersey knitted outer wear, viscose lining fabric, 1.5 cm air gap thickness and 50% wool/ 50% polyester suit fabric. Also a new apparatus for measuring thermal insulation of clothing assembly could be constructed.

1. INTRODUCTION

In winter, different wearing cases of clothing assembly can be used to protect the human body against the atmospheric conditions. One of the most effective properties related to the clothing assembly is the warmth property. The thermal conductivity and air resistance are two important physical criteria involved in warmth of clothing assembly [1]. The number and size of the air spaces per unit area in a fabric greatly affect its thermal properties. Although in general textile fibres are good heat insulator and air gap between fibres improves this insulation provided that, air is not in motion. Previous Work [2-6] on the subject of heat transmition through fabrics has concerned with the type of fibres, yarn parameters, fabric construction, fabric weight, density and thickness and very little work has been done on the effect of type of under wear, suit fabric, knitted outer wear, lining, gasket, suit fabrics, number of layers in clothing assembly and air spacing (air gap thickness) between lining and suit fabric for predicting warmth parameters of clothing assembly.

The object of this paper is to fill this gap and to design a new simplified apparatus to invistigate the important factors influencing the warmth property of clothing assembly in terms of its thermal and air resistance and to relate the observed performance of the clothing assembly to its components. And to determine optimum components for each clothing assembly.

2. EXPERIMENTAL WORK

2.1 Materials

Five wearing cases 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);

The 3 rd wearing case is consisted of five components e.g. under wear, shirt fabric and jacket (lining, air spacing and suit fabric);

The 4 th wearing case is consisted of six components e.g. under wear, shirt fabric, knitted outer wear and jacket (lining, gasket and suit fabric); and

The 5 th wearing case is consisted of six components e.g. under wear, shirt fabric, knitted outer wear and jacket (lining air spacing and suit fabric).

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

- Under wear is either Jil (J) or Tricona (T
- Shirt fabric is either poplin of Kafr -Dawar (K) or poplin of El-Mahalla El-Kubra (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 sticking (S) or without sticking (W);
- Suit fabric is 50, 70 or 100% wool (5W, 7W or 10W) and 50,30 or 100% polyester respectively.

2.2 Testing Methods

2.2.1 Thermal Resistance

Intrinsic thermal conductivity (K) and thermal resistance (R) values were measured on a heat transport apparatus shown in Fig. (1).

2.2.2 Air Resistance

Air resistance values were measured with a Shirley air permeability instrument at an air pressure difference of 49 pascals.

2.3 Measurement of Thermal Properties

The thermal properties of the fabrics were measured by the apparatus shown in Fig. (1). It consists basically of bottom hot plate, simulating a section of the surface of a human body, which can be covered with clothing assembly and sink. The heat source, guard heater, contains nickel chrome wire heater of 10.4 ohm resistance (insulated with gypsum). The temperature of the heat source was determined

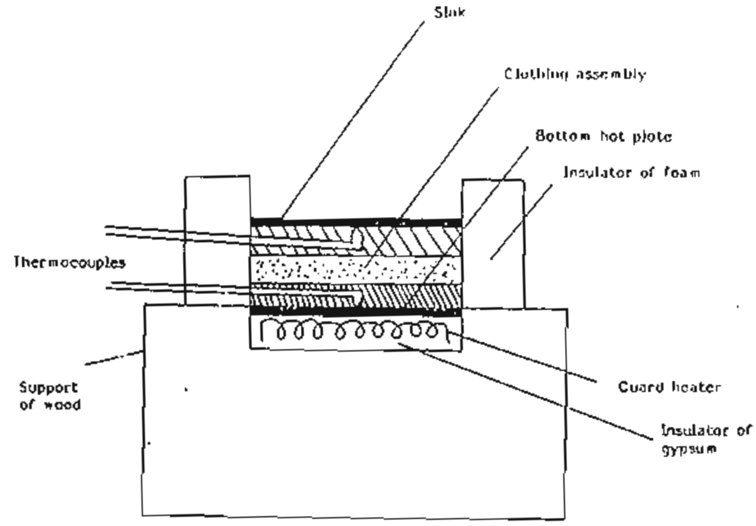

Fig. (1) Cross section of apparatus

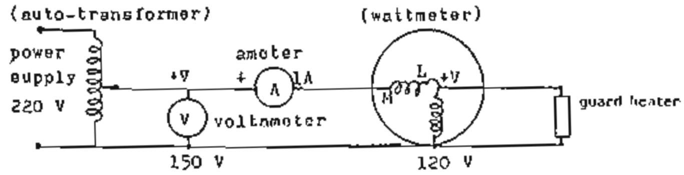

Fig. (2) Electrical circuit diagram of the apparatus.

by a copper constantan thermocouple attached to it. The heat source is insulated from the rest of the base by a support made of wood to prevent heat losses during the tests. The temperature was indirectly measured by digital multimeter, which was calibrated at regular intervals. The connections of the thermocouple to the digital multimeter are made through a 7-point switch, with one common cold junction. The insulated heater was connected to an electrical stabilized power supply as shown in Fig. (2), which can control properly the surface temperature of the bottom hot plate in a range of 32 °C to 33 °C by means of changing the circuit input voltage. Total thermal resistance of clothing assembly (R_t) could be calculated by the following equation:

$$R_t = (A.\ \Delta T) / Q\ ,\ (m^2\ .\ °C) / \text{watt} \qquad \ldots (1)$$

where A- area of heat flow, m^2;

ΔT- temperature difference, °c; and

Q- heat flux, watt.

3. RESULTS OF EXPERIMENTS

The following are the results obtained from the tests and measurements, arranged according to the plan of work.

3.1 Design of Experiment

A fractional factorial design [7] of three, five and six variables (components) at two levels, namely, -1 and +1 were chosen to investigate all the five wearing cases of clothing assembly.

The response Y is given by a second - order polynomial, i.e.:

$$Y = b_o + \sum_{i=1}^{n} b_i X_i + \sum_{i,j=1}^{n} b_{ij} X_i X_j , \qquad \ldots (2)$$

where X_i = i th variable

n = number of variables , and

b_o , b_i and b_j = regression coefficients associated with the variable.

In order to determine the regression coefficients, the response Y (thermal resistance or air resistance of clothing assembly) had to be found by using different experimental combinations of the variables under consideration.

3.1.1 The 1 st Wearing Case of Clothing Assembly

The values of thermal resistance and air resistance of the clothing assembly and its three components are given in Tables (1,2).

Table (1) : Actual Levels of Thermal Resistance of Components of Clothing Assembly.

Factor	Level -1	Level +1
R_1 = Thermal resistance of under wear, $10^4 . (m^2.°c)$ / watt	49.321 (J)	58.297 (T)
R_2 = Thermal resistance of shirt fabric, $10^4 . (m^2.°c)$ / watt	39.630 (M)	39.822 (K)
R_3 = Thermal resistance of Knitted outer wear, $10^4 (m^2.°c)$/watt	166.082 (D)	189.850 (H)

Table (2) : Experimental Plan For Three Variables.

No.	Level of Factors R_1	R_2	R_3	Thermal Resistance, $10^4 . (m^2.c°)$/watt	Air Resistance, $(N.Sec)/m^3$	Relative Value q_1	q_2	Quality Parameters: Geometric mean G	Exponential function E^*	Rank
1	+	+	+	385.11	1222.86	1	0.976	0.988	4.411	1
2	+	+	-	324.90	1253.20	0.844	1	0.919	2.467	3
3	+	-	+	352.52	304.22	0.915	0.243	0.472	0.285	5
4	+	-	-	325.77	303.59	0.846	0.242	0.453	0.232	7
5	-	+	+	369.09	1150.24	0.958	0.918	0.938	2.745	2
6	-	+	-	326.42	1170.85	0.848	0.934	0.890	2.149	4
7	-	-	+	357.02	288.41	0.927	0.230	0.462	0.258	6
8	-	-	-	327.30	285.05	0.850	0.227	0.439	0.195	8

$$^* \; E = \ln \left(\frac{1}{n} \sum_{i=1}^{n} e^{q_i} \right)$$

3.1.2 The 2 nd Wearing Case of Clothing Assembly

The values of thermal resistance and air resistance of the clothing assembly and its five components are given in Tables (3,4).

Table (3) : Actual Levels of Thermal Resistance of Components of Clothing Assembly.

Factor	Level -1	Level +1
R_1 = Thermal resistance of under wear, $10^4.(m^2.c°)/watt$	49.321 (J)	58.297 (T)
R_2 = Thermal resistance of shirt fabric, $10^4.(m^2.c°)/watt$	39.630 (M)	39.822 (K)
R_3 = Thermal resistance of lining fabric, $10^4.(m^2.c°)/watt$	29.260 (V)	35.562 (P)
R_4 = Thermal resistance of gasket fabric, $10^4.(m^2.c°)/watt$	43.938 (S)	61.702 (W)
R_5 = Thermal resistance of suit fabric, $10^4.(m^2.c°)/watt$	44.444(5w)	61.207(10W)

Table (4) : Experimental Plan For Five Variables

No.	Level of Factors R_1	R_2	R_3	R_4	R_5	Thermal Resistance, $10^4.(m^2.°c)/watt$	Air Resistance, $(N.sec)/m^3$	Relative Value q_1	q_2	Quality Parameters: Geometric Mean G	Exponential Function E	Rank
1	-	-	-	-	-	201.45	1530.40	0.609	0.444	0.520	0.425	7
2	+	-	-	+	+	330.53	2047.56	1	0.593	0.770	1.344	4
3	-	+	-	+	+	292.99	2770.49	0.886	0.803	0.844	1.772	2
4	+	+	-	-	-	228.68	2373.46	0.692	0.688	0.690	0.991	5
5	-	-	+	+	-	270.30	1088.03	0.818	0.315	0.508	0.389	8
6	+	-	+	-	+	269.66	2535.00	0.816	0.735	0.774	1.363	3
7	-	+	+	-	+	270.23	3450.42	0.818	1	0.904	2.295	1
8	+	+	+	+	-	266.66	2014.35	0.807	0.584	0.686	0.977	6

3.1.3 The 3 rd Wearing Case of Clothing Assembly

The values of thermal resistance and air resistance of the clothing assembly and its five components containing air spacing between lining and suit fabric instead of gasket fabric are given in Tables (5,6).

Table (5) : Actual Levels of Thermal Resistance of Components of clothing Assembly.

Factor	Level -1	Level +1
R_1 = Thermal resistance of under wear, $10^4.(m^2.°c)/watt$	49.321 (J)	58.297 (T)
R_2 = Thermal resistance of shirt fabric, $10^4.(m^2.°c)/watt$	39.630 (M)	39.822 (K)
R_3 = Thermal resistance of lining fabric, $10^4.(m^2.c°)/watt$	29.260 (V)	35.562 (P)
S_4 = Air spacing between lining and suit fabric, cm	0.5 (A)	1.5 (A)
R_5 = Thermal resistance of suit fabric, $10^4.(m^2.c°)/watt$	44.440 (5w)	61.207(10w)

Table (6) : Experimental Plan For Five Variables

No.	Level of Factors					Thermal Resistance, $10^4.(m^2.°c)/watt$	Air Resistance, $(N.sec)/m^3$	Relative Value		Quality Parameters		Rank
										Geometric Mean	Exponential Function	
	R_1	R_2	R_3	R_4	R_5			q_1	q_2	G	E	
1	-	-	-	-	-	707.30	704.16	0.814	0.791	0.803	1.515	5
2	+	-	-	+	+	808.84	811.98	0.931	0.493	0.678	0.944	7
3	-	+	-	+	+	839.22	836.08	0.966	0.775	0.865	1.932	3
4	+	+	-	-	-	755.49	758.64	0.870	0.967	0.917	2.451	2
5	-	-	+	+	-	839.84	842.98	0.967	0.467	0.672	0.922	8
6	+	-	+	-	+	800.64	797.49	0.922	0.502	0.680	0.953	6
7	-	+	+	-	+	786.67	789.81	0.905	1	0.951	2.998	1
8	+	+	+	+	-	868.82	865.68	1	0.722	0.850	1.814	4

3.1.4 The 4 th Wearing Case of Clothing Assembly

The values of thermal resistance and air resistance of the clothing assembly and its six components are given in Tables (7 , 8).

Table (7) : Actual Level of Thermal Resistance of Components of Clothing Assembly.

Factor	Level	
R_1 = Thermal resistance of under wear, $10^4.(m^2.°c)/watt$	49.321 (J)	58.297 (T)
R_2 = Thermal resistance of shirt fabric, $10^4.(m^2.°c)/watt$	39.630 (M)	39.822 (K)
R_3 = Thermal resistance of knitted outer wear, $10^4 (m^2.°c)/watt$	166.082 (D)	189.850 (H)
R_4 = Thermal resistance of lining fabric, $10^4 (m^2.°c)/watt$	29.260 (V)	35.562 (P)
R_5 = Thermal resistance of gasket fabric, $10^4 (m^2.°c)/watt$	43.938 (S)	61.702 (W)
R_6 = Thermal resistance of suit fabric, $10^4 (m^2.°c)/watt$	44.444 (5w)	61.207 (10w)

Table (8) : Experimental Plan For Six Variables.

No.	Level of Factors						Thermal Resistance, $10^4.(m^2.°c)/watt$	Air Resistance, $(N.Sec)/m^3$	Relative Value		Quality Parameters		Rank
											Geometric Mean	Exponential Function	
	R_1	R_2	R_3	R_4	R_5	R_6			q_1	q_2	G	E	
1	-	-	-	+	+	+	398.38	2404.24	0.763	0.794	0.778	1.383	4
2	+	-	-	-	-	+	414.39	2307.23	0.794	0.762	0.778	1.380	5
3	-	+	-	-	+	-	364.52	1987.44	0.698	0.656	0.677	0.94	7
4	+	+	-	+	-	-	44.03	2419.69	0.787	0.799	0.793	1.460	3
5	-	-	+	+	-	-	453.20	1572.34	0.868	0.519	0.671	0.920	8
6	+	-	+	-	+	-	522.21	1419.60	1	0.469	0.685	0.970	6
7	-	+	+	-	-	+	478.04	3029.63	0.915	1	0.957	3.114	1
8	+	+	+	+	+	+	497.87	2587.81	0.953	0.854	0.902	2.274	2

3.1.5 The 5 th Wearing Case of Clothing Assembly

The values of thermal resistance and air resistance of the clothing assembly and its six components, containing air spacing between lining and suit fabrics instead of gasket fabric, are given in Tables (9,10).

Table (9) : Actual Levels of Thermal Resistance of Components of Clothing Assembly

Factor	Level -1	Level +1
R_1 = Thermal resistance of under wear, 10^4 (m^2.°c)/watt	49.321 (J)	58.297 (T)
R_2 = Thermal resistance of shirt fabric, 10^4 (m^2.°c)/watt	39.630 (M)	39.822 (K)
R_3 = Thermal resistance of knitted outer wear, 10^4 (m^2.°c)/watt	166.082 (D)	189.850 (H)
R_4 = Thermal resistance of lining fabric, 10^4. (m^2.°c)/watt	29.260 (V)	35.562 (P)
S_5 = Air spacing between lining and suit fabric, 10^4(m^2.°c)/watt	0.5 (A)	1.5 (A)
R_6 = Thermal resistance of suit fabric, 10^4 (m^2.°c)/watt	44.444 (5w)	61.207 (10w)

Table (10) : Experimental Plan For Six Variables.

No.	Level of Factors R_1	R_2	R_3	R_4	S_5	R_6	Thermal Resistance, 10^4.(m^2.°c)/ watt	Air Resistance (N.Sec)/m^3	Relative value q_1	q_2	Quality Parameters Geometric Mean G	Exponential Function E	Rank
1	-	-	-	+	+	+	982.65	1115.69	1	0.758	0.870	1.974	3
2	+	-	-	-	-	+	952.37	120.96	0.969	0.693	0.820	1.615	6
3	-	+	-	-	+	-	942.48	1472.88	0.959	1	0.979	3.867	1
4	+	+	-	+	-	-	848.48	1155.49	0.863	0.785	0.823	1.635	5
5	-	-	+	+	-	-	843.52	503.58	0.588	0.342	0.448	0.221	8
6	+	-	+	-	+	-	907.66	631.61	0.924	0.429	0.630	0.7707	7
7	-	+	+	-	-	+	829.46	1192.48	0.844	0.810	0.827	1.659	4
8	+	+	+	+	+	+	908.33	1319.12	0.924	0.896	0.910	2.358	2

3.2 Experimental Analysis

The results of thermal resistance and air resistance of clothing assembly were analyzed using the computer. The regression coefficients were determined and the response-surface equations for both the total thermal resistance (R_t) and total air resistance (R_t) for each wearing case of clothing assembly are given in Table (11) with the correlation coefficients between the experimental values and the calculated values obtained from the response-surface equations. The response surfaces agree fairly well with the experimental results as can be observed from the high correlation coefficients. Contour maps were constructed by using the response-surface equations as shown in Figures (3-7).

3.2.1 The 1 st Wearing Case of Clothing Assembly

In Table (2), the eight clothing assemblies are to be ranked in order of general quality using two methods of quality assessment (geometric mean, G; and average exponential function, Q). These clothing assemblies have been ranked from 1 to 8; No. 1 represents the best clothing assembly and No. 8 represents the worse one. The final rank of the two methods is set out in Table (2) and the rankings of the two methods were in complete agreement. From analysis the mathematical model (Y_1) of total thermal resistance in Table (11), it could be observed that when changing the factors within the chosen interval, the factor (R_3) has a great influence afterwards the factors R_2, R_1 and the interactions R_2 R_3, R_1 R_2 and R_1 R_3 respectively. Total thermal resistance of clothing assembly (R_t) increases with using the level +1 of R_1, R_2 and R_3. But for the mathematical model (Y_2) of total air resistance, it could be noticed that with an increase of the factors R_1 R_2 and with using the level -1 of R_3, total air resistance of clothing assembly increases.

3.2.2 The 2 nd Wearing Case of Clothing Assembly

In Table (4), the clothing assemblies have been ranked from 1 to 8, No. 7 represents the best clothing assembly and No. 5 represents the worse one. The final rank of the two methods of quality assessment is set out in Table (4) and the rankings of the two methods were in complete agreement. From analysis the mathematical model (Y_3) of total thermal resistance in Table (11), it could be observed that the factor (R_5) has a great influence afterwards the factors R_4, R_1, R_3, R_2 and the interactions R_1 R_3 and R_1 R_4 respectively. Total thermal resistance of clothing assembly (R_t) increases with using the level +1 of R_1, R_3, R_4 and R_5 and with a decrease of the variable R_2. But for the mathematical model (Y_4) of total air resistance, it could be noticed that with an increase of the factors R_1, R_2, R_3, R_5 and with using the level -1 of R_4, total air resistance of clothing assembly increases.

3.2.3 The 3 rd Wearing Case of Clothing Assembly

In Table (6) , the clothing assembly No. 7 represents the best clothing assembly and No. 5 represents the worse one. The final rank of the two methods of quality assessment is set out in Table (6) and the rankings of the two methods were in complete agreement. From analysis the mathematical model (Y_5) of total thermal resistance in Table (11), it could be observed that the factor (S_4) has a great influence afferwards the factors R_3, R_2, R_5, R_1 and the interactions R_1 S_4 and R_1 R_3 respectively. Total thermal resistance of clothing assembly (R_t) increases with using the level +1 of R_1, R_2 R_3, S_4 and R_5. But for the mathematical model (Y_6) of total air resistance, it could be noticed that with an increase of the factor (R_2) and with using the level -1 of R_1, R_3, S_4, R_5, total air resistance of clothing assembly increases.

3.2.4 The 4 th Wearing Case of Clothing Assembly

In Table (8), the clothing assembly No. 7 represents the best clothing assembly and No. 5 represents the worse one. The final rank of the two methods of quality assessment is set out in Table (8) and the rankings of the two methods were in complete agreement. From analysis the mathematical model (Y_7) of total thermal resistance in Table (11), it could be observed that the factor (R_3) has a great influence afterwards the factors R_1, R_6, R_2, R_5 and R_4. Total thermal resistance of clothing assembly (R_t) increase with using the level +1 of R_1, R_3, R_5, R_6 and with using the level -1 of R_2 and R_4. But for the mathematical model (Y_8) of total air resistance, it could be seen that with an increase of the factors R_2, R_4, R_6 and with using the level -1 of R_1, R_3, R_5, total air resistance of clothing assembly increases.

3.2.5 The 5 th Wearing Case of Clothing Assembly

In Table (10), the clothing assembly No. 3 represents the best clothing assembly and No. 5 represents the worse one. The final rank of the two methods of quality assessment is set out in Table (10 and the rankings of the two methods were in complete agreement. From analysis the mathematical model (Y_9) of total thermal resistance in Table (11), it could be observed that the factor (S_5) has a great influence afterwards the factors R_3, R_2, R_6, R_4 and R_1. Total thermal of clothing assembly (R_t) increases with using the level +1 of R_1, S_5, R_6 and with using the level -1 of R_2, R_3 and R_4. But for the mathematical model (Y_{10}) of total air resistance, it could be seen that with an increase of the factors R_2, S_5, R_6 and with using the level -1 of R_1, R_3, R_4, total air resistance of clothing assembly increases.

4. DISCUSSION OF RESULTS

4.1 The 1 st Wearing Case of Clothing Assembly

Fig. 3 shows the effect of thermal resistance of knitted outer wear and under wear on both thermal and air resistance at $R_2 = +1$. The response surfaces are easily influenced by the variables R_1 and R_3. There is a large increase in thermal and air resistance when R_1 and R_3 are at the highest level. This is may be due to the higher resistance of tricona and half cardigan.

4.2 The 2 nd Wearing Case of Clothing Assembly

Fig. 4 shows the effect of thermal resistance of lining and suit fabric on both thermal and air resistance at $R_1 = -1$, $R_2 = +1$ and $R_4 = -1$. Warmth properties significantly increase when R_3 and R_5 are at the highest level. This is may be due to the fact that when thermal and air resistance of lining and suit fabrics increases, warmth properties of clothing assembly increases.

Table (11) : Response - Surface Equations of The Different Wearing Cases of Cloting Assembly

Wearing Case No.	Response - Surface Equation	Correlation Coefficient
1	$Y_1 = R^{*}_t \cdot 10^4 = 3\#6{:}016 + 1.059\ R_1 + 5.364\ R_2 + 19.919\ R_3 + 2.566\ R_1 R_2 + 1.822\ R_1 R_3 + 5.801\ R_2 R_3$	0.9931
	$Y_2 = R'^{**}_t = 747.426 + 23.792\ R_1 + 451.860\ R_2 - 5.998\ R_3 + 14.953\ R_1 R_2 - 1.682\ R_1 R_3 - 6.742\ R_2 R_3$	0.9999
2	$Y_3 = R_t \cdot 10^4 = 266.314 + 7.571\ R_1 - 1.673\ R_2 + 2.900\ R_3 + 23.809\ R_4 + 24.540\ R_5 - 8.622\ R_1 R_3 + 0.904\ R_1 R_4$	0.9989
	$Y_4 = R'_t = 2226.213 + 16.378\ R_1 + 425.967\ R_2 + 45.736\ R_3 - 246.106\ R_4 + 474.653\ R_5 - 13.652\ R_1 R_3 + 34.468\ R_1 R_4$	0.9986
3	$Y_5 = R_t \cdot 10^4 = 800.851 + 7.596\ R_1 + 11.699\ R_2 + 23.14\ R_3 + 38.328\ S_4 + 7.988\ R_5 + 3.143\ R_1 R_3 - 7.954\ R_1 S_4$	0.9979
	$Y_6 = R'_t = 359.899 - 21.962\ R_1 + 76.212\ R_2 - 21.177\ R_3 - 50.574\ S_4 - 11.186\ R_5 - 8.660\ R_1 R_3 + 18.631\ R_1 S_4$	0.9962
4	$Y_7 = R_t \cdot 10^4 = 442.450 + 18.912\ R_1 - 4.583\ R_2 + 45.38\ R_3 - -2.330\ R_4 + 3.296\ R_5 + 4.709\ R_6$	0.9805
	$Y_8 = R'_t = 2216.011 - 32.402\ R_1 + 290.134\ R_2 - 63.664\ R_3 + 30.011\ R_4 - 116.238\ R_5 + 366.242\ R_6$	0.9787
5	$Y_9 = R_t \cdot 10^4 = 901.869 + 2.344\ R_1 - 19.681\ R_2 - 29.627\ R_3 - 6.125\ R_4 + 33.410\ S_5 + 16.334\ R_6$	0.9826
	$Y_{10} = R'_t = 1051.475 - 19.681\ R_1 + 233.517\ R_2 - 139.778\ R_3 - 28.006\ R_4 + 83.348\ S_5 + 110.588\ R_6$	0.9960

$(R_t)^{*}$ means total thermal resistance of clothing assembly , $(m^2 \cdot °c) / watt$

$(R_t)^{**}$ means total air resistance of clothing assembly , $(N.Sec) / m^3$.

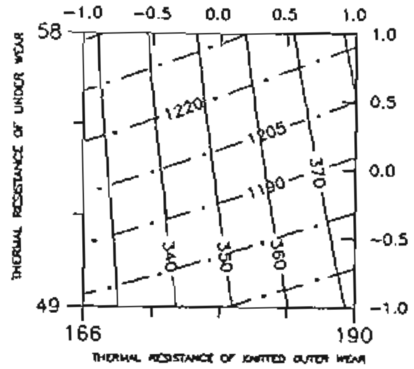

FIG.(3) THE DUPLEX CONTOURS OF WARMTH PROPERTIES FOR THE FIRST WEARING CASE OF CLOTHING ASSEMBLY.

— Thermal resistance at R_2=+1

-.- Air resistance at R_2=+1

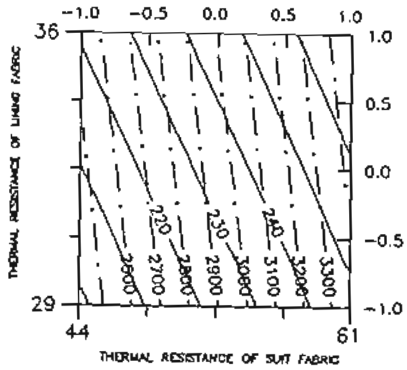

FIG.(4) THE DUPLEX CONTOURS OF WARMTH PROPERTIES FOR THE SECOND WEARING CASE OF CLOTHING ASSEMBLY.

— Thermal resistance at R_1=-1, R_2=+1, R_4=-1

-.- Air resistance at R_1=-1, R_2=+1, R_4=-1

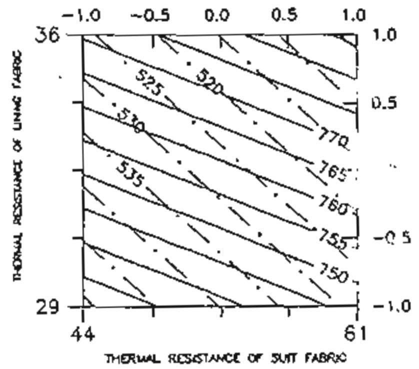

FIG.(5) THE DUPLEX CONTOURS OF WARMTH PROPERTIES FOR THE THIRD WEARING CASE OF CLOTHING ASSEMBLY.

— Thermal resistance at R_1=-1, R_2=+1, S_4=-1

-.- Air resistance at R_1=-1, R_2=+1, S_4=-1

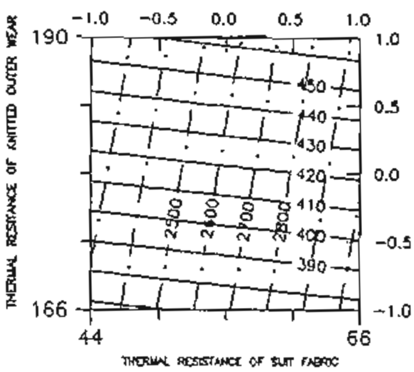

FIG.(6) THE DUPLEX CONTOURS OF WARMTH PROPERTIES FOR THE FOURTH WEARING CASE OF CLOTHING ASSEMBLY.

— Thermal resistance at R_1=-1, R_2=+1, R_4=-1, R_5=-1

-.- Air resistance at R_1=-1, R_2=+1, R_4=-1, R_5=-1

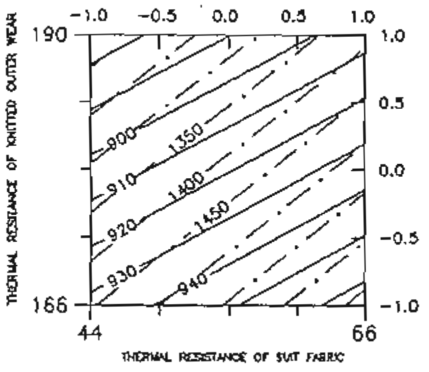

FIG.(7) THE DUPLEX CONTOURS OF WARMTH PROPERTIES FOR THE FIFTH WEARING CASE OF CLOTHING ASSEMBLY.

— Thermal resistance at R_1=-1, R_2=+1, S_5=+1, R_4=-1.

-.- Air resistance at R_1=-1, R_2=+1, R_4=-1, S_5 = +1

4.3 The 3 rd Wearing Case of Clothing Assembly

Fig. 5 shows the effect of both thermal resistance of lining and suit fabrics on warmth properties at R_1 = -1, R_2 = +1, S_4 = -1. Any increase in the variables R_3 and R_5 leads to increasing thermal resistance and decreasing air resistance. This is may be due to the exist of air spacing (air gap).

4.4 The 4 th Wearing Case of Clothing Assembly

Fig. 6 shows the effect of thermal resistance of knitted outer wear and suit fabric on warmth properties at R_1 = -1, R_2 = +1, R_4 = -1, R_5 = -1. Warmth properties increase when R_3 and R_6 are at the highest level because they share with a high value of the total thermal resistance of clothing assembly.

4.5 The 5 th Wearing Case of Clothing Assembly

Fig. 7 shows the effect of thermal resistance of knitted outer wear and suit fabric on warmth properties at R_1 = -1, R_2 = +1, R_4 = -1 and S_5 = +1. Total thermal resistance significantly increases when R_3 and S_5 are at the lowest and highest level respectively. Conversly, total air resistance significantly increase when R_3 and S_5 are at the highest and lowest level respectively. This is may be due to the exist of air gap between lining and suit fabrics. Thus, the rank of quality parameters was concided with the graphical solution of dublicating the contours of both total thermal and air resistance together.

5. CONCLUSIONS

From the work described in this paper the following conclusions have been deduced:

The optimum components for obtaining the highest warmth property of each clothing assembly are:

- The 1 st wearing case must be composed of Tricona, poplin of Kafr El-Dawar and half cardigan knitted outer wear.

- The 2 nd wearing case must be composed of Jil, poplin of Kafr El-Dawar, polyester lining fabric, sticking gasket and 100% wool suit fabric.

- The 3 rd wearing case must be composed of Jil, poplin of Kafr El-Dawar, polyester lining fabric, 0.5 cm air gap and 100% wool suit fabric.

- The 4 th wearing case must be composed of Jil, poplin of Kafr El-Dawar, half cardigan knitted outer wear, viscose lining fabric, sticking gasket and 100% wool suit fabric.

- The 5 th wearing case must be composed of Jil, poplin of Kafr El-Dawar, double jersey knitted outer wear, viscose lining fabric, 1.5 cm air gap thickness and 50% wool suit fabric.

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