A Report

to

Textile Technology Center

on

Total Heat Loss Measurements of Two Materials

from

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Two samples were submitted, by Textile Technology Center, to the Textile Protection and Comfort Center (TPACC) in the College of Textiles at North Carolina State University, for characterization of the heat and moisture transport properties that contribute to thermal comfort. The purpose of this report is to describe the test method used to characterize these materials and to present the results of the laboratory test.

Test Materials

The test samples consisted of two single layer materials. The samples received consisted of fabric materials that were cut into one 20" x 20" swatch for each fabric type. Each swatch was tested three times for thermal resistance and three times for evaporative resistance. Fabrics were allowed to dry and re-equilibrate between tests. For this report, samples are identified as follows: **A** (light brown), and **B** (dark brown).

Test Method

The heat and moisture transfer properties determined in this program were calculated from measurements of thermal transport made with the large skin model hot plate instrumentation. Samples were tested in accordance with the procedures of ASTM F 1868, Standard Test Method for Thermal and Evaporative Resistance of Clothing Materials Using a Sweating Hot Plate, Part C. A description of the measured heat transfer parameters is given below; other details pertaining to instrumentation, methods and calculations are given in Appendix A.

Dry and Sweating Skin Tests

The measurement of heat transfer is a measure of heat flow from the calibrated test plate (heated to a skin surface temperature of 35°C) through the material or composite into the test environment (25°C, 65%RH), and is determined for both simulated dry and wet skin conditions. Heat loss parameters, calculated from thermal transport measurements, are listed below.

a. **Total Thermal Resistance (R_{ct})**, $[(\Delta°C)(m^2)/W]$, the total resistance to dry heat transfer (insulation) for a fabric system including the surface air layer.

b. **Intrinsic Thermal Resistance (R_{cf})**, $[(\Delta°C)(m^2)/W]$, the resistance to dry heat transfer provided by the fabric system alone.

c. **Bare Plate Thermal Resistance (R_{cbp})**, $[(\Delta°C)(m^2)/W]$, the resistance to dry heat provided by the surface air layer as measured on the bare plate.

d.	**Apparent Total Evaporative Resistance (R_{et}^A)**, $[(\Delta kPa)(m^2)/W]$, the total resistance to evaporative heat transfer for a fabric system including the surface air layer and liquid barrier (the descriptor term 'apparent' is added to account for the fact that heat transfer may have an added condensation component in non-isothermal conditions).

e.	**Apparent Intrinsic Evaporative Resistance (R_{ef}^A)**, $[(\Delta kPa)(m^2)/W]$, the resistance to evaporative heat transfer provided by the fabric system alone.

f.	**Bare Plate Thermal Resistance (R_{epb})**, $[(\Delta kPa)(m^2)/W]$, the resistance to evaporative heat transfer provided by the liquid barrier and surface air layer as measured on the bare plate (with liquid barrier attached).

g.	**Total Heat Loss (Q_t)**, $[W/m^2]$, an indicator of the heat transferred through the test material by the combined dry and evaporative heat loss, from a fully sweating test plate surface into the test environment. Total heat loss, measured at a 100% wet skin condition, indicates the highest predicted metabolic activity level that a wearer may sustain and still maintain body thermal comfort while in a highly stressed state in the test environment. For reference, Appendix C contains a table of the metabolic rates for various activities. Note, however, that the sweating hot plate does not consider effects such as insulating air layers, garment design, and fit. Thus, the Total Heat Loss value obtained represents the highest theoretically possible amount of heat that can be transferred through a material system for a given set of environmental conditions without active cooling or ventilation.

h.	**I_t,** [clo], indicates the thermal resistance measured in units of clo which indicates the insulating ability of the test material. Materials having higher clo values provide wearers with more thermal insulation and consequently greater heat storage during exertion. A clo value of 1 represents a typical men's business suit and is expected to maintain thermal comfort for a person in a normal indoor environment. Requirements vary from about 0.5 clo for summer wear to 4 to 5 clo for outdoor winter clothing. This value includes the insulation provided by the air layer above the sample and doesn't subtract it out as with R_{cf}.

i.	The **i_m value**, or permeability index, indicates moisture-heat permeability through the material on a scale of 0 (totally impermeable) to 1 (totally permeable) normalized for the permeability of still air (naked skin). This comfort parameter indicates the effect of skin moisture on heat loss as in the case of a sweating skin condition. This value includes the evaporative resistance provided by the air layer above the sample and doesn't subtract it out as with R_{ef}^A.

Thickness

An Ames thickness comparator, model 99-0697, was used to measure sample thickness with 0.6 psi applied. Thickness is reported in millimeters (mm).

Weight

Weight is measured according to ASTM D 3776 small swatch option. One specimen (20 x 20 inch) was weighed on an analytical balance and the weight was calculated in mass per unit area (oz/yd^2).

Test Results

The average values for R_{ct}, R_{et}^{A}, R_{cf}, R_{ef}^{A}, I_t, i_m, and Q_t of each sample received are contained in Table 1. Bare plate values are shown in Table 2. Weights and thicknesses are given in Table 3. Individual results of each test sample are displayed in Appendix B. Each specimen contained some creases in the test area. It was attempted to press fabrics flat without heat, but some small creases remained. They were smoothed out by hand as best as possible to minimize unwanted air layers. Some small air pockets may have remained, but most were able to be removed.

Table 1: Sample Results from Sweating Hot Plate

Sample	R_{ct}^{1}	$R_{et}^{A\,2}$	R_{cf}	R_{ef}^{A}	I_t	I_m	Q_t
A	0.134	0.01318	0.064	0.00765	0.867	0.618	417.354
B	0.140	0.01408	0.070	0.00855	0.903	0.603	388.288

[1]Higher values indicate more insulation is provided (more body heat is trapped).
[2]Lower values indicate higher breathability.

Table 2: Bare Plate Test Results

Sample	R_{cbp}	R_{ebp}
Pre-test bare plate	0.070	.005290
Post-test bare plate	0.070	.005753
Average	0.070	.005522

Table 3: Average Weights and Thicknesses

Sample	Weight (oz/yd^2)	Thickness (mm)
A	10.06	1.30
B	14.69	1.94

Caveat

These data, obtained under controlled laboratory conditions, characterize the thermal and evaporative resistance values of test sample responses to specific environmental conditions. These results should not be used to appraise the safety benefits or risks of the materials, products, or assemblies in extreme use conditions. The relationships between laboratory tests and field performance are not simple, and many things must be considered when making practical translations. Clothing comfort and heat stress performance are determined by many factors including material properties, garment design and fit, activity level, and the environmental conditions of use. These results do not address the full range of these issues. It is not our intention to recommend, exclude, or predict the suitability of any commercial product for a particular end use.

Appendix A: Instrument, Methods, and the Calculation of Total Heat Loss Parameters

Heat Transfer With/Without Moisture (Sweating Skin Condition)
Heat transfer makes it possible to predict the body heat that will flow from the skin surface through the material into the surrounding atmosphere. Heat and moisture transfer properties are key properties affecting clothing comfort. These thermal properties are analyzed using a guarded sweating hotplate system from Measurement Technology Northwest Inc. housed in an environmental test chamber set to achieve the required ambient conditions.

Tests were run in accordance with requirements of ASTM F 1868 Standard Test Method for Thermal and Evaporative Resistance of clothing Materials Using a Sweating Hot Plate; Part C. The specifics and allowable refinements are as follows:

- For a given replicate the temperatures, humidity, voltage and current are logged at 2 minute intervals with an acceptable steady-state deviation of no more than 1.5% for at least 30 minutes.

- Wind speed is set to 1 m/s with a turbulence value of ~0.09.

- Using system constants, R_{ef}, R_{ef}^{A}, and Q_t are calculated for each replicate. The replicate values are averaged to provide overall sample averages as reported in this document.

Calculation of Total Heat Loss Parameters
Calculation of the Total Heat Loss, Q_t [W/m^2], requires measurements from both dry and sweating conditions on a hotplate. Each total heat loss calculation was derived from the average of three test replications. Total heat loss, Q_t, was calculated using the following formula:

$$Q_t = \frac{10°C}{R_{cf} + .04} + \frac{3.57\ kPa}{R_{et}^{A} + .0035}$$

where:

Q_t = Total Heat Loss (THL),

R_{cf} = the average intrinsic thermal resistance of the sample alone and is determined by subtracting the average dry bare plate resistance (R_{cbp}) from the average of the total thermal resistance (R_{ct}) of the specimens tested,

R_{ef}^{A} = Average apparent intrinsic evaporative resistance of the sample alone as determined by the apparent total evaporative resistance (R_{et}^{A}) minus the average bare plate evaporative resistance (R_{ebp}),

R_{ct} = total thermal resistance of the specimen and surface air layer defined as

$$R_{ct} = \frac{(T_s - T_a) \cdot A}{H}$$

where:

T_s = Temperature of the plate surface (35°C),
T_a = Temperature in the local environment (25°C),
A = area of the test plate (0.01 m^2), and
W = power input (W),

R_{et}^A = apparent total evaporative resistance of the specimen and surface air layer defined as

$$R_{et}^A = \frac{(P_s - P_a) \cdot A/H - (T_s - T_a) \cdot A}{R_{ct}}$$

where:

P_s = water vapor pressure at the surface plate (kPa),
P_a = water vapor pressure in the local environment (kPa),
A = area of the test plate (0.01 m^2),
H = power input (W),
T_s = temperature at the plate surface (35°C),
T_a = temperature at the local environment (25°C), and
R_{ct} = total thermal resistance of the specimen and surface air layer [(Δ°C)(m^2)/W].

Calculation of I_t (clo) and i_m

I_t (clo) values are derived using dry plate test results, from the following formula:

$$I_t = R_{ct} / 0.155$$

The i_m value (permeability index) is calculated, using both dry and sweating plate test results, from the following formula:

$$i_m = 0.0094 * (I_t/R_{et}^A)$$

Appendix B: NCSU Sweating Thermal Hot Plate Results

Sample A

Rep	R_{ct}	R_{et}^{A}	R_{cf}	R_{ef}^{A}	I_t	I_m	Q_t
1	0.134	0.01309	0.064	0.00757	0.865	0.621	420.065
2	0.133	0.01336	0.063	0.00784	0.858	0.604	413.243
3	0.136	0.01307	0.066	0.00755	0.877	0.631	418.753
AVG	**0.134**	**0.01318**	**0.064**	**0.00765**	**0.867**	**0.618**	**417.354**

Weight

Rep	Weight (oz/yd^2)
1	10.06
Average	**10.06**

Thickness

Rep	Thicness (mm)
1	1.40
2	1.38
3	1.32
4	1.36
5	1.30
6	1.24
7	1.26
8	1.26
9	1.22
Average	**1.30**

Sample B

Rep	R_{ct}	R_{et}^{A}	R_{cf}	R_{ef}^{A}	I_t	I_m	Q_t
1	0.137	0.01379	0.067	0.00826	0.884	0.603	397.983
2	0.144	0.01407	0.074	0.00854	0.929	0.621	385.145
3	0.139	0.01438	0.069	0.00886	0.897	0.586	381.737
AVG	**0.140**	**0.01408**	**0.070**	**0.00855**	**0.903**	**0.603**	**388.288**

Weight

Rep	Weight (oz/yd^2)
1	14.69
Average	**14.69**

Thickness

Rep	Thicness (mm)
1	2.02
2	2.04
3	1.96
4	2.02
5	1.88
6	1.88
7	1.88
8	1.92
9	1.88
Average	**1.94**

Appendix C: Appendix C: Metabolic Rate for Different Activities [1]*

Activity			Metabolic Rate, M w/m^2
RESTING			
Sleeping			40
Seated, quiet			60
Standing, relaxed			70
WALKING			
On the level	km/hr		
	3.2		115
	5.6		180
	8.0		330
Up a grade			
%Grade	km/hr		
5	3.2		170
5	6.4		350
15	3.2		260
15	4.8		400
25	3.2		385
OFFICE WORK			
Typing	Electrical		55
	Mechanical		65
Filing, Checking			60-65
HEAVY WORK			
Handling 50 kg bags			230
Digging trenches			345
Stag removal			435
MISCELLANEOUS OCCUPATIONS			
Laboratory Work			
Examining slides			80
General lab. work			90
Setting up apparatus			125
Teacher			90
Vehicle driving			
Car			60-115
Heavy truck			180
LEISURE ACTIVITIES			
Gymnastics			170-230
Tennis			260
Wrestling			500

*[1]: Fanger, P.O., "Thermal Comfort", McGraw Hill, New York, 24-26, (1970)