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TEXTILE SERIES - REPORT NO. 39

MEASUREMENT OF THE THERMAL TRANSMISSION OF TEXTILE FABRICS

Report of the Task Group on Thermal Transmission to Subcommittee B-1, Committee D-13, A.S.T.M. on Textile Test Methods

by

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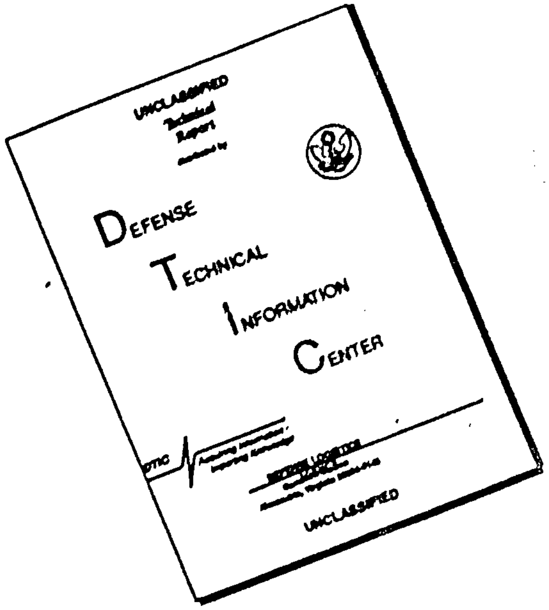

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FOREWORD

In view of its extensive procurement of cold-climate clothing, the Quartermaster Corps has a definite interest in establishing specification requirements which will set a quality level for fabrics in terms of insulating value. Up to this time, a lack of standardization in methods of measuring the thermal properties of textile materials has rendered impossible the establishment of universally accepted quantitative values, so that the warmth desired for a given purpose could be expressed only in terms of other fabric characteristics having a bearing on this property.

The Quartermaster Corps thus welcomed an opportunity to participate in an interlaboratory study of methods used for measuring the thermal transmission of fabrics conducted by a subcommittee on textile test methods of Committee D-13, American Society for Testing Materials.

The report presented herewith includes a brief review of the literature on this subject together with the detailed findings of the subcommittee.

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PART I

PREVIOUS STUDIES

The warmth of textile fabrics is without question the prime factor governing the type of clothing worn in temperate and arctic climates. So long as temperature differentials exist between the skin and the surrounding air, transfer of body heat will take place resulting in discomfort which is related to the rate of heat loss. In functioning as a resistor to heat flow, cloth behaves as do ordinary building materials in the conduction, convection and radiation of heat; however, the proximity of the warm moist skin imposes additional requirements on clothing materials which are not ordinarily considered by the mechanical engineer.

Listing of the factors which influence the transmission of heat by cloth is taken from the concepts of the building engineers [1]. Radiation is independent of the presence of material connecting heat source with receiver and travels in straight lines with approximately the same velocity as light. The maximum quantity of heat radiated from a hot body is proportional to the fourth power of its absolute temperature (in the case of a perfect radiator). A perfectly black body is a perfect radiator and also absorber of radiant heat. Convection refers to transfer of heat in a fluid medium by expansion and accompanying circulation of portions of the fluid. Where the local source of heat is a solid the problem is complicated by the formation of a barrier layer at the interfacial surface which offers fairly high resistance to transfer of heat energy. Conduction describes the flow of heat through a solid material with the energy transfer taking place between molecules themselves. Flow of this nature is proportional to the temperature drop across the material and to the reciprocal of the thickness.

Low-density materials such as textiles contain a large proportion of air within their total structures. Heat transmission through media of this type is therefore primarily dependent upon the resistivity of the air layer. The lower the proportion of fiber to air the higher will be the resistance to heat flow of the cloth. The limiting insulation is that of a layer of air equivalent in thickness to the textile material, assuming of course, static conditions with no convection currents. In practice the chief function of the cloth is to trap an air layer (with high resistance), thus preventing circulation of air currents around the subject. Opposing requirements of high porosity (low density) and low permeability (negligible convection) are satisfied in combination fabrics consisting of a thick porous lining and a thin tightly woven outer cloth. Numerous investigations have led to this development and a few of these are reviewed to illustrate the general effect of fabric geometry on heat flow properties. More detailed information concerning the methods of measuring thermal conductivity is available in the reports on the work by Haven (9), Freedman (6), Black and Matthew (3), Marsh (12), Rees (14), Cleveland (4), and Baxter (2).

As has been indicated the layer of dead air space in a textile material is of great importance in determining heat flow. Conditions of tests which tend to disturb this layer must be carefully controlled to prevent reflection of such variables in the test results. Included among these factors are wind velocity impinging against the fabric surface and tension or compression on the sample imposing a change in its geometric structure. Niven and Babbitt (13) investigate the effect of wind velocities on the thermal insulating values of some clothing during wear and find that the tightness with which a combination of fabrics is worn is of more importance than the material. Tightness of textiles of low density is accompanied by compression and loss in thermal insulation value. This has been reflected in the complaints from army troops stationed in the north to the effect that winter "Long Johns" are poor insulators.

Rees (14) collects data on a large variety of fabrics of varied fiber content and demonstrates the dependence of heat loss upon one geometric consideration, that of thickness. In a similar comparison of weight vs. heat loss he reports a general relationship to exist with points more widely scattered than in the thickness plot. Since increased thickness is generally accompanied by greater weight this relationship is logical. It is also found that, in general, low-density fabrics have higher resistance than high-density materials, for in the denser fabrics the fiber conduction losses assume greater proportions. Increasing wind velocities during test cause greater heat losses in all cases, the low textured materials undergoing the greatest change in heat flow. Single blankets which have relatively poor insulating qualities at high wind velocities are remarkably improved by addition of a light, tightly woven linen cloth. Finally, in the surface structure, smoothness vs. roughness is noted to be a contributing factor in causing the initial chill or cold feel of fabrics when brought in contact with the skin.

Hock (10) et al show the area of contact between fabric and skin to be a major factor contributing to the chilling effect of moist fabrics. The results of their experiments show progressive improvement of fabrics with respect to chilling as their wool content is increased thus effecting a more lofty structure and rougher surface. The superiority of certain types of structures is evident. This work suggests a means for constructing a fabric with minimum chilling effect namely by use of unbalanced crimp and varied counts in the warp and filling directions to promote a ribbed effect with little contact surface area.

In a study of the properties of household blankets Schiefer et al (15) confirm the finding that thermal conductance of fabrics is independent of the kind of fiber. The reciprocal of thermal conductance was found to be related linearly to thickness as shown

$$\frac{1}{\text{Conductance}} = 3.0G + 0.63$$

where G is the thickness in inches at pressure of 0.10 lb/sq. in. and conductance is expressed in B.T.U./°F./Hr./ft.^{2}.

Hamlin and Warner [8] studying 90 varying knit constructions show thermal transmission to be inversely proportional to thickness and weight. They point out however that fabrics having a given weight can be made in a considerable range of thicknesses. In the fabrics constructed thickness and weight are directly related thus accounting for the correlation between weight and thermal values. Similarly the thicker fabrics are less permeable to air and the data accordingly show higher thermal transmission with higher air permeabilities even though the tests are conducted under static air conditions.

Fletcher,[5] in her studies of knitted fabrics, treats the subject of thermal insulation in a manner similar to Schiefer's work on the subject. Plotting the reciprocals for thermal transmission against thickness, G, at 0.1 pound/square inch, she obtains a straight line represented by

$$\text{Thermal Transmission} = 3.85\ G + 0.61$$

where thermal transmission was expressed in °F hr. ft^2/B.T.U.

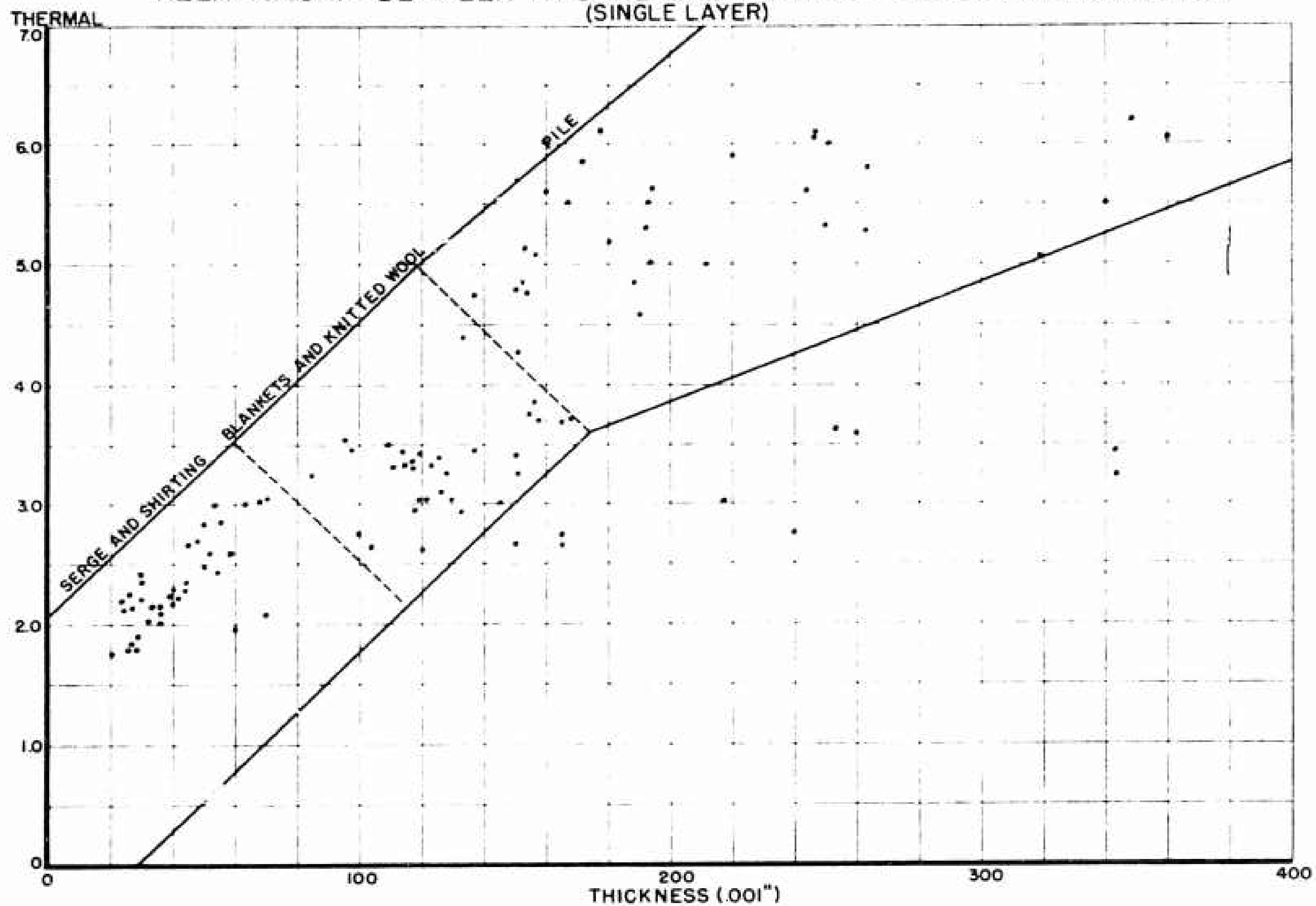
Relationships plotted by Baxter [2] show thermal-insulating values to be linearly related (approximately) to thickness up to 1 cm. Where materials exceed this thickness the slope of the T.I.V. versus G curve falls off rapidly and appears to become horizontally asymptotic. Surface emissivity is shown to be of major importance in thin fabrics but its effect dimishes as thicker materials (above .5 cm) are considered. Emissivities are dependent on radiation and convection. The former is dependent on the fibers of the fabric and upon the dyeing while the latter is a function of the geometric structure of the surface. Rough surfaces possess lower emissivities than corresponding smooth surfaces and this difference is even more pronounced with increased wind velocities.

Goddard and Van Dilla [7] experiment with air layers to determine the feasibility of an inflatable sleeping bag pad. They find that air layers reach maximum insulation at 1/2 inch after which convection currents minimize the effects of increased thickness. Bounding materials make no difference in the values recorded except where open structures are used. Reduction of convection currents in the air layers is accomplished (with increased thermal insulating values) by inclusion of triangular shaped baffles in the air space. Later reports by the Quartermaster Climatic Laboratories indicate successful increases of insulating values of air layers by inclusion of a minute amount of waterfowl down

Figure I

RELATIONSHIP BETWEEN THICKNESS & THERMAL VALUES FOR 115 FABRICS

(SINGLE LAYER)



in the layer. This principle is used in experimental pads which are highly praised by users in the arctic and wet, cold regions.

Larose [11] investigates the effect of closeness of weave and thickness upon thermal values of fabrics and shows that in winds up to 6 m.p.h. there is little disturbance of the air behind a thin fabric covering a heavy pile material for air permeabilities up to 50 ft^3/ft^2/min. at .5 inch of water. The sole effect up to this point is to change the resistance of the surface boundaries, which occurs at low velocities. From 6 to 30 m.p.h. the reduction in thermal resistance is practically proportional to wind velocity for covers of low permeability. More permeable fabrics lose more thermal resistance in the range of 6 to 24 m.p.h. then flatten off in the range of 24 to 30 m.p.h. The open structure of the under layers of fabric is seen to affect thermal resistance when higher velocities are used with more permeable cover fabric. Variations in wind direction appear to affect thermal resistance in accordance with the perpendicular vector to the fabric surface. However, this relationship does not hold at low wind velocities. Larose also shows loss in thermal resistance as a result of change in fabric thickness due to air pressure. All results reported for the fabrics are corrected for boundary air resistance and compression due to wind pressure.

During 1942 and 1943 the Quartermaster laboratory at Philadelphia had occasion to evaluate the thermal insulation of some 115 samples ranging in weight from lightweight flannels to heavy pile fabrics including both cotton and woolen materials. The physical properties of thickness, weight, density, and air permeability were tabulated and an attempt was made to relate the structure of the fabric to its warmth as measured on the laboratory apparatus. These studies revealed that thickness was the only property bearing any important relationship to thermal insulation, and that this relationship was essentially linear, as shown in Figure 1. From the standpoint of heat losses through convection, it would seem that air permeability should also be an important characteristic affecting warmth. However, by utilizing multiple correlation techniques, the Philadelphia laboratory demonstrated that no improvement in the prediction* of the thermal values of a fabric could be obtained through a consideration of its air permeability. The correlation coefficient showing the relationship between thermal insulation and thickness remained the same (.78) regardless of whether the effect of air permeability was eliminated or utilized.

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*Schiefer's equation,

$$T = \frac{1}{(3\ TH + 0.63)} \quad - \ BTU/^{\circ}F/hr/ft^2$$

may be used to predict the warmth of all kinds and types of ordinary fabrics ranging in thickness from 0 to 1/2 inch.

PART II

A. S. T. M. INVESTIGATIONS

As indicated above, technologists in England and the United States have developed numerous techniques for the measurement of the thermal transmission characteristics of textile fabrics. In general, the values reported by different laboratories for a given set of materials differed greatly. However, the fabrics were usually rated in the same order wherever significant differences between the test results were recorded. Variations in absolute values were caused by differences in conditions of measurement.

SERIES I

In October 1944, a special committee was set up under Subcommittee B-1, Section 1, Committee D-13, A.S.T.M. with the express purpose of developing a standard test for thermal transmission of textiles. Cooperative interlaboratory measurements made on four woolen materials early in 1944 served as the starting point for the committee program. A discussion of this first series of tests is included below:

Fabric	Thickness (at .005 psi pressure)
1. Serge	.065 in.
2. Arctic Serge	.129 in.
3. Doeskin	.135 in.
4. Fleece	.265 in.

Cooperating Laboratories

1. Textile Section, National Bureau of Standards
2. R. H. Macy & Company
3. Fabric Research Laboratories, Inc.
4. J. C. Penney Co.
5. Sears Roebuck & Company
6. United States Testing Company
7. Philadelphia Textile Materials Engineering Laboratory (QMC)

Test Methods

1. National Bureau of Standards. The equipment as described in the National Bureau of Standards Research Paper RP 1055, consists of a "horizontal plate heated electrically and maintained at constant temperature by means of a thermostat. The plate is surrounded by a guard plate which is also maintained at the same temperature to prevent lateral flow of heat into or out of the central test plate. A second guard heater is placed below the central plate to prevent the downward flow of heat. The specimen to be tested is laid flat without tension on the apparatus and inclosed in a copper hood placed several inches above it to eliminate the disturbing influence of air currents of the room. Since the thermostatic control results in an intermittent supply of heat to the central heater, an electric clock is added to the circuit, thus automatically adding the periods during which heat is being supplied. The difference in temperature from the central plate to the top of the hood, is measured by means of a thermocouple and microammeter. The amount of heat supplied to the control heater per unit of time divided by the difference in temperature from the central plate to the hood and by the area of the hot plate is taken as a measure of the thermal transmission of the specimen." During the tests reported herein, the temperature of the hot plate varied from 50.1 to 52.5°C while the hood temperature varied from 26.6 to 29.2°C. The difference in temperature between the hot plate and the hood varied from 21.7 to 23.9°C. The reported values, however, were corrected to read for a temperature gradient between plate and hood of 20°C. The heat loss when the apparatus was bare was 1.6 BTU/° F/hr/ft^2.

2. R. H. Macy. In a paper given before th ASTM in 1930, Mr. Freedman describes a calorimeter device around which is wound the fabric specimen. The calorimeter consists of a cylindrical container measuring 10" in height and 3" outside diameter and the wall encases the bulb of a xylene thermometer. This bulb is made of bronze tubing .090 in. outside diameter and 400 inches long, wound helically on a cylinder of 1/32 in. sheet copper. The spaces between convolutions are filled with lead so as to form a smooth outside surface. This gives a thermometric element with a total conducting surface of nearly 100 sq. inches. The indicating instrument for this thermometer has a range from 90 to 110° F with scale divisions of 1/4° F and is equipped with electric contacts for controlling the temperature within a narrow range. The thermometer was constructed for bulb immersion only and was compensated for atmospheric fluctuation along the line and at the instrument. The thermometer system is filled completely with Xylene, the bulb being a capillary tube 0.008 inches in diameter. Increase of temperature causes the pressure to rise, thus activitating a coiled Bourdon spring in the instrument which in unwinding, causes a pointer to move across the scale. An air duct is furnished for circulating air at controlled velocities past the calorimeter. A heater placed in the calorimeter maintains the temperature of the calorimeter at a predetermined point and the input wattage required for each test is determined by suitable measuring apparatus.

During the tests reported herein the four specimens were kept in the duct of the thermal transmission apparatus until temperature equilibrium was established. The calorimeter temperature was 98.7°F, the duct temperature 61.4°F, the average relative humidity 49% and the duct air velocity 4 m.p.h.

3. Fabric Research Laboratories, Inc. - Dr. Hamburger states that the apparatus used in the measurement of conductance of the fabrics submitted consisted of a heat source in the form of a calorimeter kept at 100°C., by boiling water and a receiver, in which is embedded a copper-constantan thermo-couple which is connected in series with a second copper-constantan thermo-couple maintained as nearly at room temperature as possible. The copper black body containing the receiver thermo-couple is brought to temperature equilibrium with the constant couple by observing a zero reading on the galvenometer. This apparatus is a modification of the Cenco-Fitch apparatus and permits the use of rectangular coordinates in plotting the data. The constant is obtained by the following formula:

$$\text{Constant} - \frac{\text{Mass (gms) X Specific Heat X Temperature Rise } (^{\circ}\text{C})}{\text{Area (sq.M) X Temperature Differential } (^{\circ}\text{C}) \text{ X 60 (Seconds)}}$$

The temperature rise in the above formula is indicated by the deflection of the galvanometer, and in the case of the tests herewith, represents a direct relationship of deflection to temperature in degrees Centigrade.

4. J. C. Penney Co. According to Mr. Dorn the apparatus used in measuring the insulation values of the fabrics submitted consists of an icebox which is maintained during test at a temperature of 30°F. This box is provided with an electric fan which circulates a current of air during test, but in such a manner that the air does not strike directly on the sample, but rather flows along its surface. Suspended in this box, is a copper cylinder which is insulated for a two inch space at each end. Inside the cylinder is a heating bulb and a thermostat. During this test, the temperature of this cylinder is maintained accurately at body heat. The cylinder is first calibrated to find the amount of current required to keep it at body temperature for a period of one hour with a temperature in the box at 30°. The cylinder is then covered with the material to be tested and the amount or current again recorded, that is required to keep the cylinder at body temperature while protected by the test specimen. The test specimen insulates the cylinder and it requires less current when so protected. The difference in current consumption is used as a basis for calculating the insulation offered by the material.

5. Sears, Roebuck and Company - Miss Pratt writes that the Sears, Roebuck device is similar to the Bureau of Standards machine except that a larger test area is used and different means of controlling the temperature which is normally kept at 170°±1°F. This gives a temperature difference of 100°F and eliminates errors due to fabric irregularities

or temperature fluctuation of the plate or conditioning room. In using this high temperature the fabric is practically dry while being tested. The test results reported were obtained with a flat, guarded hot plate type of device. The receiver of the heat, or cold point, was the air in the constant temperature room which was kept at 70° F ± 2 °F and at a relative humidity of 65 percent. The hot plate of the device was kept either at 100° F ± 2°F or at 50° F ± 2°F. above the room temperature. The area of the test plate, which measured 1 x 2 ft. eliminated any possible effects of fabric irregularities on the test. The air currents in the room were too small to be measured with an aneometer and the test can be called a "still air test."

6. The U. S. Testing Company - According to Mr. Monego of Forstmann Woolen Company, who arranged for these tests, the equipment used by the U. S. Testing Company was of similar design to that used by the National Bureau of Standards. In addition there was provided facility for blowing a 12 m.p.h. wind perpendicular to the hot plate.

7. Philadelphia Textile Materials Engineering Laboratory The apparatus used at the Quartermaster laboratory in Philadelphia includes a large upright cylinder, 2.5 ft. in circumference and 3.25 ft. in height, containing oil maintained at 98.6°F, or normal body temperature. The electric energy required to maintain the oil bath at the constant temperature when the entire apparatus is inclosed in a cold room at 38°F. is the basis for comparison of insulating characteristics of fabrics covering the cylinder.

Results and Discussion

It was evident in the description of the equipment that conditions of measurement varied within the laboratories. The data obtained are shown in Table I both in the original units of measurements and in BTU units for purposes of comparison. The factors used in converting the results where necessary into BTU units are as follows:

Laboratory	Method of Converting to BTU Units
2	5.2 (Watts /°F)
3	.291 (Cal/m²/°C/sec)
4	(No conversion possible)
5	$\frac{1}{\text{Warmth Coefficient}}$
7	3.68 (Relative thermal insul.value)

TABLE I

THERMAL TRANSMISSION MEASUREMENTS(1) OF FOUR WOOLEN MATERIALS BY SEVEN LABORATORIES

Lab.	Test Conditions	Unit	FLEECE Lab. Unit	FLEECE BTU/°F/hr/ft²	DOESKIN Lab. Unit	DOESKIN BTU/°F/hr/ft²	ARCTIC SERGE Lab. Unit	ARCTIC SERGE BTU/°F/hr/ft²	SERGE Lab. Unit	SERGE BTU/°F/hr/ft²
1		BTU/°F/hr/ft²	.95	.95	1.22	1.22	1.19	1.19	1.52	1.52
2		Watts/°F BTU/°F/hr/ft²	.31	1.60	.49	2.54	.49	2.57	.65	3.36
3		Cal/m²/°C/sec BTU/°F/hr/ft²	3.38	.98	5.61	1.63	7.20	2.10	11.00	3.20
4		Therm. Insul. Value (2)	34.90		21.20		18.80		14.90	
5	Temp.gradient 100°F (above room temp.)-mean temp. 120°F	Warmth Coeff. BTU/°F/hr/ft²	1.06	.95	.93	1.07	.84	1.19	.64	1.57
	Temp.gradient 50°F (above room temp.)-mean temp. 95°F	Warmth Coeff. BTU/°F/hr/ft²	1.15	.87	.85	1.18	.79	1.26	.66	1.52
6	Still air	BTU/°F/hr/ft²	1.05	1.05	1.48	1.48	1.47	1.47	1.58	1.58
	12 mph wind perp. to test plate	BTU/°F/hr/ft²	1.40	1.40	2.08	2.08	2.20	2.20	2.70	2.70
7	2.3 mph wind across cylinder	Relative Thermal Insul. Value BTU/°F/hr/ft²	3.24	1.14	2.43	1.51	2.43	1.51	1.96	1.88
	Still air	Relative Thermal Insul. Value BTU/°F/hr/ft²	2.03	.98	1.57	1.26	1.62	1.22	1.44	1.38

(1) Face of fabric away from heat source. (2) Value not convertible to BTU/°F/hr/ft².

Conversion of the data to a common unit of measurement hardly provided the absolute agreement hoped for, but consistency in ranking the four materials with respect to thermal transmission was noted. The relationship between thickness and BTU/^{o}F/hour/ft^{2} was confirmed. Factors which contributed to differences in absolute measurements included: (1) motion of wind during test (2) use of varied temperature levels and gradients on which depends the proportion of radiation loss to over-all heat loss (3) varied conditions of relative humidity during the thermal tests, and (4) sample orientations, i.e., tension or compression during measurements. The data at hand did not warrant establishing the relationship between the absolute values reported by the various laboratories and the specific conditions of test.

SERIES II

It was decided to expand the range of materials tested to provide for a more adequate comparison of the thermal transmission data with the physical properties of the fabrics. Twenty-four fabrics ranging from 7 oz. to 32 oz. per linear yard (56 inches wide) were distributed to cooperating laboratories with the request that thermal measurements be conducted according to the exact method utilized by each laboratory in its standard tests. The data were returned to the Quartermaster Textile Materials Engineering Laboratory at Philadelphia for consolidation and summary. The results of both of this second series of interlaboratory tests are presented in Tables II and III.

Cooperating Laboratories

1. R. H. Macy & Company
2. Sears, Roebuck & Company
3. J. C. Penney Company
4. Philadelphia Textile Materials Engineering Laboratory (QMC)
5. Climatic Research Laboratories (QMC)

Test Methods

The equipment described in Series I is the same as that used to evaluate the fabrics of Series II by the Macy, Sears, Penney and the Philadelphia Quartermaster laboratories respectively.

The instrument used at the Lawrence Climatic Laboratories is a modification of the guarded plate method developed at the Bureau of Standards and consists of a guard ring brass cylinger 3 1/2 inches in diameter

TABLE II

PHYSICAL PROPERTIES OF 24 WOOLEN MATERIALS

FABRIC	WT/LIN. YD. (56") (OZ.)	TEXTURE W	TEXTURE F	AIR PERM. GURLEY (SEC)	WARP YARN COUNT	WARP YARN PLY TWIST	WARP YARN SINGLE TWIST	FILLING YARN COUNT	FILLING YARN PLY TWIST	FILLING YARN SINGLE TWIST	THICKNESS AT .5-psi PRESSURE (inches)
1. Barathea	15.1	85	90	23.2	2/43.8	13.6	12.0	2/41.4	13.4	11.8	.030
2. Barathea	18.6	73	83	26.0	2/29.4	10.7	10.6	2/34.7	11.3	10.9	.034
3. Covert	15.0	73	67	15.1	2/32.1	11.9	12.5	17.3		8.8	.033
4. Elastique	18.7	119	82	15.5	2/43.5	13.5	10.9	2/40.8	14.4	11.4	.038
5. Serge	18.1	68	61	45.2	2/25.5	9.5	9.7	12.9		8.3	.036
6. Serge	21.7	57	57	57.8	2/18.6	7.7	9.6	2/19.9	7.10	8.4	.043
7. Gabardine	13.5	103	62	16.1	24.0		14.6	23.1		14.7	.028
8. Tropical	11.9	56	49	22.2	2/33.0	14.9	14.8	2/31.6	15.3	15.0	.021
9. Covert	18.9	63	59	22.3	24.4		14.5	20.5		13.5	.048
10. Doeskin	29.7	79	53	53.6	16.6		14.5	14.7		12.0	.060
11. Facing	16.2	62	61	12.7	26.4		19.1	31.5		16.6	.044
12. Flannel	12.9	39	33	8.5	18.4		13.1	20.8		14.2	.040

TABLE II (cont.)

PHYSICAL PROPERTIES OF 24 WOOLEN MATERIALS

FABRIC	WT/LIN. YD. (56") (OZ.)	TEXTURE W	TEXTURE F	AIR PERM GURLEY (SEC.)	WARP YARN			FILLING YARN			THICKNESS at .5-psi PRESSURE (inches)
					COUNT	PLY TWIST	SINGLE TWIST	COUNT	PLY TWIST	SINGLE TWIST	
13. Melton	21.4	47	46	14.1	14.9		11.3	16.0		11.1	.061
14. Melton	33.6	37	39	23.6	7.7		9.5	8.2		8.7	.091
15. Lining, Napped	23.1	29	32	4.7	9.3		8.6	9.0		7.6	.127
16. Crepe	8.5	43	35	2.1	2/17.0	20.7	19.6	2/17.3	18.9	18.8	.033
17. Flannel	12.0	73	75	8.7	22.8		10.2	22.3		11.2	.028
18. Flannel	20.8	47	50	30.6	16.3		12.4	17.0		11.0	.050
19. Lining, Napped	24.7	30	28	6.5	9.6		9.1	6.7		6.8	.141
20. Lining, Napped	25.1	30	28	6.0	9.2		9.8	6.7		6.3	.157
21. Lining, Napped	31.1	30	38	5.6	9.4		9.4	6.7		6.0	.191
22. Lining, Napped	23.3	28	29	6.3	8.8		7.9	8.6		8.1	.088
23. Lining, Napped	24.3	29	33	6.2	8.7		8.7	8.3		8.2	.149
24. Lining, Napped	26.0	30	32	6.8	8.5		9.8	8.1		7.3	.189

TABLE III

THERMAL VALUES OF 24 WOOLEN MATERIALS

AS REPORTED BY FIVE LABORATORIES

FABRIC[1]	PQM [2] Rel. Therm. Insul. Val.	CRL[3] Clo Value	MACY'S Watts (°F)	SEARS Warmth Coeff.	PENNEY Per Cent Insulation
1	1.84	0.73	0.625	0.543	14.28
2	1.89	0.72	0.640	0.533	12.25
3	2.04	0.76	0.594	0.584	18.16
4	1.95	0.72	0.598	0.543	20.58
5	2.01	0.78	0.566	0.594	26.88
6	2.16	0.80	0.513	0.618	22.40
7	1.93	0.74	0.641	0.586	16.83
8	1.80	0.70	0.688	0.540	13.80
9	2.28	0.80	0.543	0.650	21.19
10	2.34	0.82	0.523	0.686	21.80
11	2.19	0.78	0.560	0.621	19.17
12	2.14	0.77	0.573	0.641	19.67
13	2.52	0.885	0.431	0.700	24.94
14	2.77	0.96	0.386	0.759	27.59
15	3.41	1.28	0.298	1.085	38.86
16	2.03	0.82	0.532	0.618	15.18
17	1.94	0.76	0.623	0.572	12.62
18	2.27	0.81	0.531	.676	19.43
19	3.72	1.33	0.289	1.077	40.59
20	3.91	1.38	0.242	1.082	42.69
21	4.17	1.50	0.255	1.234	41.00
22	3.21	1.14	0.348	0.921	37.19
23	3.94	1.40	0.293	1.110	39.90
24	3.88	1.44	0.270	1.105	42.73

(1) For identification of fabrics, see Table II
(2) Quartermaster Textile Materials Engineering Laboratory, Philadelphia, Pa.
(3) Climatic Research Laboratory (QMC), Lawrence, Mass.

According to Colonel Talbot the cylinder is mounted in a constant temperature room which is maintained at 70°F and a relative humidity of 50-65%. The cylinder temperature is 95° F. There is no forced air movement. The air film resistance is 0.55 clo* and is included in the clo values in Table III. It is thus necessary to subtract 0.55 clo from the tabulated clo values to obtain intrinsic fabric insulation. However, in comparing the relative values furnished by the majority of the laboratories this correction was omitted. A further correction factor was recommended in comparing thermal-insulating values as measured on a cylinder with those measured on a flat plate. This correction is negligible for thin fabrics but amounts to about 0.1 clo for fabric No. 21.

In tests at the Philadelphia laboratory the outside room was maintained at + 40°F and 80% relative humidity and an air current of .5 m.p.h. was directed against the cylinder. To insure rigid adherence to the test conditions a control sample was interspersed at regular intervals during the testing of the 24 woolen materials and the averages and ranges of groups of 4 control tests were plotted according to standard A.S.T.M. techniques. As is evidenced in Figure 1, the apparatus was in control during the entire run.

In the tests conducted at Sears Roebuck & Company the measurements were made using a 100°F temperature difference between room and hot plate. Still air conditions were provided.

Results and Discussion

Complete physical analysis of the twenty-four materials is presented in Table II and in Table III are shown the results of thermal tests at the several laboratories. Of the numerous properties listed, only thickness evidenced a high relationship with thermal insulation values. This result was in complete agreement with the findings of the Philadelphia Quartermaster laboratory in 1942-1943 as mentioned earlier in this report.

The high association existing between the thickness values and the corresponding thermal values is illustrated in Figure 2. Pearson's coefficient is seen to range from .94 to .99 When the thermal values for each laboratory are ranked from the lowest 1 to the highest 24 in Table IV, the remarkably high consistency becomes evident regardless of the laboratory or the instrumentation. An analysis of variance of this ranked data shows a highly significant difference existing in the warmth of the fabrics, and the probability of their being ranked fortuitously is less than one in ten thousand. When the average rankings of the five laboratories were ranked and compared with the fabric thickness Spearman's Correlation Coefficient of .97 was obtained.

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*One clo is the insulation required to maintain in comfort a sitting resting subject at 70°F, air movement 10 feet per minute and humidity not greater than 50%.

TABLE IV

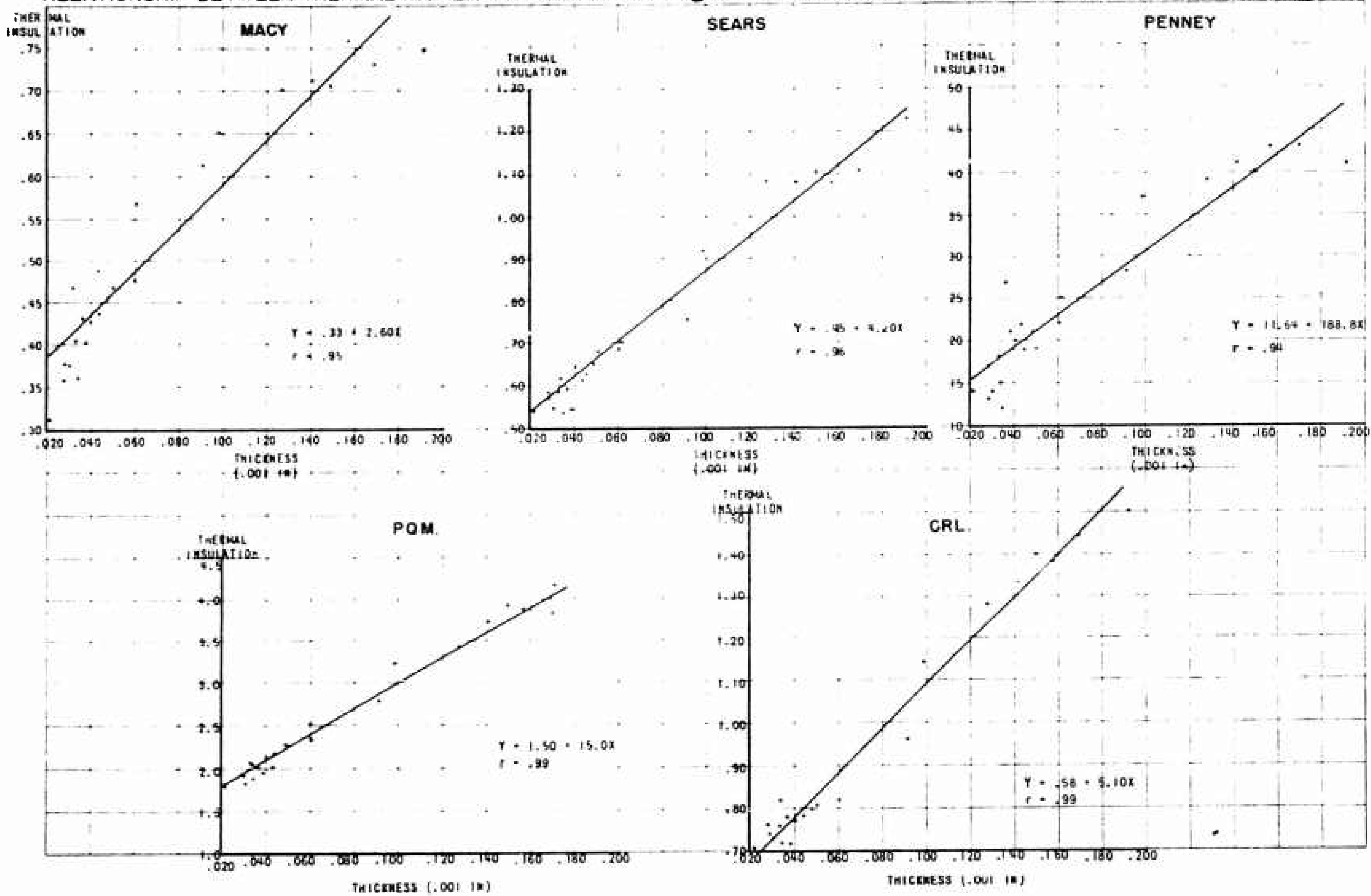
RANKINGS OF 24 WOOLEN MATERIALS BY FIVE LABORATORIES IN TERMS OF THERMAL INSULATION AND THICKNESS

FABRIC (1)	RANK OF THERMAL VALUES							RANK OF THICKNESS
	PQM (2)	CRL (3)	Macy's	Sears	Penney	Avg.	Rank of Avg.	
1	2	4	5	3.5	4	3.7	3.0	4.0
2	3	2.5	3	1	1	2.1	2.0	7.0
3	9	6.5	7	6	7	7.1	7.0	5.5
4	6	2.5	6	3.5	11	5.8	6.0	9.0
5	7	9.5	9	8	16	9.9	10.0	8.0
6	11	11.5	15	9.5	14	12.2	12.5	11.0
7	4	5	2	7	6	4.8	5.0	2.5
8	1	1	1	2	3	1.6	1.0	1.0
9	14	11.5	11	13	12	12.2	12.5	13.0
10	15	14.5	14	15	13	13.5	15.0	15.0
11	12	9.5	10	11	8	10.1	11.0	12.0
12	10	8	8	12	10	9.6	8.0	10.0
13	16	16	16	16	15	16.2	16.0	16.0
14	17	17	17	17	17	17.0	17.0	17.0
15	19	19	19	21	19	19.4	19.0	19.0
16	8	14.5	12	9.5	5	9.8	9.0	5.5
17	5	6.5	4	5	2	4.6	4.0	2.5
18	13	13	13	14	9	12.4	14.0	14.0
19	20	20	21	19	21	20.0	20.0	20.0
20	22	21	24	20	23	22.0	22.0	22.0
21	24	24	23	24	22	23.4	24.0	24.0
22	18	18	18	18	18	18.0	18.0	18.0
23	23	22	20	23	20	21.6	21.0	21.0
24	21	23	22	22	24	22.4	23.0	23.0
							ρ = .97	

(1) For identification of fabrics, see Table II
(2) Quartermaster Textile Materials Engineering Laboratory, Phila., Pa.
(3) Climatic Research Laboratory (QMC), Lawrence, Mass.

Figure 2

RELATIONSHIP BETWEEN THERMAL INSULATION VALUES & THICKNESS OF 24 FABRICS AS EVALUATED BY FIVE LABORATORIES.



Conclusions

It has been significantly indicated that conditions of testing the thermal transmission of textile materials vary from laboratory to laboratory throughout the country. As a result little agreement is had in absolute test values submitted for the same group of materials. Comparative results however show remarkably high agreement among laboratories.

Under the conditions of measurement practiced by the cooperating laboratories the thermal transmission values reported are directly related to fabric thickness and therefore are affected by all factors which influence fabric thickness. Until such time that other conditions are included in the thermal tests on the basis of correlation with actual field exposures, for example humidity and simulated perspiration (especially important in the case of lightweight tropical fabrics), wind conditions, and solar radiation, there appears to be little point in conducting an all-out program of instrument standardization. Thickness values should suffice for the present in predicting fabric performance on the laboratory equipment designed to evaluate thermal transmission of textiles under still-air conditions.

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