A Report

to

Alpaca

on

Total Heat Loss Measurements of Four Samples

from

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Raleigh, North Carolina 27695-8301

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Four samples were submitted to the Textile Protection and Comfort Center (TPACC) in the Wilson College of Textiles at North Carolina State University, for characterization of the heat 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 Material

Tested as received, the samples are identified as labeled:

Legend:

Sample	Customer ID
A	Huacaya Felt
B	Suri Felt
C	100% Huacaya
D	100% Suri

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 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})**, [(Δ°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})**, [(Δ°C)(m^2)/W], the resistance to dry heat transfer provided by the fabric system alone.

c. **Bare Plate Thermal Resistance (R_{cbp})**, [(Δ°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)**, [(ΔkPa)(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)**, [(ΔkPa)(m^2)/W], the resistance to evaporative heat transfer provided by the fabric system alone.

f. **Bare Plate Evaporative Resistance (R_{ebp})**, [(ΔkPa)(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 5clo 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}.

Weight and Thickness

Weight is measured according to ASTM D 3776 small swatch option. Three specimens (20 x 20 inch) were weighed on an analytical balance and the weight was calculated in mass per unit area (oz/yd^2). Thickness is measured according to ASTM D 1777 test option 1. Three specimens (20 x 20 inch) were measured with a thickness gauge (mm) at an applied pressure of 0.6 psi at various locations of the fabric.

*In regards to samples B, C and D; these materials did not have the correct dimensions and/or possessed different weight material on the outer edges that prevented measuring the weights accurately difficult. Therefore, weights are not reported for these samples.

Test Results

The average values for R_{ct}, R_{et}^{A}, R_{cf}, R_{ef}^{A}, $I_{t,}$ and Q_t of the 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. All specimens were free from any significant creases in the test area.

Table 1: Sample Results from Sweating Hot Plate

Sample	R_{ct}	R_{et}^{A}	R_{cf}	R_{ef}^{A}	I_t	Q_t
A	**0.214**	**0.01875**	**0.139**	**0.01301**	**1.383**	**272.67**
B*	**0.233**	**0.02225**	**0.158**	**0.01651**	**1.505**	**228.94**
C	**0.139**	**0.01347**	**0.064**	**0.00773**	**0.897**	**414.19**
D	**0.132**	**0.01321**	**0.057**	**0.00747**	**0.853**	**428.74**

*Sample B was submitted with only enough material to cut one specimen from so this sample was tested in triplicate

Table 2: Bare Plate Test Results

Sample	R_{cbp}	R_{ebp}
Bare plate 1	0.0743	0.005725
Bare plate 2	0.0755	0.005753
Bare plate 3	0.0753	0.005743
Average	**0.0750**	**0.005740**

Table 3: Average Weights and Thicknesses

Sample	Weight (oz/yd^2)	Thickness (mm)
A	**6.07**	**2.15**
B		**2.25**
C		**1.28**
D		**1.41**

Caveat

These data, obtained under controlled laboratory conditions, characterize the thermal 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 Thermetrics 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 1 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 ~0.07.
- 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
H = 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:

$$I_t = R_{ct} * 6.45$$

Appendix B: NCSU Sweating Thermal Hot Plate Results

Sample – A

Rep	R_{ct}	R_{et}^{A}	R_{cf}	R_{ef}^{A}	I_t	Q_t
1	0.205	0.01773	0.130	0.01199	1.322	289.25
2	0.2123	0.01971	0.137	0.01397	1.369	260.75
3	0.2258	0.01880	0.151	0.01306	1.456	268.00
AVG	**0.214**	**0.01875**	**0.139**	**0.01301**	**1.383**	**272.67**

Weight

Rep	Weight (oz/yd^2)
1	5.66
2	6.24
3	6.31
Average	**6.07**

Thickness

Rep	Thickness (mm)
1	1.94
2	2.26
3	2.70
4	2.00
5	2.56
6	2.14
7	1.88
8	1.90
9	1.98
Average	**2.15**

Sample – B

Rep	R_{ct}	R_{et}^{A}	R_{cf}	R_{ef}^{A}	I_t	Q_t
1	0.229	0.02178	0.154	0.01604	1.477	234.24
2	0.233	0.02267	0.158	0.01693	1.503	225.23
3	0.2378	0.02229	0.163	0.01655	1.534	227.36
AVG	**0.233**	**0.02225**	**0.158**	**0.01651**	**1.505**	**228.94**

Weight

Rep	Weight (oz/yd^2)
1	
2	
3	
Average	

Thickness

Rep	Thickness (mm)
1	2.00
2	2.10
3	2.66
4	
5	
6	
7	
8	
9	
Average	**2.25**

Sample – C

Rep	R_{ct}	R_{et}^{A}	R_{cf}	R_{ef}^{A}	I_t	Q_t
1	0.1384	0.01355	0.063	0.00781	0.893	412.35
2	0.142	0.01362	0.067	0.00788	0.916	407.18
3	0.1367	0.01324	0.062	0.00750	0.882	423.03
AVG	**0.139**	**0.01347**	**0.064**	**0.00773**	**0.897**	**414.19**

Weight

Rep	Weight (oz/yd^2)
1	
2	
3	
Average	

Thickness

Rep	Thickness (mm)
1	1.32
2	1.40
3	1.22
4	1.26
5	1.22
6	1.28
7	1.30
8	1.26
9	1.24
Average	**1.28**

Sample – D

Rep	R_{ct}	R_{et}^{A}	R_{cf}	R_{ef}^{A}	I_t	Q_t
1	0.1343	0.01369	0.059	0.00795	0.866	412.62
2	0.1317	0.01286	0.057	0.00712	0.849	439.55
3	0.1307	0.01307	0.056	0.00733	0.843	434.06
AVG	**0.132**	**0.01321**	**0.057**	**0.00747**	**0.853**	**428.74**

Weight

Rep	Weight (oz/yd^2)
1	
2	
3	
Average	

Thickness

Rep	Thickness (mm)
1	1.48
2	1.48
3	1.48
4	1.54
5	1.28
6	1.26
7	1.40
8	1.40
9	1.36
Average	**1.41**