THE WOOLMARK COMPANY

EXPLORING FABRIC DYNAMIC BREATHABILITY

FAST FACTS

- 100% wool base-layer garments provide greater thermal comfort in outdoor 'stop-go' sports – such as hiking, cycling and rock climbing – and that this is most noticeable during the resting phases of these sports when the potential for experiencing 'after-chill' is greatest.
- The study suggests that athletes wearing wool expend less energy maintaining their thermal equilibrium than if they wear other natural and synthetic fabrics, leaving athletes with more energy to use for their sport and competition.
- A dynamic variant to the ISO 11092 method is in development to more closely emulate the athlete's experience in stop-go sports.

WHAT IS DYNAMIC BREATHABILITY?

Humans and other members of the mammalian family evolved to survive the environmental extremes of nature including fire, rain, heat, humidity and cold. The structurally complex, protein-based fibres we know as wool, cashmere, alpaca, camel and mohair (and hair) were designed by nature over eons to maximise thermal comfort in the ever-changing environmental circumstances associated with physical activity, and diurnal and seasonal change. The success of these fibres for users is evidenced by the ongoing existence of mammalian species.

Active outdoor sports such as hiking, cycling and rock climbing are also known as stop-go sports as they involve surges of physical effort followed by resting periods. Stop-go athletes sweat during the active phase, which is absorbed by their clothing, and this sweat is then released from the clothing in subsequent rest periods – an inherent feature of stop-go sports is the ongoing sequence of activity and rest. Stop-go sport athletes are sensitive to the thermal changes experienced as their garments alternate between the exothermic heat generation of the sweating phase and the evaporative cooling of the drying phase. The ability of wool garments to maintain more stable thermal comfort by buffering the microclimate between the fabric and the skin is well documented and well acknowledged in the anecdotal evidence from athletes such as:

> "wool maintains its insulating properties when damp"

> "I get neither cold, nor more importantly, hot and sweaty"

> "It still keeps you warm even when wet"

However, as appropriate test methods do not exist, outdoor clothing designers use 'steady-state' laboratory equipment to develop sportswear for stop-go sports, even though they're used in anything but the steady state. Consequently, these fabric test methods such as ISO 11092 *"Measurement of thermal and water vapour resistance under steady state conditions"* are unable to effectively distinguish the thermal comfort performance of garments made for stop-go sports.

We set out to explore this knowledge gap and develop a variant to the ISO 11092 test method to more accurately emulate the dynamic phases experienced by athletes during stop-go sports.

WHAT THE CURRENT SCIENCE SAYS

Thermal comfort concerns the maintenance of body temperature at an optimum level (37°Celsius +/- 0.5°C) not only during stable conditions but also during changes in either the immediate environment (such as moving from hot to cold) or the body's metabolic rate (such as starting or ceasing exercise). Humans rely on clothing to help regulate their body temperatures and wool, more than all other common apparel fibres, helps maintain a more stable microclimate between the garment and the body.

The two properties of thermal insulation and moisture vapour management are coupled and can impart a series of benefits to users of wool products through acting independently or in combination.

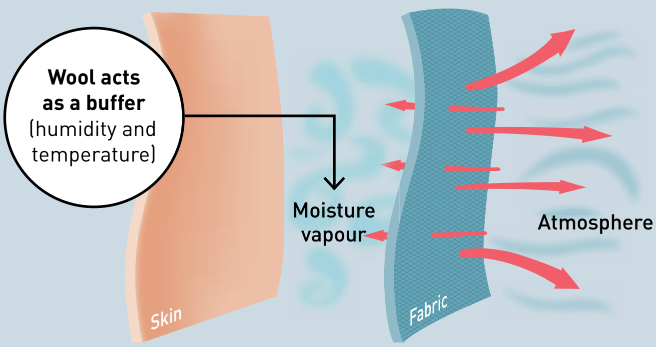


Figure 1 Wool works to buffer the dynamic micro-climate between the fabric and skin.

WHAT THE RESEARCH STUDY INVOLVED

North Carolina State University is a research leader in the textile space, with lead researcher Professor Emiel Den Hartog publishing more than 60 papers on textiles and their effect on human comfort and wellbeing.

A recently completed 3-year PhD study followed a structured research process with the ultimate goal of developing a more meaningful fabric test method. It involved using 5 carefully matched fabrics made from different fibre types and assessing them via existing fabric tests as well as dynamic sweating manikin tests and human trials.

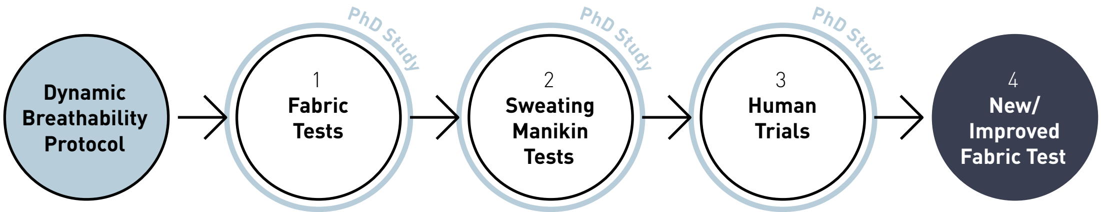


Figure 2 Dynamic breathability research process.
3-year PhD study – North Carolina State University

STAGE 1 – FABRIC TESTS

The primary function of all clothing, especially in outdoor and sporting settings, is to protect our health and wellbeing. Whilst in these settings, people are often active and move about, so the clothes they wear must not only be suitable for the environment and climate, they must also be able to respond to the changing levels of the person's activity.

We can determine the best textiles for a given end-use by measuring textile properties such as the ability to manage moisture and permeability to the heat associated with the micro-climate next to the body, as well as the general environment. These properties are often referred to as the 'breathability' of a textile.

The most notable tests are those measuring:

- Liquid moisture management – AATCC TM 195, AATCC 200 & 201, Gravimetric Absorbency Test, Horizontal AATCC TM198 and vertical AATCC TM197) wicking tests
- Thermal resistance and moisture vapour management – ISO 11092.

All these tests are designed to measure steady-state performance which might provide misleading results, because humans and their environment are rarely static.

Five fabrics (Table 1) made from different fibre types, but closely matched fabric mass and thickness, were subjected to industry standard tests including gravimetric absorbency, MMT moisture management (AATCC 195) and drying rate (AATCC TM201).

Unsurprisingly, textiles made from animal fibres such as wool, which were designed by nature to protect animals in dynamic situations, often did not perform well in these static tests.

More realistically, the performance of textiles should be assessed in 'non-static' conditions i.e. we should measure their dynamic breathability – their heat and moisture transport properties under conditions of temperature and humidity that change over time.

Two time-consuming and relatively expensive methods to do this involve sweating manikins and human trials.

Table 1 Fabric details

Sl No	Sample ID	Fabric Composition	Fabric Structure	Weight (g/m^2)	Thickness (mm)	Description
1	WBT	100% Merino Wool	Jersey Knit	213	0.69	Wool-Hydrophobic (natural wool)
2	WLT	100% Merino Wool	Jersey Knit	220	0.69	Wool-Hydrophilic
3	CL	100% Cotton	Jersey Knit	188	0.65	Cotton-Hydrophilic (natural cotton)
4	PLT	100% Polyester	Rib Knit	199	0.69	Polyester-Hydrophilic
5	VB	100% Viscose	Jersey Knit	204	0.67	Viscose-Hydrophobic

STAGE 2 – MANIKIN STUDIES

Sweating manikin studies can provide useful insights into the human experience of textiles in carefully managed environmental circumstances.

The Abedin and DenHartog 2023 study showed normal hydrophobic wool as best in buffering thermal change during transition from 45% relative humidity (RH) environment to 80% RH – showcasing a temperature buffering efficiency 26% superior to viscose, 45% superior to cotton, and 96% superior to polyester. This difference is not observed in steady state testing.

The manikin study clearly differentiated wool's potential to maintain thermal comfort during the resting phase after activity by countering the evaporative cooling effect of fabric drying.

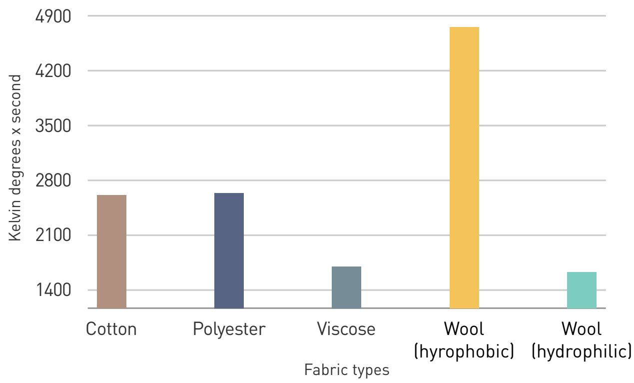
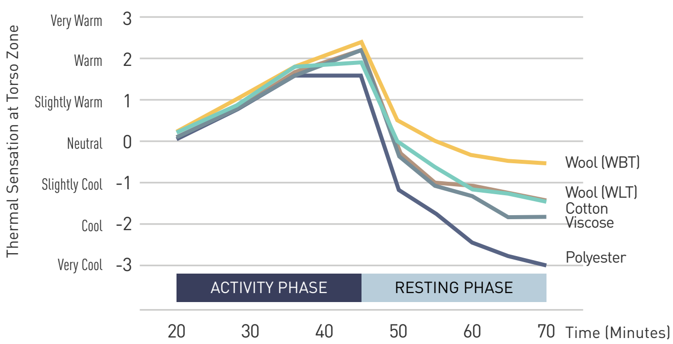


Figure 3 Heat retained during cool-down phase.

STAGE 3 – HUMAN STUDIES



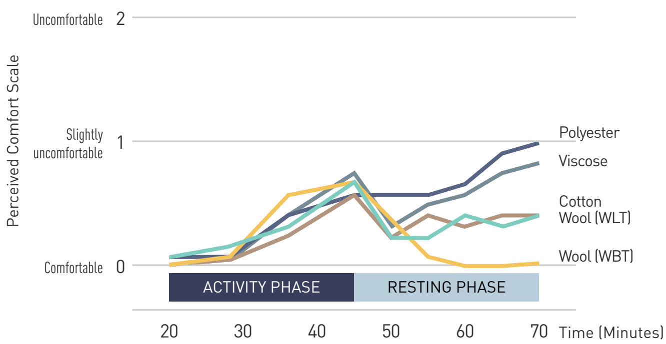


Figure 4 Thermal sensation and perceived comfort ratings over time in the activity and resting (inactive) phases of stop-go exercise.

Human studies are vital for validating and contextualising the objective evidence obtained in fabric and manikin tests. It is well known that thermal comfort is associated with clothing thermal resistance (Clo value) and the level of activity being undertaken by a body. There exists an optimum temperature range for a given Clo value and activity level. For an athlete wearing base-layer clothing, the effect of decreased metabolic rate on comfort can be dramatic. The body must create heat using stored energy reserves to maintain core body temperature.

Abedin and DenHartog 2023, evaluated the performance of textiles in human subjects undergoing a period of activity, followed by a period of rest in temperature and wind conditions, simulating stop-go sports.

The key findings evident from Figure 4 showed:

- no significant differences between fibres in perceived comfort or thermal sensation during the activity phase;
- only wool maintained ongoing comfort throughout the resting phase, with after-chill experienced for all other fibre types; and
- thermal performance differences are long-lived, with fibres still diverging after 25 minutes.

STAGE 4 – DEVELOPING A NEW, SIMPLER AND CHEAPER TEST FOR DYNAMIC BREATHABILITY

Routine use of manikin and human tests/trials is uneconomical so an alternative approach is necessary to measure for dynamic breathability.

The existing standard method is ISO *11092 "Measurement of thermal and water vapour resistance under steady state conditions"*, which uses the 'sweating guarded hotplate' apparatus. This method was modified to assess the properties of sports fabrics in dynamic stop-go activities.

The modified method involves operating a sweating guarded hotplate in an environment relevant to the scenario being assessed, i.e. appropriate temperature, relative humidity and airflow (Figure 5). A key adjustment involves removing the standard semi-permeable membrane between the fabric and the hotplate, enabling a fixed amount of liquid water to permeate the fabric.

Hydrophilic (i.e. water absorbing) fabrics exhibit rapid evaporation of liquid water shown by the higher heat flux observed for polyester in Figure 6. Conversely, for hydrophobic wool fabrics, liquid water does not spread and thus with a smaller surface area available to the environment does not evaporate as quickly.

By calculating the areas under the curves in Figure 6 we estimate heat flux or energy flow from the human body to maintain thermal equilibrium.

Given the importance of energy management in stop-go sports, it's important to differentiate fabrics requiring less energy input from the athlete.

The athlete expends less energy maintaining thermal comfort during both the activity and rest phases in wool, with the combined energy consumption, half or less that of all other fibres (Figure 7).

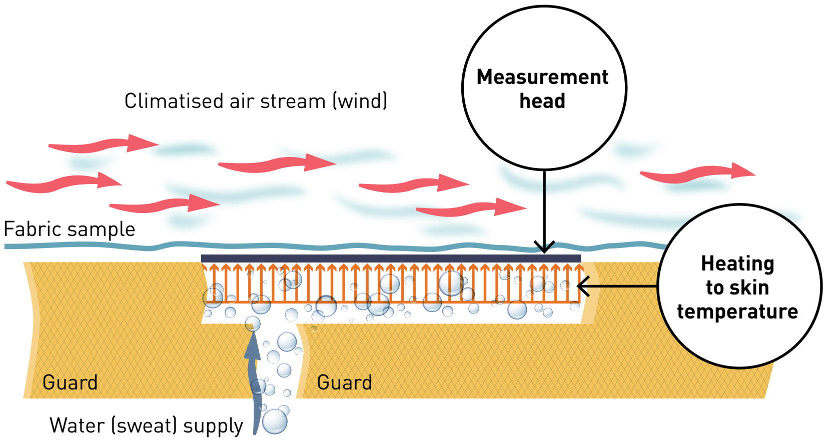


Figure 5 Modified (no semi-permeable membrane) sweating guarded hotplate.

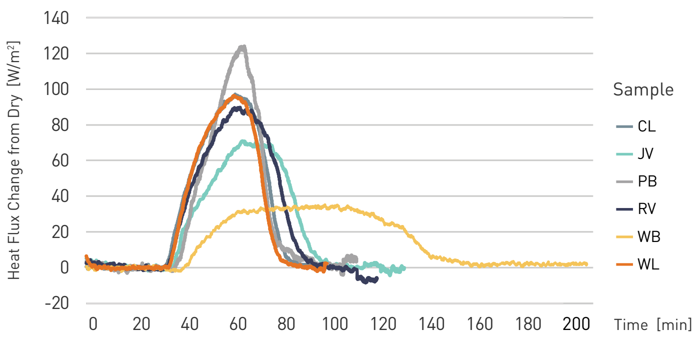


Figure 6 Heat flux profiles for 6 textile fabrics (CL – hydrophilic cotton, JV – hydrophobic viscose single jersey, PB – hydrophilic polyester rib, RV – hydrophobic Viscose rib, WB – hydrophobic wool jersey, WL – Hydrophilic wool jersey.

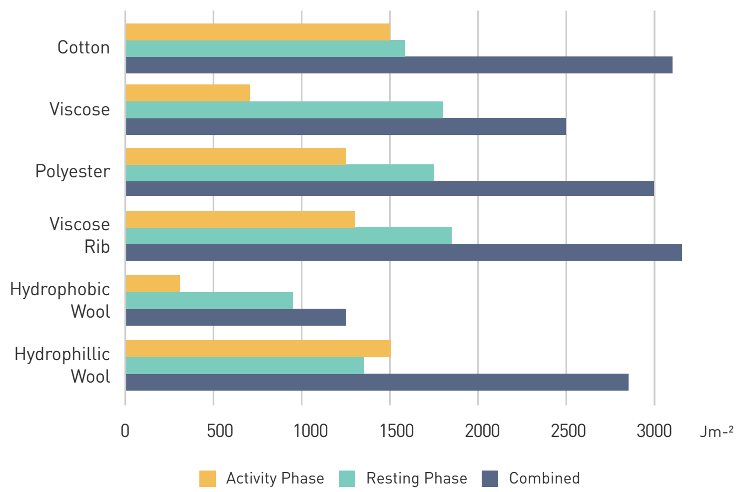


Figure 7 Energy profiles for 30 minutes activity and 30 minutes rest periods.

NEXT STEPS

Work to date has focused on a scenario involving 30 minutes activity followed by 30 minutes rest. Further work is underway to assess the thermal performance of three fibre types (wool, cotton and polyester) using scenarios which simulate the actual durations of activity and rest periods experienced in stop-go sports.

In parallel it is important to commence engagement with the body responsible for ISO 11092 to propose and encourage a dynamic modification to the method.

SUMMARY

Hygroscopic and hydrophobic fibres such as wool have been shown to reduce the energy needs of athletes and increase their comfort during stop-go activities.

Through simple modifications to the sweating guarded hotplate, the standard method ISO 11092 could test the suitability of textile fabrics for sports activities where energy conservation and comfort is important.

Support from major sports brands will be needed to encourage ISO bodies to more promptly make these changes.

SOURCES

- showed normal hydrophobic wool as best in buffering thermal change during transition from 45% relative humidity (RH) environment to 80% RH - showcasing a temperature buffering efficiency 26% superior to viscose, 45% superior to cotton, and 96% superior to polyester.

Abedin, Faisal, and Emiel DenHartog. "A new approach to demonstrate the exothermic behavior of textiles by using a thermal manikin: Correction methods of manikin model." *Polymer Testing* 128 (2023): 108195.

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Abedin, Faisal, and Emiel DenHartog. "Clothing impact on post-exercise comfort: skin-clothing physiology in transient environment." *Ergonomics* (2023): 1-17.

– Fabric test methods such as ISO 11092 (Methods for the measurement of the thermal resistance and water-vapour resistance, under steady-state conditions) are consequently unable to effectively distinguish the thermal comfort performance of garments made from different fibre types

J. Huang, Sweating guarded hot plate test method, Polymer Testing, Volume 25, Issue 5, 2006, p709-716

- The ability of wool garments to maintain more stable thermal comfort by buffering the microclimate between the fabric and the skin is well documented.
- For an athlete wearing base-layer clothing, the effect of decreased metabolic rate on comfort can be dramatic. The body must create heat using stored energy reserves to maintain core body temperature.

Li, Y The Science of Clothing Comfort, Text Prog 31 2001 p 55

- Humans rely on clothing to help regulate their body temperatures and wool, more than all other common apparel fibres, helps maintain a more stable microclimate between the garment and the body.

Li, Y. Holcombe B. V. and Apcar F., Moisture buffering behaviour of hygroscopic fabric during wear, Textile research Journal, 1992, 619-627.

- The two properties of thermal insulation and moisture vapour management are coupled and can impart a series of benefits to users of wool products through acting independently or in combination

J. C. Barnes and B.V. Holcombe, Moisture Sorption and transport in clothing during wear, Textile Research Journal, 1996, 77-786.

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