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Short Communication

Studies in thermal properties of knitted fleece fabrics

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This study investigates the thermal performance of three-thread knitted fleece fabrics developed using different ground fibre compositions to evaluate their suitability for thermal comfort applications. Nine fleece fabric variants were produced on a special circular knitting machine using bamboo, modal, and cotton as ground yarns combined with polyester binder and loop yarns. The fabrics were characterized in terms of thickness, GSM, air permeability, thermal resistance, CLO value, and warmth retention using standard ASTM test methods. Statistical analysis, including regression modelling and 3D spatial visualization, was employed to examine the relationship between thermal resistance and key structural and comfort parameters. Results revealed significant variation in thermal behaviour depending on fibre composition. Bamboo-based fleece fabrics exhibited the highest thermal resistance (0.0182–0.0184 m²K/W), CLO value, and warmth retention, indicating superior insulation performance, while modal-based fabrics showed the lowest thermal resistance due to higher breathability and reduced heat retention. Cotton-based fabrics demonstrated intermediate behavior. Regression analysis confirmed that thermal resistance is governed by the combined influence of structural and comfort-related variables rather than individual parameters alone. The study highlights the critical role of fibre selection in designing knitted fleece fabrics with enhanced thermal comfort and provides practical insights for the development of winter and sportswear textiles.

Keywords*:* Yarn material, Thermal resistance, Polyester, Fleece fabric, Fabric structure

The characteristics of fibre, yarn, and fabric play a major role in the thermal comfort properties of textile materials. Parameters like fibre type, spinning process, yarn count, twist, hairiness, fabric thickness, cover factor, porosity, and finishing processes are of prime importance in deciding fabric comfort[1].

Comfort is one of the most essential demands in casual wear products, besides benefits like elasticity, freedom of movement, ease of handling, ease of manufacturing, and low cost of production[2].Comfort in clothing has become a prominent concern among consumers, which has a significant impact on their choice of clothing, apart from its visual appeal. Comfort is a subjective feeling that the wearer experiences, and it is closely linked to thermal and moisture management[3]. Clothing should facilitate the body's thermoregulatory process by sustaining a constant microclimate close to the skin surface during various physical activities[4]. This is especially important in sports clothing, as improper thermo-physiological properties can have adverse effects on health, well-being, and physical performance. As the human body constantly produces metabolic heat, proper thermal regulation by clothing is required.

Clothing comfort, particularly for next-to-skin clothing, is a major requirement and is described as a sense of comfort and warmth. This is dependent on three major aspects: psychological, sensory, and thermo-physiological. Thermal properties are the main factors that influence thermo-physiological comfort, which is the main aim of this research[5].

The human body itself is an internal heat source, which generates a thermal gradient between the body and the clothing. The gradient is dependent on environmental conditions, with perspiration playing a major role in heat transfer by phase-change evaporation. Taking into account all the factors involved in heat transfer makes the study complex[6].

Recent developments in thermal management textiles have encouraged research into the physical properties and human applicability of such materials. Heat transfer between the body and the environment is dependent on various factors, including environmental temperature, air movement, mean radiant temperature, relative humidity, and clothing properties. Thus, the need for the development of lightweight, flexible materials with enhanced thermal management properties is a priority in contemporary clothing design[7].

Clothing is mainly designed to protect the body against environmental, chemical, physical, and sanitary factors, with thermal protection being one of its basic requirements. Clothing has been used by humans for thermal regulation purposes since time immemorial[8].

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Clothing is a regulatory mechanism that helps to maintain the normal body temperature irrespective of changes in the environment or physical activity. The human body maintains a central temperature of about 37 °C through effective thermoregulation. When the body is engaged in strenuous activities, the production of heat through metabolism is enhanced, and hence, there is a need for effective heat dissipation to maintain thermal equilibrium. Vasodilation and sweating mechanisms help in cooling by facilitating the loss of heat through evaporation of sweat; hence, clothing should facilitate evaporation of sweat to maintain comfort levels[9, 10].

The thermal comfort properties of materials are of prime importance in determining overall physiological comfort. The factors that mainly influence thermal comfort are air temperature, humidity, mean radiant temperature, air movement, clothing, activity level, and rate of change of these factors.

Thermal comfort requires maintaining equilibrium between heat gain and heat loss as environmental conditions change. Clothing plays a critical role in this balance, as effective heat transfer and moisture management are essential, particularly for protective, athletic, and sportswear applications. Polyester fibre is widely used due to its controllable morphology, which allows optimization of thermal, dimensional, transport, and mechanical properties. Thermal analysis techniques enable accurate evaluation of these characteristics. Recent developments in advanced materials aim to improve thermal comfort under varying environmental conditions, where maintaining an insulating air layer is especially important in cold climates[11].

The growing demand for warm and functional apparel has increased interest in winter clothing development. Advances in materials, technology, and design have expanded options that balance insulation, durability, breathability, and style[12-14]. Current innovations focus on improving performance while incorporating sustainable and engineering-based textile solutions[15,16].

Thermal resistance is a key property in winter clothing, as it helps retain body heat, maintain a comfortable microclimate, reduce heat loss, and support safety, mobility, and prolonged outdoor activity[17,18]. Layered clothing systems further enhance thermal insulation by allowing users to adjust garments according to environmental conditions and comfort needs[19,20].

In this study, two- and three-thread raised fleece fabrics were produced using a special circular knitting machine with different inner and outer layer yarn materials, and their thermal characteristics were evaluated.

Materials and methods

Materials

Seven different yarns were purchased from Arihant yarns, Tirupur which are mentioned in Table 1.

The knitted fabric is produced with the above yarns “Unitex machine” special circular knitted machine. Thermal properties 9 different fabrics were evaluated.

Methodology

Knitting

Nine different fleece fabrics were produced using the sourced yarns, with 3 varying loop lengths, on a Unitex circular knitting machine (Figure 1) at Agasthya Knit Fab, located in Arulpuram, Tirupur. The sourced yarns were knitted with Unitex special circular knitting machine to produce a 9 different fleece fabric with the specification below in Table 2.

Cotton was used as a ground yarn, polyester as a binder yarn, and a blend of cotton/polyester (C/P) as a loop yarn. Similar blends were created using Modal and Bamboo yarns. The sample code based on yarn type (Bamboo /Modal/Cotton) and loop lengths are as below: (Table 3)

Fabric produced

From the above sourced yarn as in table 1, the 9 different fabric samples were produced as mentioned in Table 4.

Evaluation

After Knitting 9 fleece fabric with the different combination of bamboo, Modal and cotton with polyester were developed and they are taken to examine its physical and thermal properties like GSM, Thickness, Air Permeability, thermal Resistance, Warmth Retention and CLO Value.

Table 1 — Sourced different types of yarn

S. No	Particulars 34s 100% Bamboo
1	
2	34s 100% Modal
3	34s 100% Cotton
4	12s (60% Bamboo / 40% Polyester)
5	12s (60% Modal / 40% Polyester)
6	12s (60% Cotton / 40% Polyester)
7	50D Polyester Filament

Fig. 1 — Unitex Knitting Machine

Table 2 — Specification of Knitting Machine

S. No	Specification	Measures
1	Machine Make	Unitex special circular knitting machine
2	Diameter	30”
3	Gauge	20 Needles/ Inch
4	No. of Feeders	90
5	No. of Needles	1850
6	Speed	20 to 25 rpm

Results and Discussion

Thickness and GSM

Thickness and GSM value for fleece fabric produced with bamboo, Modal, Cotton polyester filament and its blend with different loop length are shown in Table 5. The ASTM standard for thickness is ASTM D1777 and GSM is ASTM D3776.

The C1 sample, made from 100% Cotton ground, 50D poly back (Loop- 60:40 C/P) loop knit, exhibits the highest GSM value among all samples. This indicates that it is a denser fabric, which may contribute to its durability and comfort. The sample C3 100% Cotton ground, 50D poly back (Loop- 60:40 C/P) loop knit shows less GSM and A3 100% Bamboo ground, 50D poly back (Loop-60:40 B/P) loop knit show low thickness when compared to all the 9 fleece fabric. This has been validated through an earlier study[21] where in similar type of result was obtained.

Air permeability

Air permeability value for Fleece Fabric produced with bamboo, Modal, Cotton polyester filament and its blend with different loop length is shown in Table 6. The convective heat exchange between the human body and the environment as well as the gas exchange between the pants environment and the environment are significantly influenced by the air permeability of clothes. It should be remembered that air exchange occurs between the human body and surroundings even when people are wearing regular clothing and when things are inert. This air exchange is brought on by the differential in temperature between the environment and the area beneath the clothing. In windy conditions, the direction of air exchange is significantly impacted by the wind's effect, which is significantly bigger than the effect of heat. The ASTM standard method used is ASTM D737.

The C2 100% Cotton ground, 50D poly back (Loop- 60:40 C/P) loop knit sample stands out for its high air permeability, indicating better breathability and moisture-wicking properties, while the C1 100% Cotton ground, 50D poly back (Loop- 60:40 C/P) loop knit sample is notable for its lower air permeability, suggesting a more substantial and potentially warmer fabric. Each sample serves different needs based on its physical properties and intended use. This has been validated by a previous study[22], which yielded similar results.

Thermal resistance

The ratio of the temperature differential between two fabrics faces to the rate of heat transfer per unit area normal to the faces is commonly used to describe a textile material's thermal resistance[23]. Numerous studies are still being done on thermal resistance, a crucial characteristic of textile textiles. It is based on the material thickness, yarn and fibre configuration, and the heat conductivity of the fibres[24]. And it is measured using ASTM D1518.Thermal Resistance values for 9 Fleece fabrics are shown in Table 7.

This sample A1 100% Bamboo ground, 50D poly back (loop-60:40 B/P) loop knit has the highest thermal resistance among all the samples, indicating it offers the best insulation. And the B1 sample 100% Modal ground, 50D poly back (Loop- 60:40 M/P) loop knit has the lowest thermal resistance, indicating poor insulation. Since, Bamboo has a better thermal resistance compared to Modal and Cotton due to its unique hollow structure and greater ability to trap air and Modal, being smoother and less porous, results in the lowest thermal resistance among the tested

Table 3 — Sample Code Based on Yarn Type (Bamboo /Modal/Cotton) And Loop Lengths

Sample code on the basis of yarn type (Bamboo/Modal/ Cotton)	Position of the Yarn Ground	Yarn type 100% Bamboo	Loop length in mm	Sample Code based on loop length
1	Binder	Polyester filament	28 mm	A1
	Loop	Bamboo – Polyester (60: 40)	17 mm	
	Ground	100% Bamboo	40 mm	A2
	Binder	Polyester filament	30 mm	
	Loop	Bamboo – Polyester (60: 40)	17 mm	
	Ground	100% Bamboo	42 mm	A3
	Binder	Polyester filament	32 mm	
	Loop	Bamboo – Polyester (60: 40)	17 mm	
	Ground	100% Modal	38 mm	B1
2	Binder	Polyester filament	28 mm	
	Loop	Modal – Polyester (60: 40)	17 mm	
	Ground	100% Modal	40 mm	B2
	Binder	Polyester filament	30 mm	
	Loop	Modal – Polyester (60: 40)	17 mm	
	Ground	100% Modal	42 mm	B3
	Binder	Polyester filament	32 mm	
	Loop	Modal – Polyester (60: 40)	17 mm	
	Ground	100% Cotton	38 mm	C1
3	Binder	Polyester filament	28 mm	
	Loop	Cotton – Polyester (60: 40)	17 mm	
	Ground	100% Cotton	40 mm	C2
	Binder	Polyester filament	30 mm	
	Loop	Cotton – Polyester (60: 40)	17 mm	
	Ground	100% Cotton	42 mm	C3
	Binder	Polyester filament	32 mm	
	Loop	Cotton – Polyester (60: 40)	17 mm	

Table 4 — Different Fleece Fabrics

Sample Code	Fabric Produced
A1	100% Bamboo ground, 50D poly back (loop-60:40 b/p) loop knit
A2	100% Bamboo ground, 50D poly back (Loop-60:40 B/P) loop knit
A3	100% Bamboo ground, 50D poly back (Loop-60:40 B/P) loop knit
B1	100% Modal ground, 50D poly back (Loop- 60:40 M/P) loop knit
B2	100% Modal ground, 50D poly back (Loop- 60:40 M/P) loop knit
B3	100% Modal ground,50D poly back (Loop- 60:40 M/P) loop knit
C1	100% Cotton ground, 50D poly back (Loop- 60:40 C/P) loop knit
C2	100% Cotton ground, 50D poly back (Loop- 60:40 C/P) loop knit
C3	100% Cotton ground, 50D poly back (Loop- 60:40 C/P) loop knit

materials. The same kind of result has been derived by the earlier researchers on their works[25].

CLO Value

The level of insulation that a piece of clothing provides is indicated by the CLO value. A CLO number of 1 corresponds to how much clothes a resting person needs to stay warm in a room that is 71 degrees Fahrenheit (21 degrees Celsius) in temperature. The ASTM standard used to measure the CLO value here is ASTM F1291.

1. CLO = 0 – represents a naked person.
2. CLO = 1 – represent to the insulating value of the clothing needed to maintain a person in comfort sitting at rest in a room at 21^0 (70^0) with the air movement of 0.1 m/s and humidity less than 50% - typically a person wearing a business suit.

CLO values for all 9 Fleece fabrics are shown in Table 8.

The sample A1 100% Bamboo ground, 50D poly back (loop-60:40 B/P) loop knit shows high CLO value. This may be because of the good moisture absorption and air-trapping properties of bamboo. And the sample B1 100% Modal ground, 50D poly back (Loop- 60:40 M/P) loop knit shows low CLO

Table 5 — Thickness and GSM value for Fleece Fabric produced with bamboo, Modal, Cotton polyester filament and its blend with different loop length

Sample Code	Particulars	Thickness (mm)	GSM (g/m^2)
A1	100% Bamboo ground, 50D poly back (loop-60:40 B/P) loop knit	1.03	2.40
A2	100% Bamboo ground, 50D poly back (Loop-60:40 B/P) loop knit	1.20	2.60
A3	100% Bamboo ground, 50D poly back (Loop-60:40 B/P) loop knit	0.98	2.13
B1	100% Modal ground, 50D poly back (Loop- 60:40 M/P) loop knit	1.13	2.44
B2	100% Modal ground, 50D poly back (Loop- 60:40 M/P) loop knit	1.15	2.53
B3	100% Modal ground,50D poly back (Loop- 60:40 M/P) loop knit	1.05	2.24
C1	100% Cotton ground, 50D poly back (Loop- 60:40 C/P) loop knit	1.30	2.63
C2	100% Cotton ground, 50D poly back (Loop- 60:40 C/P) loop knit	1.21	2.56
C3	100% Cotton ground, 50D poly back (Loop- 60:40 C/P) loop knit	0.89	2.14

Table 6 — Air permeability value for Fleece Fabric produced with bamboo, Modal, Cotton polyester filament and its blend with different loop length.

Sample Code	Particulars	Air Permeability (cc/sec/cm^2)
A1	100% Bamboo ground, 50D poly back (loop-60:40 b/p) loop knit	68.41
A2	100% Bamboo ground, 50D poly back (Loop-60:40 B/P) loop knit	69.68
A3	100% Bamboo ground, 50D poly back (Loop-60:40 B/P) loop knit	68.70
B1	100% Modal ground, 50D poly back (Loop- 60:40 M/P) loop knit	67.60
B2	100% Modal ground, 50D poly back (Loop- 60:40 M/P) loop knit	68.21
B3	100% Modal ground,50D poly back (Loop- 60:40 M/P) loop knit	68.01
C1	100% Cotton ground, 50D poly back (Loop- 60:40 C/P) loop knit	69.30
C2	100% Cotton ground, 50D poly back (Loop- 60:40 C/P) loop knit	69.70
C3	100% Cotton ground, 50D poly back (Loop- 60:40 C/P) loop knit	69.50

value and this might because of the modal's properties like its softness and moisture absorbance.

Warmth retention

The quantity of heat that a material or object can retain over time is referred to as warmth retention. The test method used here is ASTM F2732.

Warmth Retention value for 9 Fleece fabrics are shown in Table 9.

The sample A1 100% Bamboo ground, 50D poly back (loop-60:40 B/P) loop knit shows high warmth retention. This may be because of bamboo's excellent insulating properties, and a likely dense knit structure contributes to the high value. And the sample B3 100% Modal ground,50D poly back (Loop- 60:40 M/P) loop knit shows low warmth retention and this might because of the modal's lower thermal

Table 7 — Thermal Resistance value for 9 Fleece fabrics

Sample Code	Particulars/Test Results	Thermal Resistance (m^2 K/W)
A1	100% Bamboo ground, 50D poly back (loop-60:40 B/P) loop knit	0.0182
A2	100% Bamboo ground, 50D poly back (Loop-60:40 B/P) loop knit	0.0183
A3	100% Bamboo ground, 50D poly back (Loop-60:40 B/P) loop knit	0.0184
B1	100% Modal ground, 50D poly back (Loop- 60:40 M/P) loop knit	0.0045
B2	100% Modal ground, 50D poly back (Loop- 60:40 M/P) loop knit	0.0053
B3	100% Modal ground,50D poly back (Loop- 60:40 M/P) loop knit	0.0054
C1	100% Cotton ground, 50D poly back (Loop- 60:40 C/P) loop knit	0.0045
C2	100% Cotton ground, 50D poly back (Loop- 60:40 C/P) loop knit	0.0050
C3	100% Cotton ground, 50D poly back (Loop- 60:40 C/P) loop knit	0.0065

Table 8 — CLO value for all 9 Fleece fabrics

Sample Code	Particulars/Test Results	CLO
A1	100% Bamboo ground, 50D poly back (loop-60:40 B/P) loop knit	0.1771
A2	100% Bamboo ground, 50D poly back (Loop-60:40 B/P) loop knit	0.1182
A3	100% Bamboo ground, 50D poly back (Loop-60:40 B/P) loop knit	0.1188
B1	100% Modal ground, 50D poly back (Loop- 60:40 M/P) loop knit	0.0337
B2	100% Modal ground, 50D poly back (Loop- 60:40 M/P) loop knit	0.0343
B3	100% Modal ground,50D poly back (Loop- 60:40 M/P) loop knit	0.0354
C1	100% Cotton ground, 50D poly back (Loop- 60:40 C/P) loop knit	0.1312
C2	100% Cotton ground, 50D poly back (Loop- 60:40 C/P) loop knit	0.0377
C3	100% Cotton ground, 50D poly back (Loop- 60:40 C/P) loop knit	0.0419

Table 9 — Warmth Retention value for all 9 Fleece fabrics

Sample Code	Particulars	Warmth Retention (%)
A1	100% Bamboo ground, 50D poly back (loop-60:40 B/P) loop knit	0.2090
A2	100% Bamboo ground, 50D poly back (Loop-60:40 B/P) loop knit	0.1380
A3	100% Bamboo ground, 50D poly back (Loop-60:40 B/P) loop knit	0.1386
B1	100% Modal ground, 50D poly back (Loop- 60:40 M/P) loop knit	0.0380
B2	100% Modal ground, 50D poly back (Loop- 60:40 M/P) loop knit	0.0445
B3	100% Modal ground,50D poly back (Loop- 60:40 M/P) loop knit	0.0456
C1	100% Cotton ground, 50D poly back (Loop- 60:40 C/P) loop knit	0.0442
C2	100% Cotton ground, 50D poly back (Loop- 60:40 C/P) loop knit	0.0481
C3	100% Cotton ground, 50D poly back (Loop- 60:40 C/P) loop knit	0.0500

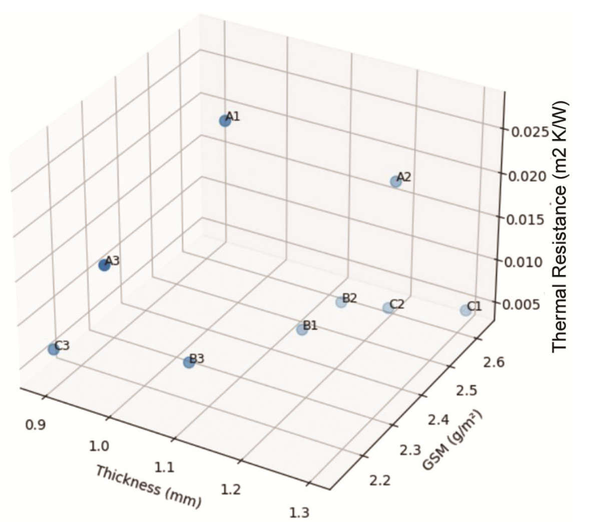

Fig. 2 — 3D spatial diagram of thermal resistance (measured in m² K/W) in relation to two variables: thickness (mm) and GSM (g/m²).

resistance, combined with the knit structure or lower density, results in minimal warmth retention.

Statistical analysis

In this study, we aim to examine the factors influencing the thermal resistance of different textile fabrics. Thermal resistance is a critical parameter that determines a fabric's ability to provide insulation, making it essential for applications in garments, blankets, and other textile products designed for warmth. To identify the key drivers of thermal resistance, 3D spatial diagram representing the relationship between thermal resistance, thickness, and GSM have been discussed in Figure 2.

- The 3D spatial diagram illustrates the relationship between thermal resistance (dependent variable) and two independent variables: thickness (in mm) and GSM (grams per square meter). The diagram presents a surface plot, where the x-axis represents the thickness of the samples, the y-axis represents the GSM, and the z-axis indicates the thermal resistance.
- The plot showcases how thermal resistance varies with changes in both thickness and GSM. From the graph, it is evident that as the thickness increases, the thermal resistance tends to increase as well, though the trend is not uniform across all GSM values. Additionally, there appears to be a slight variation in thermal resistance when the GSM changes, suggesting that both thickness and GSM jointly influence the thermal resistance.
- The 3D spatial diagram illustrates the relationship between thermal resistance (dependent variable) and two independent variables: CLO and warmth retention (%). The diagram presents a surface plot, where the x-axis represents the CLO, the y-axis represents the warmth retention, and the z-axis indicates the thermal resistance. The plot showcases how thermal resistance varies with changes in both CLO and warmth retention.
- From the graph, it is evident that as CLO increases, the thermal resistance tends to increase as well, though the trend is not uniform across all warmth retention values. Additionally, there appears to be a noticeable variation in thermal resistance with changes in warmth retention, suggesting that both CLO and warmth retention jointly influences the thermal resistance. (Fig. 3)

The 2D scatter plot illustrates (Fig. 4) the relationship between thermal resistance (dependent variable) and air permeability (independent variable) for nine samples. The x-axis represents the air permeability of the samples (in cc/sec/cm²), and the y-axis indicates the thermal resistance (in m²·K/W). The plot showcases the distribution of data points for each sample code (A1–C3), highlighting the variation in thermal resistance across different levels of air permeability.

From the graph, it is evident that there is no uniform trend linking air permeability to thermal resistance, as the data points are scattered without a clear pattern. However, distinct clusters are visible:

- Samples in Group A (A1, A2, A3) generally exhibit higher thermal resistance values (above 0.018 m²·K/W).

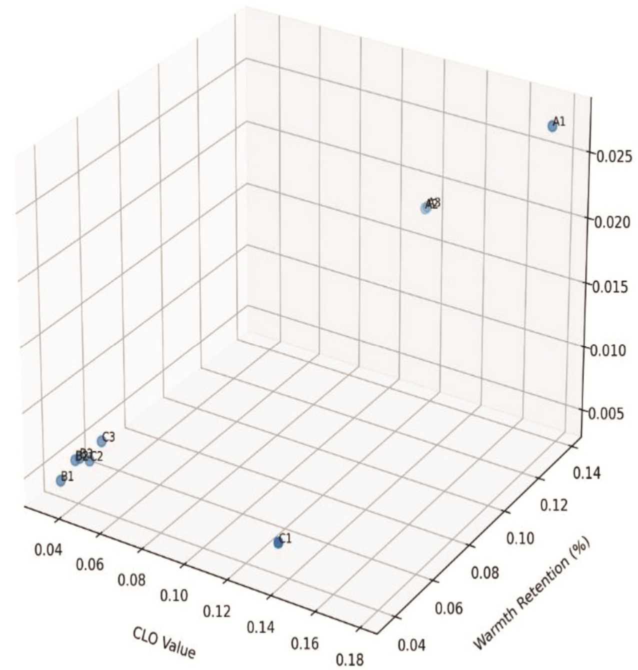

Fig. 3 — 3D spatial diagram of thermal resistance (measured in m² K/W) in relation to two variables: CLO (a measure of thermal insulation) and warmth retention (%).

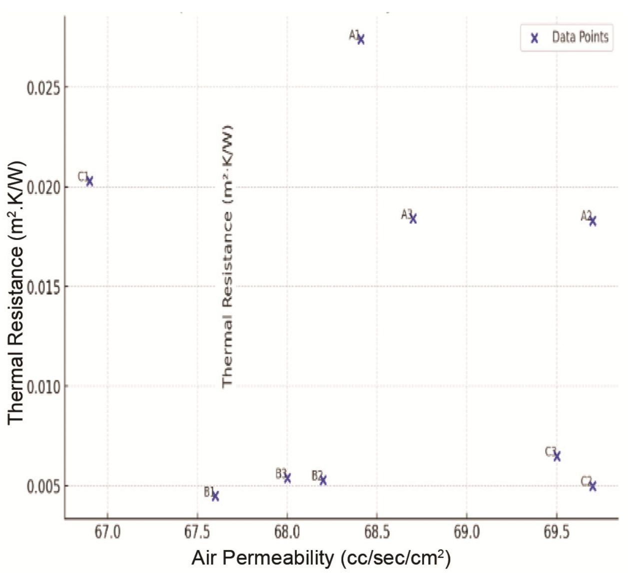

Fig. 4 — Graphical representation of thermal resistance in relation to air permeability (cc/sec/cm^2)

- Samples in Group B (B1, B2, B3) display consistently low thermal resistance (around 0.004–0.005 m²·K/W) with moderate air permeability.
- Samples in Group C (C1, C2, C3) show more variability in thermal resistance, ranging from 0.005 to 0.020 m²·K/W, across a broader range of air permeability values.

Regression analysis of thermal resistance value for 9 Fleece fabrics is shown in Table 10.

The regression equation can be written as:

y = a+ (Coefficient of x1×x1) + (Coefficient of x2×x2) + (Coefficient of x3×x3) + (Coefficient of x4×x4)+ (Coefficient of x5×x5)

Where,
y = Thermal Resistance
a = Intercept
x1= Warmth Retention
x2= Thickness
x3= GSM
x4= CLO
x5= Air Permeability

Key Interpretation Points:

- The regression model shows a strong overall relationship between thermal resistance and the selected fabric parameters ($R^2 = 0.9687$), meaning about 96.8% of variation is explained by the model.
- The adjusted R^2 (0.9164) indicates that the model still explains a high level of variation even after accounting for multiple predictors.
- The ANOVA result is statistically significant (Significance F = 0.018 < 0.05), showing that the independent variables collectively influence thermal resistance.
- The model includes five predictors: Thickness, GSM, Air Permeability, CLO, and Warmth Retention.
- Warmth retention shows the strongest positive effect on thermal resistance (highest positive coefficient), indicating better heat retention contributes to higher insulation.
- GSM shows a positive coefficient, suggesting that increased fabric mass may slightly increase thermal resistance.
- Thickness has a negative coefficient in this dataset, indicating an inverse trend with thermal resistance under the given sample conditions.
- Air permeability shows a negative relationship, implying that higher air flow tends to reduce thermal resistance.
- CLO value shows a positive coefficient but is not statistically significant individually.
- Individual predictor p-values are greater than 0.05, meaning none of the variables are statistically significant on their own at the 95% confidence level.

Table 10 — Regression analysis of thermal resistance value for all 9 Fleece fabrics

Regression Statistics								
Multiple R	0.984209303							
R Square	0.968667952							
Adjusted R Square	0.916447871							
Standard Error	0.002461393							
Observations	9							
ANOVA								
df		SS	MS	F	Significance F			
Regression	5	0.000561914	0.000112383	18.5497216	0.018302492			
Residual	3	1.81754E-05	6.05846E-06					
Total	8	0.000580089						
	Coefficients	Standard Error	t Stat	P-value	Lower 95 %	Upper 95%	Lower 95.0 %	Upper 95.0%
Intercept	0.04148364	0.094914699	0.437062336	0.69161478	-0.260577294	0.343544574	-0.260577294	0.343544574
Thickness	-0.047385055	0.022980339	-2.06198239	0.13124625	-0.120518751	0.025748641	-0.120518751	0.025748641
GSM	0.025424971	0.014887433	1.707814302	0.18620712	-0.021953485	0.072803426	-0.021953485	0.072803426
Air Permeability	-0.000770274	0.001463585	-0.52629276	0.63511364	-0.005428053	0.003887505	-0.005428053	0.003887505
CLO	0.030316045	0.041116446	0.737321632	0.514359	-0.100534836	0.161166926	-0.100534836	0.161166926
Warmth Retention	0.138143095	0.050585111	2.730904235	0.07188598	-0.022841306	0.299127495	-0.022841306	0.299127495

- The results suggest that thermal resistance is influenced by the combined interaction of variables rather than a single dominant factor.
- The small sample size (n = 9) may reduce statistical power and affect individual variable significance.

Overall Conclusion: The regression analysis also verifies that thermal resistance is a property that is significantly affected by the combined effect of fabric structural and comfort-related properties, as evident from the high value of the model fit and the significant ANOVA results. Although the individual parameters are not statistically significant, there is a tendency for warmth retention, GSM, and CLO values to positively affect thermal resistance, while air permeability and thickness are inversely related to thermal resistance in the studied samples. In general, the results indicate that thermal resistance in knitted fabrics is a multivariable property that is affected by the combined effect of fabric structure, bulk, and thermal comfort properties, and further research is recommended.

Conclusion

The result of thermal resistance measurement for the developed loop knit fabric samples reveals the variation in thermal insulation properties based on the composition of the ground fibre. The outcome shows that the type of fibre used has a major influence on the thermal properties of the fabrics, besides the cumulative effect of other structural and comfort-related factors such as thickness, GSM, air permeability, CLO, and warmth retention.

Among all the samples, the 100% Bamboo ground with 50D polyester back (Loop-60:40 B/P) recorded the highest thermal resistance values (0.0182-0.0184 m^2K/W), which is an indication of better insulation properties. This implies that the thermal comfort properties of bamboo-based loop knit fabrics are better due to their inherent fibre properties, such as superior moisture management and effective warmth retention, which contribute to higher thermal resistance.

Conversely, the 100% Modal ground with 50D polyester back (Loop-60:40 M/P) recorded the lowest thermal resistance values (0.0045-0.0054 m^2K/W), which is an indication of relatively poor insulation properties. The lower thermal resistance can be attributed to higher breathability and lower resistance to heat flow, which enables higher air and moisture transfer through the fabric.

The 100% Cotton ground with 50D polyester back (Loop-60:40 C/P) had moderate thermal resistance values (0.0045-0.0065 m^2K/W), which indicate the moderate insulation properties between the bamboo and modal-based fabrics.

The results of this study have confirmed that the thermal comfort properties of loop knit fabrics are largely dependent on the type of ground fibre used, and that the bamboo-based loop knit structures have the highest thermal insulation properties, while the modal-based fabrics have higher breathability and lower thermal resistance.

Reference

1 Li, Y., 2001. The Science of clothing comfort. *Textile Progress*, 31, pp. 1–135.
2 Oglakcioglu, N. and Marmarali, A., 2007. Thermal comfort properties of some knitted structures. *Fibres & Textiles in Eastern Europe*, 15, pp. 94–96.
3 Bivainytė, A., Mikučionienė, D. and Kerpauskas, P., 2012. Investigation on thermal properties of double-layered weft knitted fabrics. *Materials Science*, 18(2), pp. 167–171.
4 Brazaitis, M., Kamandulis, S. and Skurvydas, A., 2010. The effect of two kinds of T-shirts on physiological and psychological thermal characteristics during exercise and recovery. *Applied Ergonomics*, 44(2), pp. 619–624.
5 Unknown, 2009. Smart textiles. [online] Available at: http://textilepapers.tripod.com/smart.htm.
6 Tilioua, A., *et al*., 2018. Characterization of the thermal properties of fibrous insulation materials made from recycled textile fibers for building applications: Theoretical and experimental analyses. *Applied Thermal Engineering*.
7 Peng, L., Su, B., Yu, A. and Jiang, X., 2019. Review of clothing for thermal management with advanced materials. *Cellulose*, 26, pp. 6415–6448.
8 Pan, N., 2014. Exploring the significance of structural hierarchy in material systems—A review. *Applied Physics Reviews*, 1(2), 021302.
9 Mahnke, F.H. and Mahnke, R.H., 1993. *Color and Light in Man-made Environments*. John Wiley & Sons, Inc.
10 Frydrych, I., Dziworska, G. and Bilska, J., 2002. Comparative analyses of the thermal insulation properties of fabrics made of natural and man-made cellulose fibres. *Fibres & Textiles in Eastern Europe*, 39, pp. 40–44.
11 Eom, R.I., Lee, H. and Lee, Y., 2019. Evaluation of thermal properties of 3D spacer technical materials in cold environments using 3D printing technology. *Polymers*, 11(9), p. 1438.
12 Oğlakcıoğlu, N. and Marmaralı, A., 2010. Thermal comfort properties of cotton knitted fabrics in dry and wet states. *Textile and Apparel*, 20(3), pp. 213–217. Available at: https://dergipark.org.tr/en/pub/tekstilvekonfeksiyon/issue/23639/251785.
13 Peng, L., Su, B., Yu, A. and Jiang, X., 2019. Review of clothing for thermal management with advanced materials. *Cellulose*, 26, pp. 6415–6448.
14 Maughan, R.J., 2003. Impact of mild dehydration on wellness and on exercise performance. *European Journal of Clinical Nutrition*, 57, pp. 19–23.
15 Fanger, P.O., 1970. *Thermal Comfort: Analysis and Applications in Environmental Engineering*. Danish Technical Press.
16 Akcagun, E., Bogusławska-Baczek, M. and Hes, L., 2019. Thermal insulation and thermal contact properties of wool and wool/PES fabrics in wet state. *Journal of Natural Fibers*, 16, pp. 199–208.
17 Peng, L., Su, B., Yu, A. and Jiang, X., 2019. Review of clothing for thermal management with advanced materials. *Cellulose*, 26, pp. 6415–6448.
18 Maughan, R.J., 2003. Impact of mild dehydration on wellness and on exercise performance. *European Journal of Clinical Nutrition*, 57, pp. 19–23.
19 Harris, N.C., 1988. Modern air conditioning practice. *3rd ed*. McGraw-Hill Inc.
20 Anas, M.S., Abbas, A., Awais, H., Sarwar, M.E., Hassan, T.U. and Abbas, H., 2023. A study on the effect of material type, structure tightness and finishing process on the physical and thermo-physiological properties of sandwich terry socks for winter wear. *Journal of Engineered Fibers and Fabrics*, 18.
21 Chidambaram, P. and Govindan, R., 2012. Influence of blend ratio on thermal properties of bamboo/cotton blended woven fabrics. *Silpakorn University Science and Technology Journal*, 6(2), pp. 49–55.
22 Sekerden, F., 2018. A study on comparison of air permeability properties of bamboo/cotton and cotton towels. *Scientific Research and Essays*, 13(13), pp. 143–147.
23 Mitra, A., Majumdar, A., Majumdar, P.K. and Bannerjee, D., 2013. Predicting thermal resistance of cotton fabrics by artificial neural network model. *Experimental Thermal and Fluid Science*, 50, pp. 172–177.
24 Debnath, S., 2017. Sustainable production and application of natural fibre-based nonwoven. In: *Sustainable Fibres and Textiles*, pp. 367–391. Woodhead Publishing.
25 Aruchamy, K., Subramani, S.P., Palaniappan, S.K., Pal, S.K., Mylsamy, B. and Chinnasamy, V., 2022. Effect of blend ratio on the thermal comfort characteristics of cotton/bamboo blended fabrics. *Journal of Natural Fibers*, 19(1), pp. 105–114.