

THE INTERNATIONAL FIRE FIGHTER PROTECTIVE CLOTHING BREATHABILITY RESEARCH PROJECT

Phase II Report

Laundered Turnout Clothing

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FOREWORD

The International Fire Fighter Protective Clothing Breathability Project was initiated in 1998 with the aim of documenting the heat stress and comfort of several NFPA 1971-compliant turnout systems with a range of heat loss values. In Phase I of the project, objective and subjective measures of human physiological and psychological responses were applied to quantify turnout performance in several categories. Phase I also documented the use of a device, the guarded sweating hot plate, used for independent measurement and comparison with human subject results.

In Phase II of the project, documented here, the effects of laundering on the total heat loss measured on the turnout materials is assessed.

The data developed in this independent project was initially for consideration by the NFPA Technical Committee responsible for NFPA 1971, *Protective Ensemble for Structural Fire Fighting*. It is hoped that this report will also be valuable to fire departments, brigades and related organizations who are considering the breathability of protective clothing ensembles.

The Research Foundation expresses its gratitude to Dr. Roger Barker of North Carolina State University's College of Textiles for his technical guidance and the preparation of this report. The Foundation and authors thank the project's Technical Advisory Committee listed on the following page for their contributions of expertise, financial resources and in-kind donations.

Of course, participation on the Technical Advisory Committee does not necessarily constitute a participant's endorsement of every statement in this report.

**THE INTERNATIONAL FIRE FIGHTER PROTECTIVE CLOTHING
BREATHABILITY RESEARCH PROJECT**

Phase II

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A Report

to the

National Fire Protection Research Foundation

on

**International Fire Fighter Protective Clothing Breathability Research Project
Phase II**

from

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College of Textiles
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**Characterization of Test Composites
for the
International Fire Fighter Protective Clothing Breathability Research
Project**

Phase II

Six turnout fabric lay-ups were submitted by the National Fire Protection Research Foundation to the Textile Protection and Comfort Center (T-PACC) in the College of Textiles at North Carolina State University, for characterization of the heat and moisture transport properties that contribute to thermal comfort.

Phase I of this project was conducted in the first half of 1998. That work provided independent scientific documentation, through comprehensive laboratory testing, to help inform the NFPA 1971 Technical Committee on Structural Fire Fighting Protective Clothing and Equipment in consideration of the breathability performance requirements for structural fire fighting garments.

The objective of Phase II of this project was to assess the effects of laundering on the total heat loss measured on the turnout materials used in Phase I of the project.

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 composite systems, consisting of an outer shell, moisture barrier and an insulator liner, were tested following five laundering cycles per the procedure outlined in Appendix C. Samples are identified as 1, 2, 3, 4, 5, and 6.

Test Method

The heat and moisture transfer properties determined in this program were calculated from measurements of thermal transport made with the skin model hot plate instrumentation. Measurements were made using the laboratory test procedure proposed for use in NFPA 1971. (See Appendix A for a description of the instrumentation and test procedures). The reported heat loss parameters are listed and described below.

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, include:

a. **Average Intrinsic Thermal Resistance (R_{cf})**, ($\Delta^{\circ}\text{C})(\text{m}^2)/\text{watt}$, is an indicator of heat transferred from a dry, heated test plate through a fabric or composite into the test environment.

b. **Average Apparent Intrinsic Evaporative Resistance (A_{Ref})**, ($\Delta\text{kPa})(\text{m}^2)/\text{watt}$, is an indicator of the resistance of a fabric to transport heat and moisture while in contact with a wet, heated plate surface.

c. **Average Total Heat Loss (Q_t)**, watts/m^2 , is an indicator of the heat transferred through the composite by the combined dry and evaporative heat loss, from a fully sweating test plate surface into the test environment.

Test Results

Summarized test results are presented in Table 1 and shown graphically in Figures 1 - 3. Detailed results can be found in Appendix C.

Comments

These data indicate that washing has a complex effect on the total heat loss of the turnout composites tested by this study. Both the magnitude and direction of washing related heat loss changes varies depending on the particular turnout system tested (Figure 1). We observe that washing caused the intrinsic thermal resistance (R_{cf}) of all tested systems to increase (Figure 2). Concurrently, washing caused the apparent evaporative resistance (A_{Ref}) of many systems to decrease. The effect of washing on lowering the apparent evaporative thermal resistance is substantial for some systems (Figure 3). Since total heat loss is calculated as a combination of intrinsic thermal resistance and intrinsic apparent evaporative resistance, competing effects produced the indicated results.

**Table 1. Effect of Washing on
Total Heat Loss Parameters for Turnout Systems**

System	-----Before Washing-----			-----After Washing-----		
	Rcf	ARef	Qt	Rcf	ARef	Qt
1	0.118	0.016	251	0.174	0.017	218
2	0.153	0.017	222	0.193	0.015	236
3	0.161	0.034	146	0.216	0.010	311
4	0.134	0.087	97	0.154	0.082	94
5	0.115	0.016	247	0.141	0.013	277
6	0.118	0.034	158	0.183	0.010	304

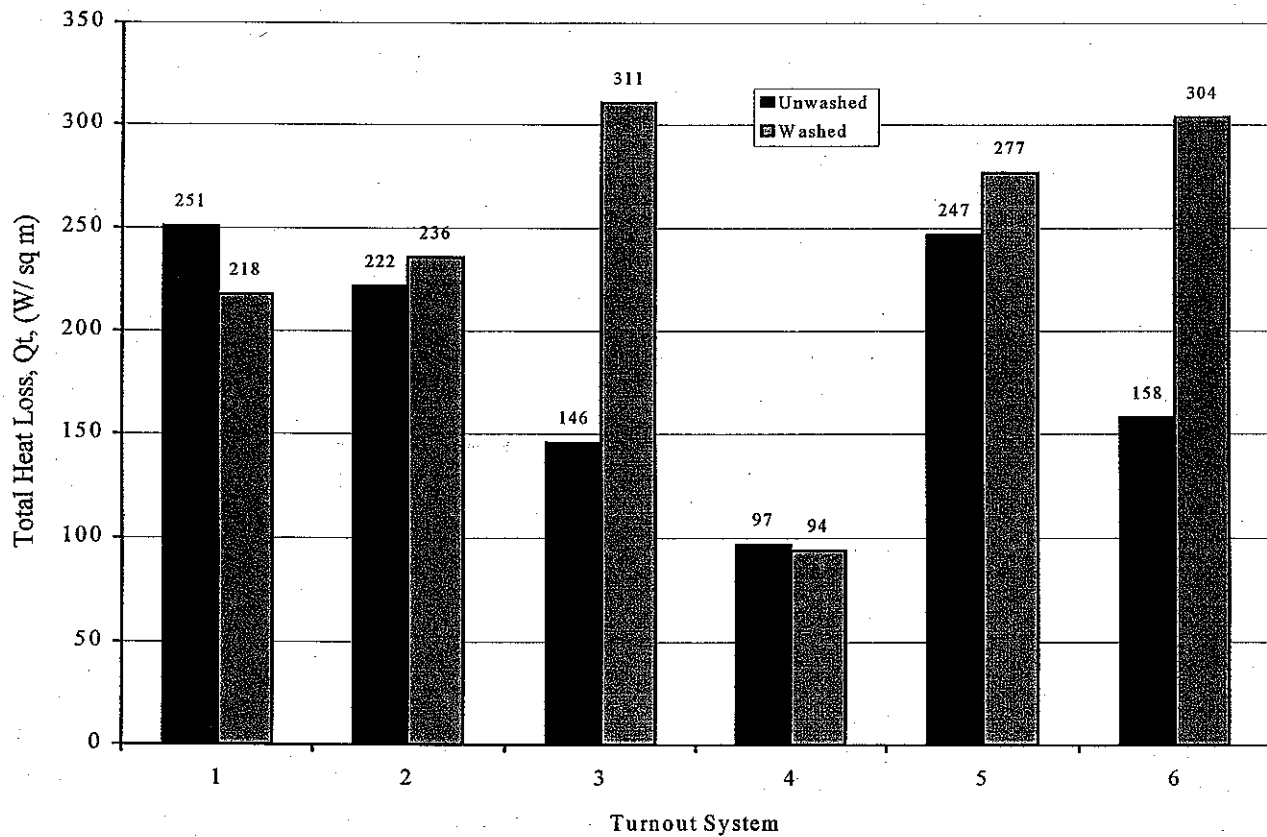


Figure 1. Comparison of Total Heat Loss, Q_t

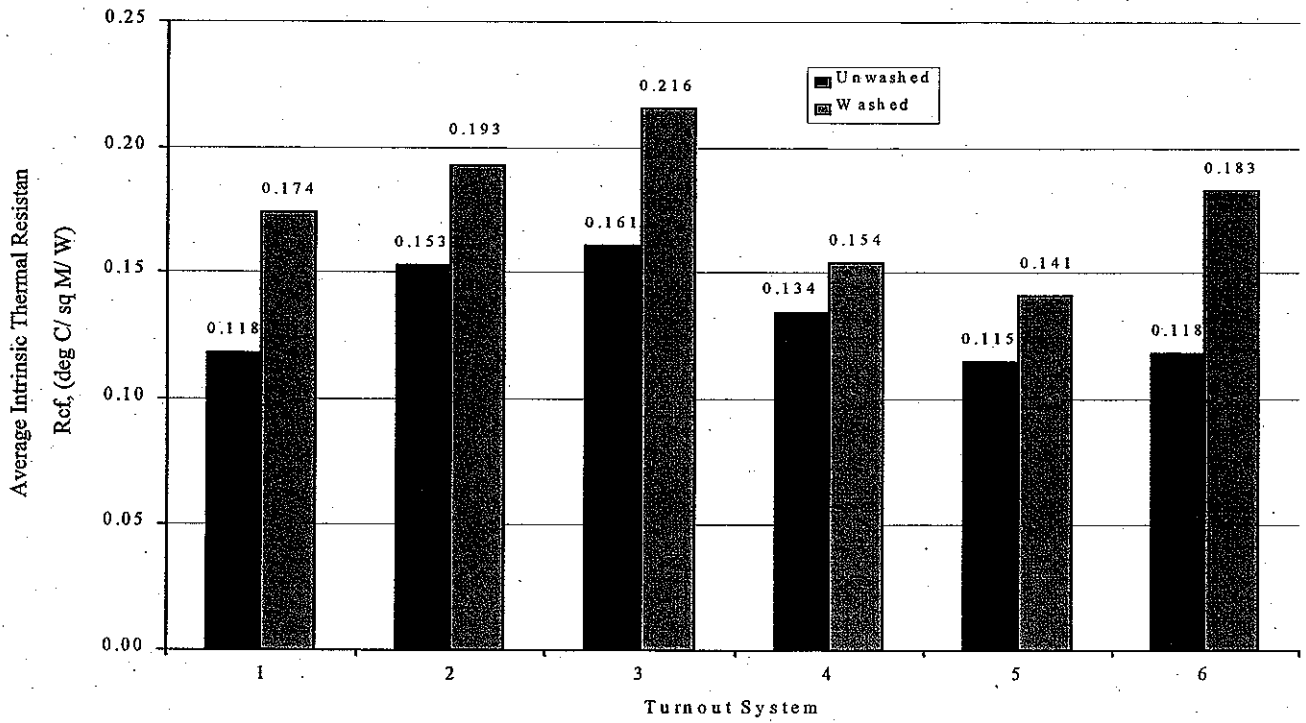


Figure 2. Average Intrinsic Thermal Resistance (Rcf)

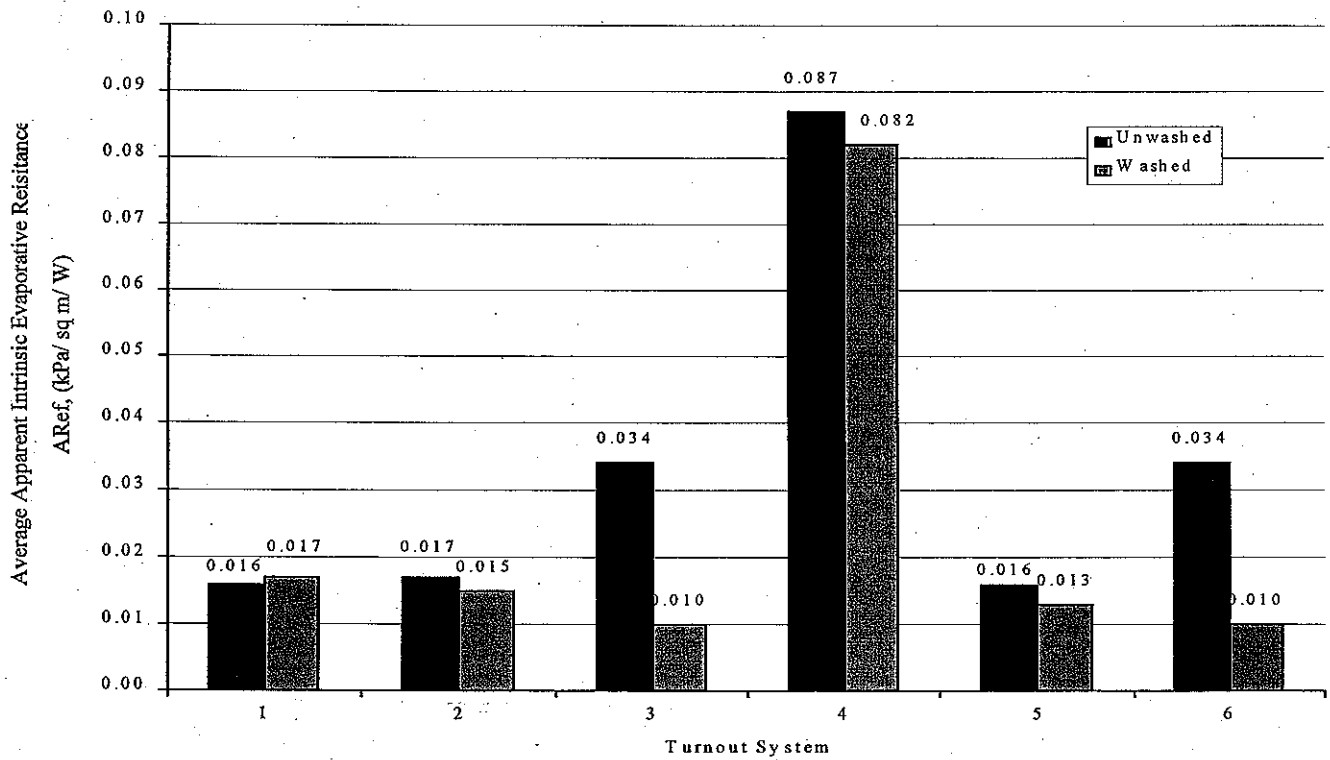


Figure 3. Average Apparent Intrinsic Evaporative Resistance, ARef

Appendix A

Instrument, Method, and the Calculation of Total Heat Loss Parameters

Heat Transfer (watts/m²°C) 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 Holometric Guarded Hot Plate Thermal Measuring System. A Tenny Model T30 chamber is used to obtain and maintain the required ambient conditions.

The tests were run in accordance with requirements of the protocol for "Total Heat Loss Test" proposed for the National Fire Protection Association (NFPA) Standard 1971: Protective Clothing and Equipment for Wildland Fire Fighting 1993; Section 3-4.5. The specifics and allowable refinements are as follows:

- For a given replicate the temperatures, humidity, voltage and current were measured at 1 minute intervals.
- After ten measurements, the values were averaged and recorded. The test continued until six consecutive average values met the method requirement of less than a 3% drift per hour. Actually, the maximum-minimum difference for both R_{ct} and A_{Ret} were nominally less than 2 percent.
- Using system constants, Ref, A_{Ref}, 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

Calculations of the total heat loss, Q_t (watts/m²), requires measurements from both dry and wet plate (sweating) tests. 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:

$$Q_t = \frac{10^\circ\text{C}}{R_{ct}} + \frac{3.57 \text{ kPa}}{A_{Ret}}$$

where:

Q_t = total heat loss (W/m²)

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.

A_{Ref} = Average apparent intrinsic evaporative resistance of the sample alone as determined by the apparent total evaporative resistance (A_{Ret}) minus the average bare plate evaporative resistance (R_{ebp}).

Rct = total thermal resistance of the specimen and surface air layer (°C)(m²)/W

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

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 m²)

W = power input (W)

ARet = apparent total evaporative resistance of the specimen and surface air layer (kPa/m²/W)

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

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 m²)

H = power input (W)

T_s = temperature at the plate surface (35 °C)

T_a = temperature at the local environment (25 °C)

Rct = total thermal resistance of the specimen and surface air layer (°C/m²/W)

Appendix B

Laundry Procedure

Washing Procedure for Test Fabrics

In preparation for washing, the composite systems consisting of an outer shell fabric, moisture barrier and an insulator liner, were machine stitched together along the perimeter using a zigzag stitch. This stitching was removed prior to testing.

The washing procedure selected was the automatic home laundering procedure described in AATCC method 135. The options used, as outlined in NFPA 1971 Washing and Drying Procedure for Garments, Gloves, Hoods and Wristlets, were Machine Cycle 1, 120°F wash temperature and Drying Procedure Ai. Details are listed below.

- 1) Approximately a 4 pound load
- 2) 18 gallon washer capacity
- 3) Normal washing cycle setting (10 Minute wash)
- 4) Approximately 49 +/- 3°C (hot) wash temperature
- 5) Cold rinse
- 6) 5 wash-dry cycles
- 7) 1 capful of liquid Ultra Tide
- 8) Tumble dry, "Optimum Dryness" setting (avg. 45 minutes)
- 9) Remove from dryer

Appendix C

Detailed Data

Table C1. Test Results on Unwashed Composites

Sample	Test	Ref	Aref	Qt
1	A	0.1161	0.0154	253.08
	B	0.1191	0.0156	250.01
	C	0.1201	0.0157	248.56
	AVG	0.1185	0.0155	250.55
	SD	0.0021	0.0001	2.31
	CV	1.7712	0.9620	0.92
	2	A	0.1604	0.0172
B		0.1504	0.0177	220.63
C		0.1474	0.0175	223.72
AVG		0.1527	0.0175	222.28
SD		0.0068	0.0003	1.56
CV		4.4777	1.6009	0.70
3		A	0.1658	0.0313
	B	0.1568	0.0372	138.57
	C	0.1589	0.0330	148.22
	AVG	0.1605	0.0338	146.01
	SD	0.0047	0.0031	6.62
	CV	2.9506	9.0219	4.54
	4	A	0.1329	0.0958
B		0.1341	0.0784	101.02
C		0.1349	0.0854	97.37
AVG		0.1340	0.0865	97.42
SD		0.0010	0.0087	3.59
CV		0.7509	10.0867	3.68
5		A	0.1127	0.0169
	B	0.1124	0.0159	249.29
	C	0.1210	0.0153	251.70
	AVG	0.1153	0.0161	247.05
	SD	0.0049	0.0008	6.08
	CV	4.2191	5.0481	2.46
	6	A	0.1186	0.0339
B		0.1233	0.0345	155.11
C		0.1108	0.0343	160.85
AVG		0.1176	0.0342	158.16
SD		0.0063	0.0003	2.89
CV		5.3492	0.9378	1.83

Table C2. Test Results on Washed Composites

Sample	Test	Rcf	Aref	Qt
1	A	0.1764	0.0171	219.44
	B	0.1684	0.0185	210.07
	C	0.1772	0.0165	224.71
	AVG	0.1740	0.0174	218.07
	SD	0.0048	0.0010	7.41
	CV	2.7802	6.0221	3.40
	2	A	0.1939	0.0137
B		0.1894	0.0164	223.48
C		0.1965	0.0150	235.64
AVG		0.1932	0.0150	236.38
SD		0.0036	0.0013	13.30
CV		1.8649	8.7753	5.63
3		A	0.2326	0.0112
	B	0.2078	0.0080	349.91
	C	0.2084	0.0100	305.08
	AVG	0.2163	0.0098	311.26
	SD	0.0142	0.0016	35.96
	CV	6.5604	16.5906	11.55
	4	A	0.1596	0.0725
B		0.1526	0.0859	91.85
C		0.1498	0.0880	91.72
AVG		0.1540	0.0821	93.56
SD		0.0051	0.0084	3.07
CV		3.2853	10.2573	3.28
5		A	0.1442	0.0134
	B	0.1374	0.0123	282.16
	C	0.1397	0.0121	284.07
	AVG	0.1405	0.0126	277.09
	SD	0.0034	0.0007	10.48
	CV	2.4432	5.6259	3.78
	6	A	0.1760	0.0094
B		0.1852	0.0109	291.66
C		0.1887	0.0106	296.04
AVG		0.1833	0.0103	303.53
SD		0.0065	0.0008	16.90
CV		3.5713	7.8677	5.57