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Article

# A technical overview of thermal comfort properties of bi-layer knitted sportswear: A review

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## Abstract

This study investigates the thermal comfort characteristics of various bi-layer knitted fabrics constructed using Modal/Bamboo yarn for the outer layer and Microfiber polyester, polyester, or acrylic yarn for the inner layer. A total of seven different bi-layer knitted textiles were produced, and their comfort properties were evaluated through both objective and subjective assessments. The results revealed that the bi-layer fabric with a one-tuck point, made with bamboo as the outer layer, exhibited the best performance. It demonstrated lower moisture absorption and superior air permeability, water vapor permeability, wicking ability, and drying rate compared to the other materials tested. Bi-layer knitted fabrics are being explored due to their advantages over single-layer knits, including better breathability, thermal insulation, and moisture-wicking capabilities. Furthermore, the study provides valuable scientific insight into how different fabric structures and fiber compositions affect thermal comfort. It also discusses various methods for evaluating these comfort-related properties, such as air and water vapor permeability, wicking, and drying rate. These findings can help textile manufacturers develop more advanced, functional sportswear that offers improved comfort and performance for the wearer. In39 addition, by understanding the fabric structure–performance relationship, the research supports innovation and potential use of eco-friendly materials in bi-layer fabric construction.

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Bi-layer knitted fabric; thermal comfort; air and water vapor permeability; wicking and drying rate

## Introduction

The human body produces 800–1300W of heat during physical exercise and maintains a core temperature of 37°C. Sweating is triggered by the neurological system to control this excess heat. Sweat glands produce sweat, which cools the body by absorbing heat and evaporating it (Chinta et al., 2013).

Apparel profoundly influences comfort and performance in occupational or athletic activities, since physiological strain may diminish both physical and cognitive capabilities (Bishop, 2014). Thermo-physiological comfort encompasses elements like the thermal characteristics, water vapor permeability, sweat absorption, and drying capacity of materials (Demiryürek &

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Uysaltürk, 2013). The contained still air and exterior air movement are the primary elements influencing heat transmission through fabric, which is affected by the fabric's structure, thickness, and material (Epps & Song, 1948).

Water vapor permeability is essential while perspiring lightly because clothing has to expel moisture from the skin's microclimate to avoid becoming wet. To provide comfort during vigorous exercise, garments should also efficiently transfer perspiration (Das et al., n.d.; Supuren et al., 2011).

Wicking is a crucial feature to maintain a comfortable feeling while perspiring. It quickly removes perspiration and moisture from the skin's surface, transfers it to the fabric's surface, and then evaporates it using the capillary principle. Double-face constructions have been the subject of several studies [15–18] to attain a high degree of comfort. In terms of thermo-physiological regulation, layered fabric performs better than single-layer textile structures (Thangamuthu Suganthi et al., 2017).

Synthetic fibers with superior moisture-wicking properties, such as polyester, nylon, acrylic, or polypropylene, are often used for the inner layer of multi-layer clothing systems. The outer layer, on the other hand, is made of moisture-absorbing fabrics like cotton, wool, viscose rayon, or their mixtures. Together, these layers have a significant impact on important properties, including breathability, heat conduction, and water vapor release, all of which enhance wearability and convenience. Synthetic sportswear performs better than natural materials, providing observable improvements in the average control of skin temperature and subjective comfort during physical activity (Manshahia & Das, 2013; T Suganthi & Senthilkumar, 2018; Thangamuthu Suganthi et al., 2017). As the weight of multi-layer materials grows, so does their thermal resistance. One layer's moisture content is affected by neighboring layers in addition to its characteristics. Moisture control is improved by using various yarns for the outer and interior layers. Improved wicking, water retention, and vapor transfer are shown by fabrics having viscose or cotton on the outside and polypropylene filaments on the inside. For summer, active, and sportswear, two-layer materials with cotton on the outside and polypropylene inside provide excellent comfort and effective moisture transmission (Öner et al., 2013; Srinivasan et al., 2007). In contrast to pure wool or bamboo, blending wool with polyester or bamboo improves fabric comfort. Moisture control is enhanced by double-layer knitted textiles with an exterior layer of cotton or viscose and an interior layer of polypropylene. Better thermal comfort is achieved by combining 70% polyester and 30% Tencel in the outer layer as opposed to using just polyester. PET has poor drying efficiency, even though it enhances wicking when paired with thermo-regulating Outlast viscose. To create high-comfort textiles for active sportswear, this research focuses on assessing the thermal comfort of bi-layer knitted fabrics derived from mixes of polyester and bamboo (Fangueiro et al., 2010; Troynikov & Wardiningsih, 2011).

## Definition of Comfort

According to the definitions, the meaning of comfort is a situation or sense of joyful ease, well-being, and satisfaction. Comfort is a highly complicated blend of several extremely subjective experiences. Simply put, comfort is frequently described as the lack of discomfort, i.e., the absence of pain or bad emotion. In the context of textiles and clothes, wear comfort is presumably a condition. When we are unconscious of the garment, we are wearing it (Rossi, 2005).

Specifically, the comprehension of textile comfort, its significance in garment selection, and various evaluation techniques have been explored. It was investigated how clothing characteristics and materials affected how comfortable the garments were. We assessed users' views of comfort on a psychological, physical, and physiological level. Most researchers were found to be primarily concerned with thermal and sensory comfort. The presentation covered hand comfort in detail, including evaluation techniques. Additional sensory comfort qualities were also suggested, especially auditory and aesthetic. In fabric comfort, the flow of noticeable and insensible sweat is a crucial factor. Enhancing the thermal comfort properties of knitted textiles is necessary to achieve fabric comfort (Udaya Krithika et al., 2020).

## Types of Comfort

Comfort in textiles, especially for knitted fabrics, is a multidimensional concept that includes physical, psychological, and physiological aspects. Here are the main types of comfort commonly considered in textile and apparel science:

### *Thermal and Moisture Comfort*

Thermal comfort in clothing refers to the wearer's subjective feeling of warmth or coolness, achieved when the garment facilitates a comfortable heat and moisture balance between the body and the environment. Since pain impairs efficiency, comfort is a crucial component of sportswear. Comfort is an essential component in sports gear since it influences the performance of the wearer, owing to discomfort. The thermal comfort properties of bi-layer knitted materials with tuck stitch on the 12th wale and 18th course with varied yarn compositions in the inner layer have been investigated.

Thermal comfort is crucial in daily life. Since the early days, humans have discovered ways to guarantee that their housing arrangements, with adaptation to local climate, are thermally pleasant. Tribe The Hadza demonstrated that the first people likely employed the domicile hut as their dwelling place to enhance the temperature stability of their working surroundings(Zaki et al., 2021).The duration of the method, contact level, and surgery surroundings are all strongly connected to the thermal and moisture comfort of gowns. Operating temperatures in the room range from 15.6 °C/60 °F, according to Brandt (1993). Mangrum and colleagues (1999) record humidity ratio readings of 30–60%, while temperatures range from 25.6 °C/78 °F. Overhead lights' radiative heat also increases (Cao & Cloud, 2011).

### *Tactile Comfort*

As described by the World Health Organization (WHO) in the preamble of the constitution in February 1946 in New York, human health is not seen just as the absence of disease but in terms of a complete feeling of physical, mental, and social well-being. Survival, health, and illness prevention have been primary concerns of human beings in the consumption of their clothing goods.

Similarly, the term 'comfort' is a complex and integrated physiological and psychological response to various environmental stimuli that might be used to describe a feeling of contentment, a sense of cosiness, or a state of physical and mental well-being, which is closely related to human health. (*B20696620*, n.d.).A subtype of clothing comfort, sensory pleasure refers to the wearer's contentment with the way a material or item of clothing is viewed by the wearer's senses. A garment's feel on the skin, appearance, sound while moving, scent, and even taste can all have an impact on comfort (a newborn, for instance, frequently suckles a favorite material). Every one of these feelings is triggered by distinct bodily stimuli and adds to the whole assessment of garment comfort (Sweeney & Branson, 1990).

### *Psychological Comfort*

One of the most crucial apparel qualities that contemporary customers expect is comfort. The purpose of this study is to use 10 feelings (clammy, clinging, sticky, moist, heavy, prickly, scratchy, fit, etc.) to mimic psychological sensory judgements of garment comfort. Both warm and flexible. Twenty-two top performers were asked to cycle in a climate-controlled room while donning multiple outfits in the course of a set of trials (Wong et al., 2002). It has been determined that clothing meets a wide spectrum of human social, psychological, and physiological requirements. Different clothing types are preferred by people to satisfy all of these demands.

### *Fit Comfort*

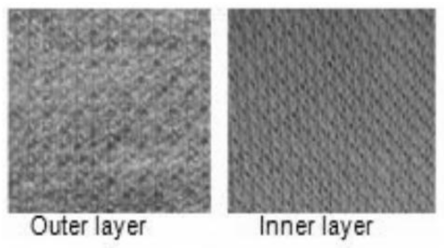
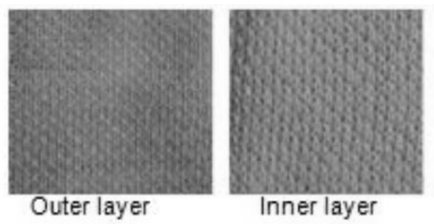
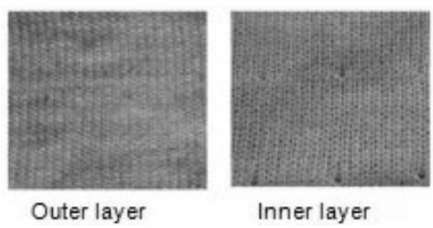
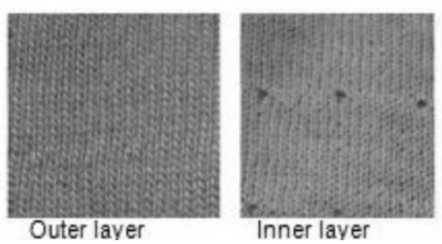
When choosing an attire, it's crucial to take into account the collar, cuffs, cuffs, and general fit for convenience and safety. When conducting work-related tasks, surgical clothing should provide the user with an appropriate range of motion. Gowns that fit poorly can have a detrimental impact on protection levels. Because the gowns must be made to accommodate a variety of body types and sizes within a limited number of sizes, extra fabric is frequently used (Cao & Cloud, 2011). When designing clothing that is both comfortable and useful, fit is a crucial consideration. Clothing fit is a multifaceted characteristic that is influenced by ease, line, and grain. Additionally, it is affected through personal awareness, garment size variances, and the latest trends (Geršak, 2014).

## Materials

Using yarns with a count of 40 Ne, polyester, modal, and bamboo were used to create double-layer knitted garments for samples Types 1-4. A circular weft knitting machine with a 28-inch diameter, 68 feeders, an 18-gauge setting, and 3168 needles was used to manufacture the samples.

A two-layer cloth was made for this experiment. Polyester, the material used for the inner layer, transfers moisture rapidly but does not readily absorb it. Regenerated fibers, such as bamboo or modal, which soak more and dry more quickly, are used to make the outer layer. The cylinder needles get the yarn for the inner layer, while the dial needles receive the yarn for the outside layer. Two kinds of knitted double-layer patterns were created. Dial needles knit at the second, fourth, seventh, and ninth feeders in the first one's five-course repetition pattern, whereas cylinder needles knit at the third, fifth, eighth, and tenth feeders. At the first, sixth, and ninth feeders, tuck stitches are formed. With dial needles knitting at all odd-numbered feeders and cylinder needles knitting at all even-numbered ones, the second pattern has an 18-course repetition. The cylinder needles in this design create tuck stitches at the first feeder of every repetition. For Types 5-7, ordinary polyester, acrylic, or microfiber polyester yarn with a 150 Denier depth was utilized for the inner layer. 132 Denier modal yarn was used to create the outer layer. A circular multi-track rib knitting device (Kemyong-KILM-72AV) with 68 feeders, 18-gauge, 3168 needles, and a 28-inch diameter was used to create all double-layer knitted garments. The device was adjusted to certain parameters. The outside layer was generated by the yarn fed into the cylinder needles, while the inner layer was formed by the yarn placed into the dial needles. Tuck stitches were inserted at the 12th and 18th Wales of each bi-layer knitted fabric's 18-course repeat. With tucks created at the first and 37th feeders, the dial needles knitted at every odd-numbered feeder and the cylinder needles knitted at every even-numbered feeder. The table beneath displays the various fabric specifications.

**Table 1.** Bi-layer knitted fabric with specifications

| Fabric Type | Inner Layer | Outer Layer | Fabric design | Fabric surface |
|---|---|---|---|---|
| Type 1 | Polyester (40%) | Modal (60%) | Bi-layer Interlock Fabric |  |
| Type 2 | Polyester (40%) | Bamboo (60%) | Bi-layer Interlock Fabric |  |
| Type 3 | Polyester (40%) | Modal (60%) | Piqué |  |
| Type 4 | Polyester (40%) | Bamboo (60%) | Piqué |  |

| | | | | |
|---|---|---|---|---|
| Type 5 | Micro Fiber Polyester | Modal | Rib |  Outer layer  inner layer |
| Type 6 | Polyester | Modal | Rib |  Outer layer  inner layer |
| Type 7 | Acrylic | Modal | Rib |  Outer layer  inner layer |

## Method

The method is the section that explains the process, results, tools, and steps used to conduct the research or experiment. The double-layer knitted textiles were tested in a conventional room with a temperature of 21°C (±2 °C) and a relative humidity of 65% (±5%).

### Air Permeability

The quantity of air, expressed in milliliters, that passes through 100 mm² of fabric in a second when there is a pressure differential equivalent to 10 mm of water is known as air permeability. It shows the ease of airflow through the fabric. (Saville, 2002). A fabric's permeability to air may have a variety of effects on comfort. First, a fabric that allows air to flow through it often permits water to flow through it as liquid or vapor. Thus, a fabric's capacity to withstand wetness is often correlated with its air permeability. Second, the still air trapped within the fabric, which is affected by the fabric's construction, is a major factor in its resistance to heat. (Bhattacharya & Ajmeri, 2014).

### Moisture Absorbency

The term "water absorbency" describes a fabric's capacity to take in moisture and quantify how much water it can hold in total. The quantity of water absorbed by the cloth was measured using the static immersion technique, which complies with BS 3449(Davies, 2018). The cloth sample's water absorbency was determined by calculating its % weight increase. As a percentage, moisture absorption is determined by dividing the mass of water absorbed by the initial mass of the cloth. (Suganthi T, n.d.).

## Water Vapor Permeability

Water vapor permeability is the term used to describe how sweat moves across a fabric and how beneficial it is. Sweating effectively is the only way to control the extra heat that the human body produces. The substance must exhibit strong water vapor permeability for efficient sweating. (Premalatha et al., 2023). A Shirley water vapor permeability analyzer was applied to measure the water vapor permeability in compliance with the BS 7209:1990 standard. A common method for evaluating a textile's capacity to transmit moisture is the cup technique. During this process, the specimen is maintained in a controlled atmosphere (20°C and 65% relative humidity) over a cup of water that has been distilled water. To calculate the water vapor permeability (WVP), which is measured in $g/m^2/day$, the following formula is applied:

$$WVP = 24M / At$$

The mass decrease of the construction, expressed in grams, over time t, is denoted by M in the above formula. Here, A is the surface area of the cloth that was most exposed during evaluation, measured in square meters, and t is the interval in hours between successive measurements of the weight of the finished product.

## Drying Behaviour

Bi-layer knitted fabric drying behavior describes how this particular fabric structure loses moisture under various drying settings, such as hot air, ambient drying, or tumble drying. Compared to single-layer textiles, bi-layer fabrics have more complex drying behavior because they are made up of two separate knitted layers, frequently with different fiber kinds, structures, or threads. To simulate natural drying circumstances, the materials were wetted using the static immersion technique and then dried for 30 minutes at 300°C in an oven.

Following removal, the textiles were weighed, and the difference between the wet and dry masses was used to calculate the water loss. The drying time needed for the wet textiles to attain their dry mass was also noted as the drying time.

## Wicking

Wicking in fabric refers to the capacity of a material to pull moisture, such as perspiration, away from the skin and towards the outside surface of the fabric. According to Patnaik, Rengasamy, Kothari, and Ghosh (2006), wicking is the spontaneous displacement of the solid/air interface with the solid/liquid interface in a capillary system (Atasağun et al., 2016) The fabric's wicking ability is primarily determined by fabric structure, thickness, yarn regularity, and fiber category (Senthilkumar & Suganthi, 2019) The vertical wicking test is recommended to ascertain the textile's liquid transport characteristics. (Atasağun et al., 2016). According to the BS 3424 standard, vertical wicking was measured using a 20 cm × 2.5 cm test cloth strip at 20°C and 65% relative humidity (Suganthi T, n.d.) It monitors the rise of liquid on the fabric by submerging one end of the fabric in liquid (Atasağun et al., 2016) Next, until the water achieves consistency, the pace at which the leading edge of the water rises is monitored every five minutes.

## Results and Discussion

This section provides a methodical analysis and interpretation of the developed bi-layer knitted materials' physical and thermal comfort characteristics. These characteristics are essential for assessing a fabric's suitability for final uses, particularly in clothing meant for active wear or thermal control. The result of these seven types of bi-layer knitted fabric is discussed below:

### Air Permeability

Compared to Types 1, 2, and 3, Type 4 fabric, which has polyester inside and bamboo on the outside, has a higher air permeability, as Figure 2 illustrates. Type 4 has fewer loops per area, which explains this. Additionally, compared to Type 1, Type 2's longer loops allow more air to pass through by lowering stitch density. Additionally, bamboo fibers are more breathable than modal fibers due to their microscopic gaps. Compared to Type 2, Type 1 fabric has a denser surface and tighter loops. Type 4 exhibits greater air permeability due to variations in its bi-layer structure, despite Type 2 and Type 4 having comparable tightness. Type 4 is looser than Type 2 because it includes fewer tuck loops in one place. More air may flow through Type 3 and Type 4 fabrics because they are often less dense than Type 1 and Type 2. More air is blocked by fabrics that are heavier and thicker, yet Type 4 fabrics provide improved ventilation and increased wearer comfort. Also, Figure 2 shows that Type 5 bi-layer fabric has the highest air permeability in both dry and wet states, followed by Type 6 and Type 7 fabrics. Although the structure stays the same, changes in inner yarn type and fabric properties affect air flow. Type 5 fabric has higher porosity because of the microfiber polyester, creating more gaps for air to pass through. Overall, thinner fabrics with lower mass allow better air permeability (T. Suganthi & Senthilkumar, 2018). Improved air permeability is a result of Type 6 and Type 5 textiles' reduced bulk of polyester and micro-fiber polyester yarns. The heavy acrylic yarn in Type 7 fabric makes it thicker and heavier, which traps more air and decreases airflow. High porosity, improved ventilation, and increased comfort make fabrics with an exterior layer of modal and an interior layer of microfiber polyester perfect for sportswear. So the highest air permeability fabric is Type 7, then Type 6, Type 5, Type 1, Type 2, Type 3, and the least is Type 4.

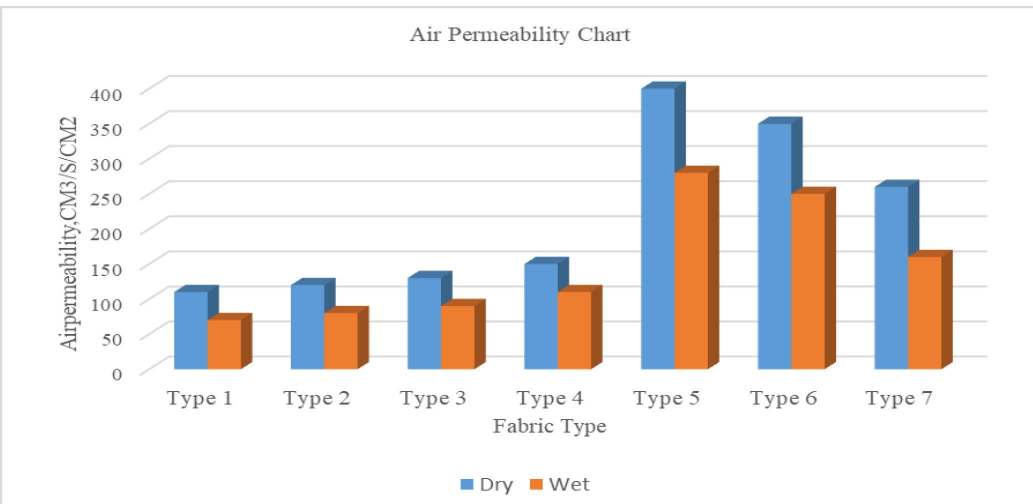



**Figure 1.** Air permeability of bi-layer knitted fabrics

## Moisture Absorbency

The fabric of sportswear should retain moisture when the user perspires a lot to prevent them from feeling sticky and sweaty (Senthilkumar & Suganthi, 2019). Type 1 and Type 2 textiles showed the highest absorbency, followed by Type 3 and Type 4. Bi-layer knitted constructions with five tuck points showed significantly greater water absorbency than those with only one tuck point, as shown in Figure 3**.** Type 1 performs better under moderate to intense sweating situations because of its higher stitch density, which helps fabric retain more moisture. Furthermore, the Type 1 and Type 2 five-tuck point bi-layer knitted fabrics were thicker and heavier than the Type 3 and Type 4 one-tuck point versions, which is a major factor in their higher moisture absorption (Suganthi T, n.d.). Reduced thickness and mass per unit area are the effects of fewer tuck stitches, which suggests less moisture absorption. (Senthilkumar & Suganthi, 2019)As shown in Figure 3, type 7 bi-layer knitted textiles have the highest moisture absorption, followed by type 6 and type 5. The kind of fiber and the characteristics of the fabric are crucial in this case. Type 7 fabric easily absorbs moisture in its yarn core because of the intrinsic properties of acrylic yarn. Furthermore, the type 7 fabric exhibits greater mass and thickness per unit area. Compared to type 6 and type 7 bi-layer knitted textiles, the type 5 bi-layer knitted fabric had a lower moisture absorption %. Because of its increased capillary action, the channeled structure of microfibre polyester absorbs less moisture and improves transmission to the outer layer. In comparison to type 6 and type 7 bi-layer cloth, type 5 fabrics have reduced mass per unit area, thickness, and moisture absorption. Because filament polyester has intermediate moisture transfer qualities, type 6 textiles absorb more moisture than type 7 but less than type 5. So the highest wicking fabric type is 7, then type 6, type 5, type 1, type 2, type 3, and the lowest type 4. So, as a result highest absorbency type is 7 and the lowest type is 4.

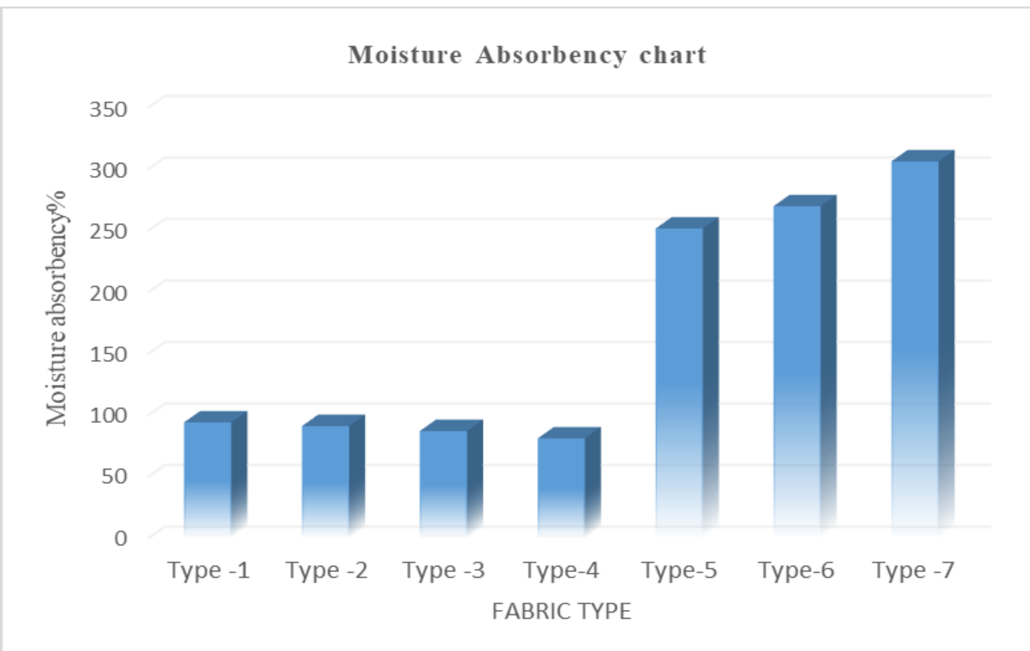



**Figure 2.** Moisture absorbency of bi-layer knitted fabrics

## Water Vapor Permeability

Water vapor permeability is a crucial functional feature for badminton gear. Sweat is produced when human tissue overheats, and the heat from its cells dries it. Because of its reduced thickness and usage of bamboo yarn, which has high vapor diffusivity and moisture absorption, Figure 4 illustrates that Type 4 had the greatest water vapor permeability of all the bi-layer knitted textiles examined. The smaller construction of Type 4 improves permeability by lowering the distance moisture must travel. Types 1 and 3 have shorter loop lengths, which further restricts moisture transfer, whereas Types 1 and 2 have lower permeability because of their greater thickness. Furthermore, compared to the modal yarn used in Types 1 and 3, the hygroscopic qualities of bamboo yarn in Types 2 and 4 enable quicker sweat evaporation. These results demonstrate that water vapor permeability is greatly influenced by the fiber content and organizational geometry of the cloth.

The water vapour permeability of type 5 is more than types 6 and 7. This is mostly because of the inner yarn's substance and structural characteristics. A larger surface area and an effective humidity transport system are produced by the microfiber polyester in Type 5, which has a channeled structure and finer filaments. This mechanism aids in removing moisture from the skin and transferring it to the outermost layer, which speeds up evaporation.

In comparison to microfiber, Type 6 textiles contain wider filament spaces, which reduce moisture transfer even if they are still quite permeable. Because acrylic fibers are quite bulky and obstruct moisture transport, Type 7 textiles have poor water vapor permeability. These results confirm that the kind of fiber employed in the inner layer is crucial for managing water vapor, independent of the fabric's architecture. Water movement is also influenced by structural elements like thickness and areal density. Microfiber polyester's high performance indicates that it is a good choice for sportswear applications that need effective moisture control. So, the highest Water vapor permeability fabric is Type 4, then Type 5, Type 3, Type 6, Type 2, Type 1, and the least is Type 7. So, as a result highest Water vapor permeability fabric is Type 4, and the least is Type 7.

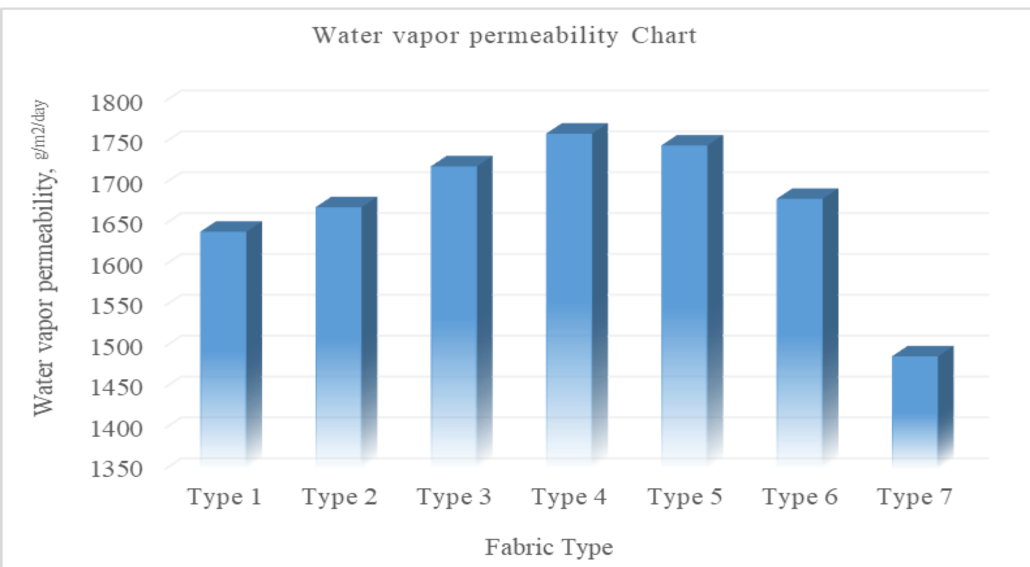



**Figure 3.** Water vapor permeability of bi-layer knitted fabrics

## Drying Behaviour

Body temperature regulation is greatly aided by moisture transport. Moisture on the skin or clothes affects endurance and overall physical performance while increasing body heat loss.(Sampath et al., 2011). Compared to Types 1, 2, and 3, Type 4 fabric the drying rate of Type 4 and Type 2 layered textiles is greater than that of Type 3 and Type 1, respectively, as shown in Figure 5. Types 4 and 3 of the bi-layer knitted textiles took less time to dry. Their increased moisture vapour transfer, decreased thickness, and lower mass per unit area are the reasons for this.

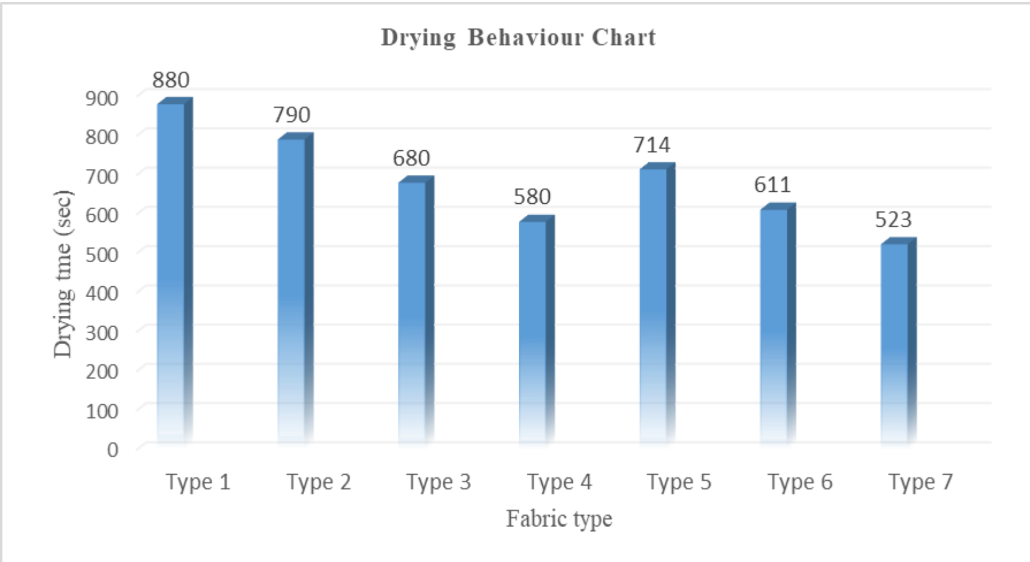



**Figure 4.** Drying behaviour and permeability of bi-layer knitted fabrics

Figure 5 also shows that Type 7 bi-layer fabric has the highest drying behaviour, followed by Type 5 and Type 6 fabrics. Specifically, Type 7 shows higher drying rates, indicating faster moisture evaporation and quicker return to initial dry mass. These characteristics collectively contribute to the superior performance of Types 7 and Type 4 in terms of drying efficiency. Special microstructure allows it to effectively absorb and release perspiration, creating a cozy feeling. This enhanced drying behaviour can be attributed to several structural factors:

- Higher moisture vapour transfer capabilities, allowing more efficient release of moisture.
- Reduced fabric thickness, which minimizes the moisture retention capacity.
- Lower mass per unit area, leading to less material holding moisture and thus faster drying.

These characteristics collectively contribute to the superior performance of Types 4 and 7 in terms of drying efficiency. Bi-layered knitted textiles' drying performance was mostly determined by their thickness and mass per unit area, with knitted structural factors having little impact.

## Wicking

The physical and structural characteristics of the yarn or fabric, the kind of fiber, and the chemical treatment all influence how a textile wicks (Atasağun et al., 2016). Figure 6 illustrates that Type 4 has the best longitudinal wicking performance. The reason for this is that its structure effectively removes and transports moisture to the outer surface, acting as a capillary system. Because Type 4 is looser than Type 3, which is more compact, liquid moisture may permeate the cloth more readily. Furthermore, Types 2 and 4 exhibit superior wicking capabilities in comparison to Types 1 and 3, respectively. This is explained by the fact that Type 2 and Type 4's outer layers include bamboo yarn, which wicks moisture better than Type 1 and Type 3's modal yarn. Because Type 4 has a lower stitch density and thinner fabric than Type 3, it exhibits the greatest wicking rate of all [3] Bamboo fiber has a stronger wicking capacity & Breathable, cool, soft, antibacterial, and resistant to UV rays than modal yarn because of its many micro-gaps and micro-holes in its cross-section (Suganthi T, n.d.) (Rathod & Kolhatkar, n.d.). Also, Figure 6 displays the bi-layer knitted fabric's vertical wicking in wale and course-wise, together with microfiber polyester, polyester, acrylic, and modal yarn. We refer to the first two as "classic polyester," and they are produced by Rhone-Poulenc (der Hart et al., 2001). The wicking effect of the composite fabric causes the wickability values for each structure to vary, even though polyester has the same properties and functions as an inner layer for all of them (Suganthi T, n.d.).

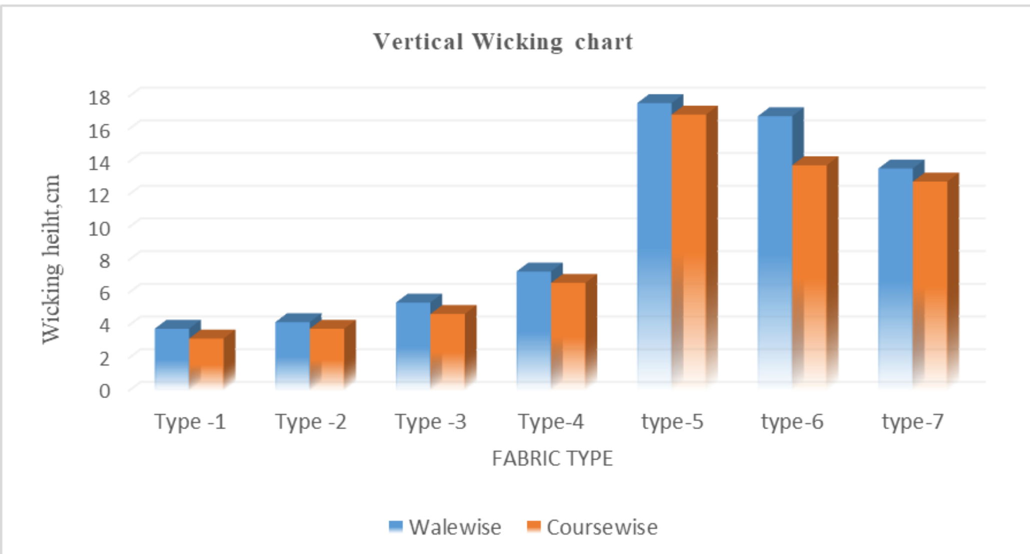



**Figure 5.** Vertical wicking permeability of bi-layer knitted fabrics

Compared to the other two bilayer cloths, the type 5 knitted cloth has a higher vertical wicking height than the other cloths. First, in both wale and course orientation, all of the bi-layer knitted materials exhibit superior water absorption. However, compared to textiles made of polyester and acrylic, the bi-layer knitted fabric with micro-fibre polyester composition had a greater initial water take-up. When compared to other cloths, the type 5 cloth with the lowest thickness and stitch density exhibited the most water absorption. In comparison to the type 5 bi-layer knitted fabric, types 6 and 7, with greater thickness, showed reduced wick ability in both the wale and course directions. The inner layer of type 5 contains micro-fibre polyester yarn, which decreases the fabric's capillary size and enhances wicking capabilities. Because it transports perspiration through the inner layer and evaporates as it reaches the outer layer, the bi-layer knitted fabric type 5 with high wicking ability is ideal for athletes. So the highest wicking fabric type is 5, then type 6, type 7, type 4, type 3, type 2, and the lowest type 1. In all bi-layer knitted materials, vertical wicking is more pronounced in the wale-wise direction than in the course-wise direction. Bi-layer knitted textiles' vertical wicking ratings reveal notable variations in the fabric structures (Senthilkumar & Suganthi, 2019).

## Conclusion

By examining thermal conductivity, air permeability, water vapor permeability, wicking, moisture absorbency, and drying rate, this study assessed the thermal comfort of multilayer knitted sporting materials. Sportswear and next-to-skin applications can benefit from the improved thermal comfort provided by bi-layer knitted textiles that combine hydrophobic and hydrophilic fibers. Because of its reduced thickness, lower stitch density, and fiber structure, the Modal/Micro-fiber polyester fabric, which has modal in the outer layer and micro-fiber polyester in the inner layer, showed the best water vapor permeability, greatest air permeability, and highest thermal conductivity. Additionally, it outperformed Modal/Polyester and Modal/Acrylic textiles in terms of moisture control and water absorption. Thermal conductivity, drying capacity, and general comfort were all strongly impacted by the kind of yarn and the structure of the fabric.

## Abbreviations

**PET** – Polyethylene Terephthalate

**WHO** – World Health Organization

**BS** – British Standard (e.g., BS 3449, BS 7209:1990, BS 3424)

**Ne** – English Cotton Count (a unit of yarn thickness, e.g., "40 Ne")

**Denier** – A unit of fiber thickness (e.g., "150 Denier")

**WVP** – Water Vapor Permeability

**Piqué** – A type of knitted fabric structure (though not strictly an abbreviation, it's a technical term)

**RH** – Relative Humidity (implied in "65% (±5%)" but not explicitly abbreviated)

## Declarations

*Competing interests:* The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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## References

Atasağun, H. G., Okur, A., Akkan, T., & Akkan, L. (2016). A test apparatus to measure vertical wicking of fabrics – A case study on shirting fabrics. *Journal of the Textile Institute*, *107*(12), 1483–1489. https://doi.org/10.1080/00405000.2015.1128225

b20696620. (n.d.).

Bhattacharya, S. S., & Ajmeri, J. R. (2014). Air permeability of knitted fabrics made from regenerated cellulosic fibres. *International Journal of Engineering Research*, *10*(7). www.ijerd.com

Bishop, P. A. (2014). Ergonomics and comfort in protective and sport clothing: A brief review. *Journal of Ergonomics*, *S2*(02). https://doi.org/10.4172/2165-7556.S2-005

Cao, W., & Cloud, R. M. (2011). Balancing comfort and function in textiles worn by medical personnel. In *Improving comfort in clothing* (pp. 370–384). Elsevier. https://doi.org/10.1533/9780857090645.3.370

Chinta, S. K., Pooja, D., & Gujar, D. K. T. E. (2013). Significance of moisture management for high performance textile fabrics. *International Journal of Innovative Research in Science, Engineering and Technology*, *2*. www.ijirset.com

Das, B., Das, A., Kothari, V., Fanguiero, R., & Araujo, M. D. (n.d.). Moisture flow through blended fabrics-effect of hydrophilicity. *Journal of Engineered Fibers and Fabrics*, *4*. http://www.jeffjournal.org

Davies, A. J. (2018). Performance evaluation and testing of water repellent textiles. In *Waterproof and water repellent textiles and clothing* (pp. 347–366). Elsevier. https://doi.org/10.1016/B978-0-08-101212-3.00012-5

Demiryürek, O., & Uysaltürk, D. (2013). Thermal comfort properties of Viloft/cotton and Viloft/polyester blended knitted fabrics. *Textile Research Journal*, *83*(16), 1740–1753. https://doi.org/10.1177/0040517513478458

van der Hart, M., Viallier, P., & Durand, B. (2001). Forms in native celluloses, in "The structure of celluloses." *Journal of Applied Polymer Science*, *111*(3). American Chemical Society.

Epps, H. H., & Song, M. K. (1948). Hoemer. In *Goodings*.

Fangueiro, R., Filgueiras, A., Soutinho, F., & Meidi, X. (2010). Wicking behavior and drying capability of functional knitted fabrics. *Textile Research Journal*, *80*(15), 1522–1530. https://doi.org/10.1177/0040517510361796

Geršak, J. (2014). Wearing comfort using body motion analysis. In *Anthropometry, apparel sizing and design* (pp. 320–333). Elsevier. https://doi.org/10.1533/9780857096890.2.320

Harnett, P. R., & Mehta, P. N. (n.d.). A survey and comparison of laboratory test methods for measuring wicking.

Manshahia, M., & Das, A. (2013). Comfort characteristics of knitted active sportswear: Liquid water transportation. *Journal of the Institution of Engineers (India): Series E*, *17*(3).

Öner, E., Atasağun, H. G., Okur, A., Beden, A. R., & Durur, G. (2013). Evaluation of moisture management properties on knitted fabrics. *Journal of the Textile Institute*, *104*(7), 699–707. https://doi.org/10.1080/00405000.2012.752895

Premalatha, C., Kumar, M. R., Udaya Krithika, S. M., & Prakash, C. (2023). Analysis of thermal comfort properties of tri-layer knitted fabrics. *Journal of Natural Fibers*, *20*(1). https://doi.org/10.1080/15440478.2022.2164107

Rathod, A., & Kolhatkar, A. (n.d.). Physical & UV protection properties of knitted bamboo fabrics. www.fibre2fashion.com

Rossi, R. (2005). Interactions between protection and thermal comfort. In *Textiles for protection* (pp. 233–260). Elsevier. https://doi.org/10.1533/9781845690977.1.233

Sampath, M. B., Mani, S., & Nalankilli, G. (2011). Effect of filament fineness on comfort characteristics of moisture management finished polyester knitted fabrics. *Journal of Industrial Textiles*, *41*(2), 160–173. https://doi.org/10.1177/1528083711400774

Saville, B. P. (2002). *Physical testing of textiles*. Woodhead Publishing Limited: CRC Press.

Senthilkumar, P., & Suganthi, T. (2019). Influence of tuck stitch in wale direction on thermal comfort characteristics of layered knitted fabrics. *Indian Journal of Fibre & Textile Research*, *44*.

Srinivasan, J., Ramakrishnan, G., Mukhopadhyay, S., & Manoharan, S. (2007). A study of knitted fabrics from polyester microdenier fibres. *Journal of the Textile Institute*, *98*(1), 31–35. https://doi.org/10.1533/joti.2005.0180

Suganthi, T. (n.d.). Thermo-physiological comfort of layered knitted fabrics for sportswear. *Tekstil ve Konfeksiyon*, *27*(4).

Suganthi, T., & Senthilkumar, P. (2018). Comfort properties of double face knitted fabrics for tennis sportswear. *Indian Journal of Fibre & Textile Research*, *43*.

Suganthi, T., & Senthilkumar, P. (2018). Thermal comfort characteristics of bi-layer knitted fabrics for sportswear. *International Journal of Fashion Design, Technology and Education*, *11*(2), 210–222. https://doi.org/10.1080/17543266.2017.1378733

Suganthi, T., Senthilkumar, P., & Dipika, V. (2017). Thermal comfort properties of a bi-layer knitted fabric structure for volleyball sportswear. *Fibres and Textiles in Eastern Europe*, *25*(1), 75–80. https://doi.org/10.5604/12303666.1227885

Supuren, G., Oglakcioglu, N., Ozdil, N., & Marmarali, A. (2011). Moisture management and thermal absorptivity properties of double-face knitted fabrics. *Textile Research Journal*, *81*(13), 1320–1330. https://doi.org/10.1177/0040517511402122

Sweeney, M. M., & Branson, D. H. (1990). Sensorial comfort: Part I: A psychophysical method for assessing moisture sensation in clothing. *Textile Research Journal, 60*(7), 371–377. https://doi.org/10.1177/004051759006000701

Troynikov, O., & Wardiningsih, W. (2011). Moisture management properties of wool/polyester and wool/bamboo knitted fabrics for the sportswear base layer. *Textile Research Journal, 81*(6), 621–631. https://doi.org/10.1177/0040517510392461

Udaya Krithika, S. M., Prakash, C., Sampath, M. B., & Senthil Kumar, M. (2020). Thermal comfort properties of bi-layer knitted fabrics. *Fibres and Textiles in Eastern Europe, 28*(5), 50–55. https://doi.org/10.5604/01.3001.0014.2384

Wong, A. S. W., Li, Y., & Yeung, K. W. (2002). Statistical simulation of psychological perception of clothing sensory comfort. *Journal of the Textile Institute, 93*(1), 108–119. https://doi.org/10.1080/00405000208630556

Zaki, S. A., Rosli, M. F., Rijal, H. B., Sadzli, F. N. H., Hagishima, A., & Yakub, F. (2021). Effectiveness of a cool bed linen for thermal comfort and sleep quality in air-conditioned bedroom under hot-humid climate. *Sustainability (Switzerland), 13*(16). https://doi.org/10.3390/su13169099