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Research Article

Fabric Selection to Balance Evaporative Cooling and Infrared Radiation Attenuation

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Abstract

Background: Fabric properties influence heat and moisture transfer between the body and the surrounding environment. For outdoor workers, air permeability and sweat evaporation can support cooling, while attenuation of solar infrared (IR) radiation can reduce radiant heat exposure. These properties may involve competing performance demands. This study developed and applied a laboratory protocol to compare five fabric types in relation to air permeability, water evaporation, fabric temperature change, and IR radiation penetration.

Methods: Five fabric types including cotton, polyester, nylon, silk, and cashmere were evaluated. Air permeability was measured using a negative-pressure airflow system. Evaporative performance was assessed by exposing water-saturated fabric samples to controlled airflow inside a wind tunnel. IR radiation penetration was measured using an IR heat-lamp platform. All tests were performed three times and the resulting values averaged.

Results: Cashmere had the highest measured air permeability (99% of the control airflow), while nylon had the lowest (49%). Cashmere also had the greatest initial water absorption (6.921g). Silk lost the greatest amount of water during the five-minute evaporation test (0.497g), whereas polyester and nylon each lost 0.421g. Cashmere had the largest fabric temperature reduction (7.0 °C). Polyester provided the greatest IR attenuation (63%), followed by cotton (58%) and silk (57%).

Conclusions: The laboratory protocol distinguished among the five fabrics across measures related to air movement, evaporation, temperature change, and IR attenuation. No fabric ranked first on all measures. The results support evaluating clothing materials using more than one thermal performance criterion.

Keywords: Protective clothing; Evaporative cooling; Moisture transport; Air permeability; Infrared heat radiation attenuation

Introduction

Workers in agriculture, construction, landscaping, and other outdoor occupations may spend many hours exposed to high air temperatures and direct sunlight. When the exposures occur simultaneously with strenuous physical activity, the body may have difficulty maintaining a safe core temperature. Heat strain can reduce comfort and work capacity and, in severe cases, contribute to heat-related illness [1-5].

The body relies on sweat evaporation to release heat. As sweat changes from liquid to vapor, it takes heat from the skin. How well this process works depends in part on whether moisture can move through clothing and escape into the surrounding air. Air-permeable fabrics can allow more air exchange within the clothing microenvironment and may help moisture evaporate. In contrast, fabrics that restrict airflow or retain moisture may slow drying and allow heat and humidity to build up next to the skin. Fiber composition, fabric

thickness, weave, surface characteristics, and moisture absorption can all affect these processes [6-15].

Clothing can also reduce the amount of solar infrared (IR) radiation that reaches the body. Fabrics differ in how much radiation they reflect, absorb, and transmit. A material that attenuates more incoming radiation may reduce radiant heat transfer, but its performance may come at the expense of airflow or moisture evaporation. The reverse may also occur: a fabric that allows air and moisture to pass readily may provide less protection from radiant heat. For this reason, judging a fabric by only one property can give an incomplete picture of its potential value in hot outdoor environments. A useful comparison should consider both evaporative performance and the amount of IR radiation transmitted through the material [10, 11,15,16].

The objective of this study was to develop and apply a laboratory testing protocol for comparing fabric properties relevant to evaporative cooling and attenuation of solar IR heat radiation. The protocol included measurements of air permeability, water loss and fabric temperature change during evaporation, and IR radiation penetration. The goal was to provide a practical basis for comparing materials, rather than to determine the physiological effects of wearing the fabrics [8,9,13,17,18].

Material and Methods

Five fabric materials including 100% cotton, 100% polyester, 100% nylon, 100% silk, and 100% cashmere were evaluated in this study. Samples were obtained from used clothing. Fabric thickness, mass, weave, drying time, chemical treatments, etc., were not considered. Tests were conducted only to characterize air permeability, evaporative performance, and attenuation of IR radiation. Each test was performed three times and the values averaged. The procedures and results are described separately below.

Air permeability

A negative-pressure airflow system (Figure 1) was used to assess the reduction in airflow when a fabric sample was placed over the test platform. The system was calibrated to an airflow of 6.6m/s. For each fabric sample, the measured air velocity was compared with the control airflow, and air permeability was expressed as a percentage of the control value.

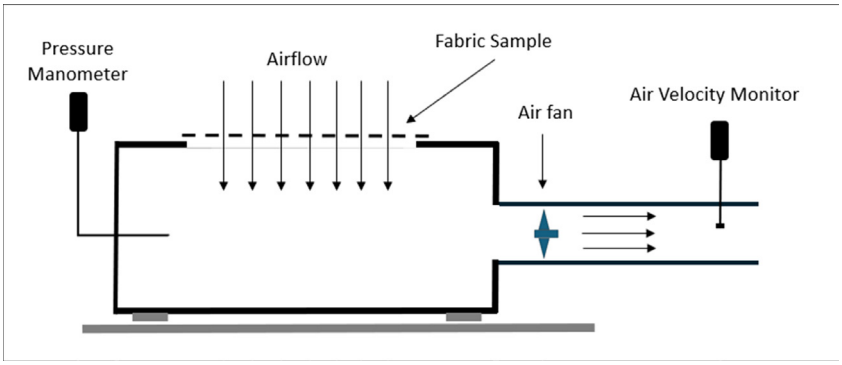


Figure 1: Negative pressure airflow system used for determining air permeability of cotton, polyester, nylon, silk and cashmere fabric samples.

Evaporative cooling

A laminar-flow wind tunnel (Figure 2) was used to assess the cooling associated with water evaporation from saturated fabric samples. Each 50cm^2 sample was exposed to an airflow of 1.5m/s for five minutes. Air temperature was maintained at 22.5 °C and relative humidity at 40%. The dry weight and initial water absorption of each sample are summarized in Table 1. Water loss and the change in fabric temperature were recorded during the tests.

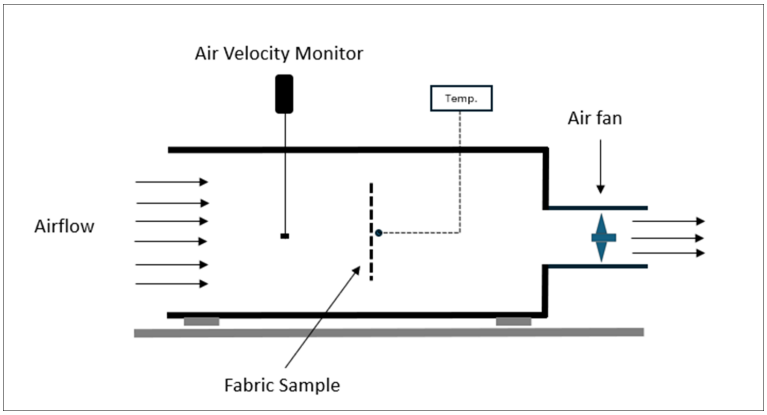


Figure 2: Wind tunnel system used for assessing fabric temperature changes resulting from water evaporation.

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Table 1: Summary of fabric sample weights and their water content prior to testing.

Fabric Sample	Fabric Dry Weight (g)	Fabric Water Absorption (g)
Cotton	0.628	3.645
Polyester	0.802	4.737
Nylon	0.616	3.467
Silk	0.563	4.091
Cashmere	0.933	6.921

IR radiation

IR radiation penetration through each fabric sample was measured using the exposure platform shown in Figure 3. A 220W heat lamp was positioned 22cm above a sample. The reported radiation spectrum was 0.78-10µm, with an exposure intensity of 400W/m^2.

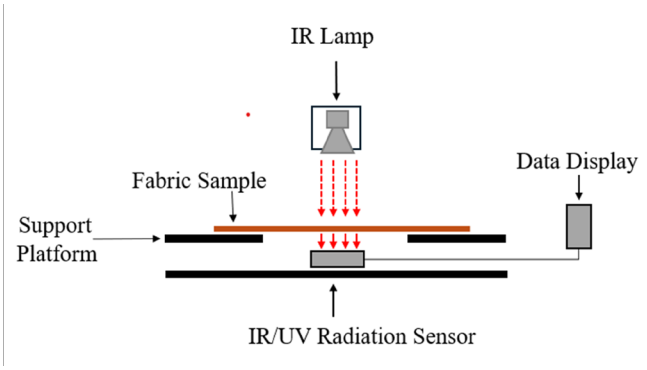


Figure 3: Infrared heat radiation exposure platform.

Samples measured 17cm × 17cm and were exposed to the IR radiation for two minutes. IR attenuation was calculated relative to the 400W/m^2 control exposure.

Results

Air permeability (Table 2)

Table 2: Summary of air velocity values recorded for the five fabric samples evaluated. Air permeability is expressed as a percentage of air velocity relative to "control".

Fabric Sample	Air Velocity (m/sec)	Air Permeability (%)
"Control"	6.60	100
Cotton	4.36	66
Polyester	3.52	53
Nylon	3.23	49
Silk	4.40	67
Cashmere	6.55	99

Evaporative cooling (Table 3)

Table 3: Summary of water evaporated during exposure and resulting cooling of the fabric. Exposure time to the airflow inside the wind tunnel was five minutes.

Fabric Sample	Water Evaporation (g)	End Temperature (˚C)	Temperature Reduction (˚C)
Cotton	0.465	17.3	-5.4
Polyester	0.421	17.5	-5.2
Nylon	0.421	17.9	-4.6
Silk	0.497	16.3	-6.0
Cashmere	0.424	16.0	-7.0

IR radiation attenuation (Table 4)

Table 4: Summary of infrared heat radiation penetration through fabric samples. Attenuation was calculated relative to the "control" of 400 W/m^2.

Fabric Sample	IR Penetration (W/m2)	IR Attenuation (%)
"Control"	400	0
Cotton	167	58
Polyester	147	63
Nylon	245	39
Silk	173	57
Cashmere	199	50

Discussion

Comparison of Tables 5&6 shows that the fabric with the best performance in one category was not necessarily the best in another. Cashmere ranked first for air permeability and for the recorded temperature reduction but ranked fourth for IR attenuation. Polyester ranked first for IR attenuation, but fourth for air permeability and evaporative cooling. Silk showed a relatively balanced pattern: it ranked third for air permeability, second for the temperature-reduction, and third for IR attenuation. Cotton also showed intermediate performance across the three categories.

Table 5: Comparison of air permeability, evaporative cooling and IR heat radiation attenuation for the five fabric samples tested.

Fabric Sample	Air Permeability	Evaporative Cooling	IR Attenuation
Cotton	66%	- 5.4 ˚C	58%
Polyester	53%	- 5.2 ˚C	63%
Nylon	49%	- 4.6 ˚C	39%
Silk	67%	- 6.0 ˚C	57%
Cashmere	99%	- 7.0 ˚C	50%

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Table 6: Relative performance ranking. The best performance was defined as #1. The lowest performance was defined as #5.

Fabric Sample	Air Permeability Rank #	Evaporative Cooling Rank #	IR Attenuation Rank #
Cotton	2	3	2
Polyester	4	4	1
Nylon	5	5	5
Silk	3	2	3
Cashmere	1	1	4

These patterns have practical implications for the development of clothing for outdoor exposures. A garment intended for work in direct sunlight may need to limit radiant heat transmission, but it must also allow the wearer to release metabolic heat and evaporate sweat. A fabric that is selected only because it blocks IR radiation and could restrict airflow or moisture movement. Conversely, a highly air-permeable fabric may allow more radiant energy to reach the wearer. The present results suggest that material selection should begin with the expected work environment and then weigh the relative importance of radiant protection, airflow, and evaporative performance.

The results show that the five fabrics differed across all three measures. Cashmere allowed the greatest airflow in the test system, while polyester and nylon allowed less. The evaporation test produced a different pattern: silk lost the greatest amount of water during five minutes, while polyester and nylon lost the least. Cashmere showed the largest temperature reduction. These results illustrate why air permeability, water loss, and fabric temperature change should not be treated as interchangeable measures of evaporative cooling.

Future work should include factors such as fabric thickness, mass, weave, color, moisture transport, and drying time. The most promising materials could then be evaluated as complete garments under controlled heat exposure and, ultimately, in field studies with workers. Physiological responses and perceived comfort would help determine whether the laboratory differences translate into meaningful reductions in physiological heat strain. Blended fabrics and layered designs may also offer a way to combine radiant protection with adequate air and moisture transport.

Conclusion

The goal of protective clothing design should be to provide an effective balance between reducing external radiant heat exposure and supporting the body's natural cooling through sweating. The test protocol developed in this study provides a foundation for identifying and evaluating fabric materials that may contribute to more effective heat-stress protective clothing for outdoor workers. An important outcome of this study is the development of a laboratory approach that allows fabric materials to be compared using multiple performance criteria rather than relying on a single measurement. This strategy can help identify materials with complementary properties suitable for the development of improved protective clothing for workers exposed to high temperatures and solar IR radiation in the future.

Conflicts of Interest

The authors declare no conflicts of interest.

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