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INVESTIGATION OF THE INFLUENCE OF YARN COMPOSITION ON THE THERMAL INSULATION OF WEFT KNITTED SWEATERS USING A THERMAL MANIKIN

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Abstract

Evaluation of the thermal properties of clothing enables a reliable assessment of the wearer's thermal comfort and provides a basis for the technical design and development of new garments. In this study, the thermal insulation of weft knitted sweaters produced from 100% cotton, 100% acrylic and 50/50% acrylic/cotton yarns with a linear density of 36 tex × 2 were investigated. The weft knitted sweaters were produced on a flat V-bed knitting machine in gauge E10 (10 needles per inch), using a 4 × 4 rib structure. Measurements were performed using a segmented thermal manikin with the shape of a human body. The thermal manikin was placed in an air-conditioned chamber under controlled environmental conditions, and at a regulated manikin surface temperature. Thermal insulation was measured under static conditions, simulating a standing human, and dynamic conditions, simulating walking. The results were used to determine the influence of yarn composition on the thermal insulation of weft knitted sweaters using a thermal manikin.

Keywords: thermal insulation; thermal manikin; yarn composition; static and dynamic conditions; weft knitted sweaters

1. Introduction

Thermal comfort is basically how comfortable we feel when we are wearing clothes in a certain environment. It is about finding a balance between our body and the world around us, so we feel okay physically, mentally, and emotionally. This balance is really important for our overall comfort when we are wearing clothes. Clothing plays a fundamental role in maintaining the thermal balance of the human body by influencing heat and moisture exchange with the surrounding environment [1]. In addition to protecting against external weather conditions, garments create a microclimate between the skin and the fabric surface. The characteristics of this microclimate significantly affect thermophysiological comfort, as clothing and its associated air layers regulate the transfer of heat and water vapour [2]. Under thermal equilibrium conditions, metabolic heat generated by the human body is balanced by heat losses through conduction, convection, radiation, evaporation and respiration [3].

One of the key clothing characteristics related to thermal comfort is thermal insulation, which describes the ability of a garment system to reduce heat loss from the body to the environment. Thermal insulation provides a quantitative

measure of the effectiveness of clothing as a thermal barrier [4]. Together with air permeability and moisture transport properties, it strongly influences the comfort experienced by the wearer. Consequently, the development of functional garments requires reliable methods for evaluating thermal interactions between the body, clothing and ambient environment.

Methods for assessing thermal comfort can be broadly divided into subjective and objective approaches. Subjective assessments are based on wearer trials and provide direct information about perceived comfort during actual use. However, such investigations often involve considerable costs, lengthy testing procedures and, in some cases, safety concerns for participants. Objective methods overcome many of these limitations and include hot plate techniques, cylindrical test devices and thermal manikins. While hot plate and cylinder methods are suitable for characterising material properties and simple clothing assemblies, thermal manikins enable the evaluation of complete garments under controlled laboratory conditions and are therefore widely used in clothing comfort research [5].

According to ISO 7730:2025, thermal comfort represents a subjective perception of satisfaction with the thermal environment [6]. Achieving this state depends on the interaction between environmental conditions, activity level and clothing characteristics. By regulating heat exchange between the body and the surroundings, clothing helps maintain thermal equilibrium. This function becomes especially important during intensive physical activity or exposure to extreme environmental conditions, where appropriate clothing may be essential for health, safety and performance [7].

The thermal insulation of clothing is commonly expressed in SI units as m^2 K W^{-1}. In clothing ergonomics, thermal insulation is also frequently described using the clo unit. An insulation value of approximately 0.155 m^2 K W^{-1} corresponds to 1 clo, which is associated with the thermal comfort provided by a typical business suit [8]. By comparison, the unclothed human body has an insulation value close to 0 clo. A value of 1 clo is generally associated with thermal comfort in a ventilated indoor environment with an air temperature of about 21 °C, an air velocity of 0.1 m s^{-1} and relative humidity below 50% [9].

Numerous studies have investigated the influence of knitted fabric parameters on thermal behaviour. Mikučionienė and Milašienė analysed heat transfer dynamics in knitted fabrics manufactured from different polyester-based yarns and knitting structures. Their results indicated that variations in knit construction had a greater influence on heating behaviour than the use of specialised functional polyester yarns, while air permeability was only slightly affected by the knitting pattern [10].

Research conducted by Bivainytė et al. on double-layer weft knitted fabrics produced from natural, regenerated and synthetic yarn combinations demonstrated that thermal performance is governed by both material selection and structural design. The authors reported increases in thermal insulation with increasing fabric thickness, while loop length influenced thermal conductivity. Among the investigated parameters, knitting pattern was identified as the most influential factor affecting thermal properties [11].

Abreu et al. investigated sportswear fabrics made from pure cotton as well as blends of synthetic fibres. Their results showed that cotton garments had lower thermal insulation, which may be beneficial in warm conditions as it enhances heat dissipation and supports thermoregulatory processes [12].

Soundri et al. explored how fibre composition and fabric structure influence thermal comfort in bilayer knitted fabrics. They reported that blends of polyester and modal offer good moisture management and air permeability, while also showing relatively high thermal conductivity. Their findings underline that both the type of fibres and the compactness of the structure play an important role in determining moisture and thermal behaviour [13].

Research on multilayer knitted fabrics points to the complex nature of their thermal performance. Buzaite et al. showed that the thermal insulation and heat transfer of weft knitted multilayer fabrics are strongly affected by the configuration and type of yarns used. Although wool-containing fabrics generally demonstrated higher air permeability, thermal insulation could not be reliably inferred from permeability alone [14].

In a subsequent study, Buzaite and Mikučionienė examined spacer fabrics, focusing on the influence of inner-layer thickness and structural compactness. They found that these parameters affect thermal insulation and air permeability in different ways. Their results also suggest that similar levels of thermal insulation can be achieved with less material by optimising the fabric structure. Additionally, an inverse relationship between thermal insulation and air permeability was found [15].

In another study, Soundri et al. analysed interlock layered knitted fabrics intended for sportswear. By combining objective measurements with subjective wearer evaluations, they concluded that fabrics made from polyester and modal fibres provided the best overall comfort performance among the tested materials [16].

Naseer et al. examined three-dimensional cross-tuck honeycomb knitted structures made from different natural and synthetic fibres. Fabrics containing nylon and polyester showed the highest air permeability, whereas those made from acrylic fibres exhibited the greatest thermal insulation. The study also highlighted the importance of fibre surface characteristics in influencing moisture transport behaviour [17].

Stanković et al. examined single jersey knitted fabrics manufactured from natural and regenerated cellulose fibres. Their findings confirmed that heat transfer within textile structures is strongly influenced by fibre morphology, yarn surface characteristics and the amount of air trapped within the fabric structure, which together determine the overall thermal behaviour of the material [18].

Most research so far has been on two-dimensional knitted fabrics, as in non-garment. These studies are helpful, but they do not tell us much about how a whole garment behaves when it is being worn. This is because when you wear a garment, there is a layer of air between your body and the fabric that can affect how warm or cool you feel. To get a better

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understanding of this, we looked at sweaters made from weft knitted fabric using a special manikin that can measure heat. All the sweaters were made with the same type of knit, a 4 × 4 rib structure, and we did not change the design or the way they were knitted. This meant we could see how different yarns affected the thermal performance of the sweaters without other factors getting in the way.

The aim of this study was to determine the influence of yarn composition on the thermal insulation of weft knitted sweaters under static and dynamic conditions using a thermal manikin. Three sweaters made from 100% acrylic, 50/50% acrylic/cotton, and 100% cotton yarns were compared. Garment size and pattern, knitting structure, machine gauge, and knitting parameters were kept constant. Measurements were performed under static conditions simulating a standing person and under dynamic conditions simulating walking.

2. Methodology

Three weft knitted sweaters in a 4 × 4 rib structure were produced on a computerized flat V-bed knitting machine in gauge E10 (Stoll, Germany), using yarn with a linear density of 36 tex × 2. The sweaters were produced from 100% cotton, 100% acrylic and 50/50% acrylic/cotton yarns. Knitting parameters such as fabric take-down value, knitting speed, stitch length and tension of yarn have been maintained constant throughout the production. All three weft knitted sweaters had the same clothing size and pattern with different raw material composition.

All weft knitted sweaters were produced using seamless knitting and therefore required no cutting and sewing processes. Seamless knitting reduces yarn consumption by eliminating cutting waste and can greatly improve production efficiency. Seamless knitting requires loop transfer, where loops are transferred from the needles on which they were formed to other needles. In the production of the sweaters, only knit loops were used. Tuck or miss loops were not used. Front knit loops are formed on front needle bed and back loops on rear needle bed. Using this technique, required rib structure was created.

Thermal manikin was designed to represent an adult human body, which means it consists of an anatomically shaped head, chest, abdomen, back, buttocks, arms, hands, legs and feet, Fig. 1.

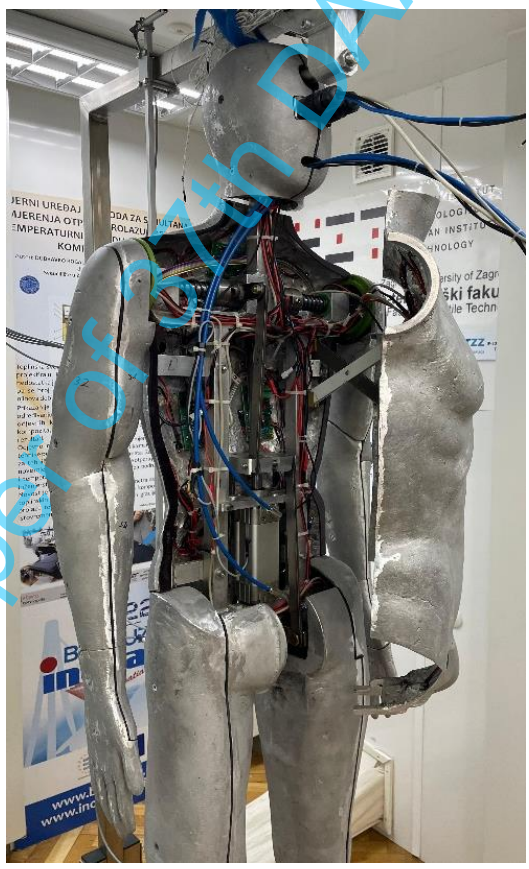

Fig. 1. Thermal manikin with visible interior

The manikin consists of 24 independently controlled segments with built-in 32 electric heaters, 52 temperature sensors and 14 microcontroller interfaces. The system also includes a pneumatic system that enables the movement of arms and legs. Thermal manikin is used to determine static and dynamic measurements in accordance with the simulation of human walking. This measurement system is characterized by the fact that the pneumatic assembly and the movement mechanism are integrated within the cast itself and are not visible from the outside of the structure. In other known experimental

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measurement systems intended for the same purposes, the movement mechanism is in a separate external housing, and the extremities are moved externally using long levers that are connected to the arms and legs. The thermal manikin is connected to two external personal computers, each with its own monitor. One monitor is used as the control interface (Fig. 2), while the other is used as the measurement interface (Fig. 3) [9].

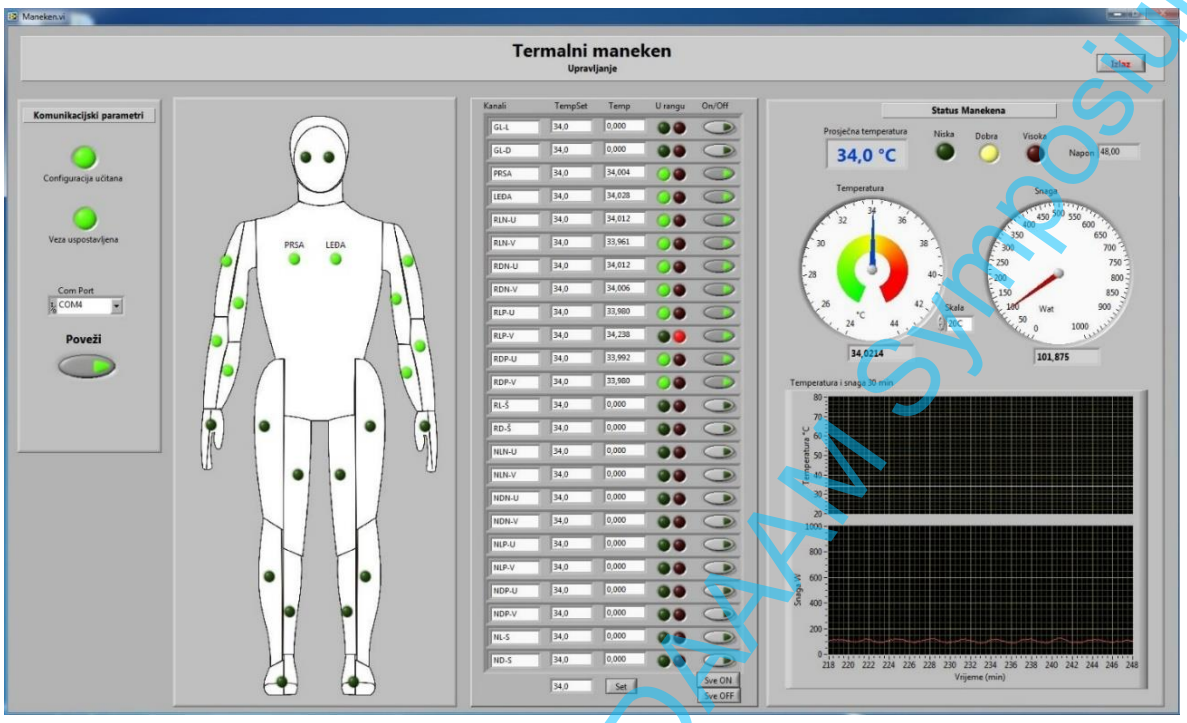

Fig. 2. Thermal manikin control interface

The manikin is 1.70 m tall and has a total surface area of 1.77 m^2. During simulated walking, the stride distance measured from the tip of the leading foot to the tip of the trailing foot is 73 cm, while the hand movement length, measured between the wrist at the base of the thumb, is 63 cm. The segments included in the thermal insulation measurements cover a total area of 0.828 m^2: front torso, back torso, left upper arm (inner and outer), right upper arm (inner and outer), left forearm (inner and outer) and right forearm (inner and outer).

In accordance with ISO 15831:2004 [19], during the measurements the temperature of the heated segment of the thermal manikin was maintained at 34 °C. The ambient temperature in the climatic chamber was 18 °C, relative humidity was 40%, and air velocity was 0.3 m s^{-1}.

Once stable environmental conditions were established, the total thermal insulation of the selected segments (the segments to be covered by the sweater) including the boundary air layer, R_{ct0}, was determined using the following expression:

$$R_{ct0} = \frac{(T_s - T_a) \cdot A}{H_0} \quad (1)$$

where R_{ct0} is the total thermal insulation of selected segments of the thermal manikin including the boundary air layer, m^{2}KW^{-1}; A is the surface area of the selected segments, m^2; T_s is the surface temperature of the thermal manikin, °C; T_a is the ambient air temperature in the climatic chamber, °C and H_0 is the electrical power required to heat the measuring surface of the thermal manikin, W.

After determining the constant R_{ct0}, the thermal manikin is dressed in the selected garment (or several garments) and the operation of the device is monitored until a new thermal equilibrium is reached. After achieving equilibrium, which is seen by the stabilization of the parameter values (numerically and via diagram), a series of measurements and calculations of the thermal insulation R_{ct} are performed according to the equation:

$$R_{ct} = \frac{(T_s - T_a) \cdot A}{H} - R_{ct0} \quad (2)$$

where H is the supplied electrical power required to maintain the set temperature of the measuring surface of the thermal manikin on which the measuring sweater samples is placed, W [9].

For design and preparation of weft knitted sweater samples, M1plus software was used, Fig. 4.

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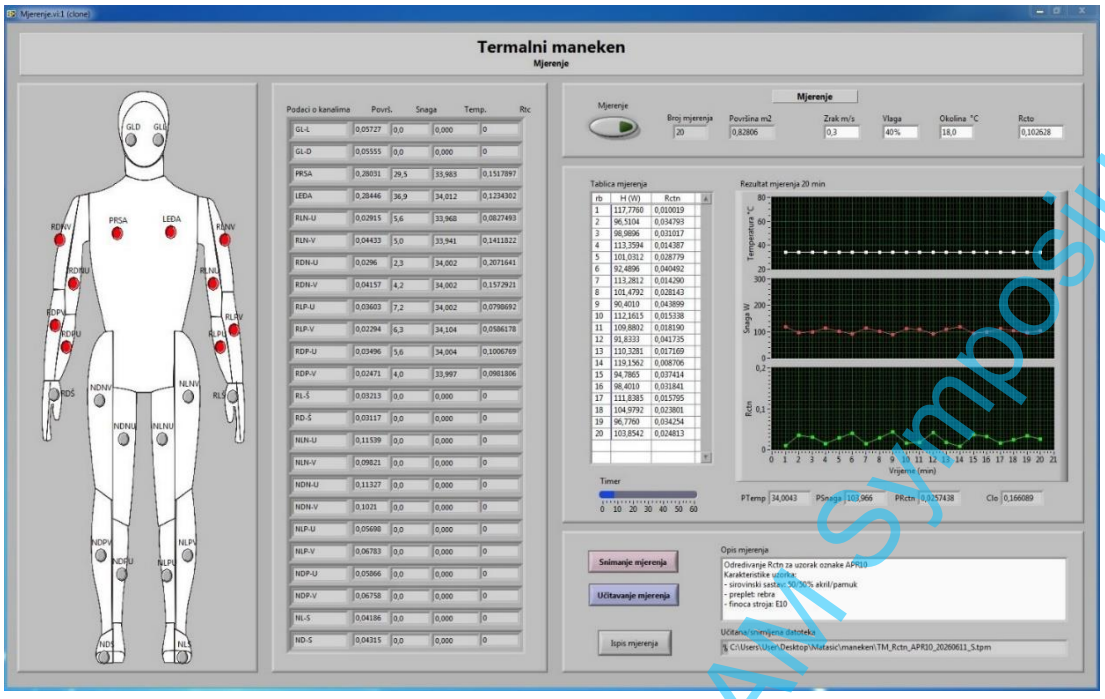

Fig. 3. Thermal manikin measurement interface

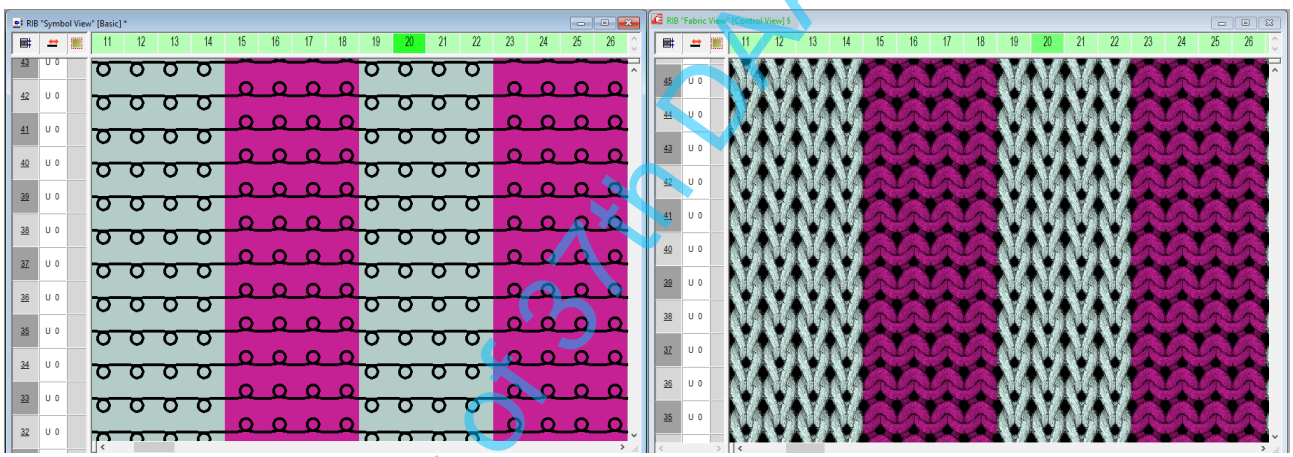

Fig. 4. Software symbol view (left) and fabric view (right) of rib knit sample

M1plus software was also used to transfer the designed knit structure and garment pattern into a file ready for machine use. M1plus software, developed by Stoll, is a professional CAD/CAM software for designing, programming, and preparing production for Stoll flat knitting machines. It enables designers and technologists to create different knitting structures, garment patterns, color patterns, fully fashioned garment pieces, and generate machine-ready programs. Using the M1Plus software, the operator can adjust knitting parameters in real time or within stored program files (even during production), without mechanical intervention. Every change made via the M1Plus software is processed electronically, meaning it goes through a syntax error-checking algorithm, which ultimately reduces human error and speeds up the entire production process.

M1plus software has two work views, symbol view and fabric view. In symbol view, user draws knitting structure with different kinds of loops in desired color. Fabric view is useful since it displays actual look of the fabric, which is very practical in design of complex knitting structures.

3. Results and discussion

The influence of yarn composition on the thermal properties of weft knitted sweaters was investigated under static and dynamic conditions. Static measurements simulated a standing person, whereas dynamic measurements involved limb movements at a rate of 45 ± 2 double steps/min and 45 ± 2 double arm movements/min during simulated walking, in accordance with HRN EN ISO 15831. The corresponding thermal insulation values are given in Table 1.

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No.	Rct_0, m^2KW^{-1}	Measurements under static conditions (simulated standing)			Measurements under dynamic conditions (simulated walking)		
		Acrylic	Acrylic/ Cotton	Cotton	Acrylic	Acrylic/ Cotton	Cotton
		Rct, m^2KW^{-1}	Rct, m^2KW^{-1}	Rct, m^2KW^{-1}	Rct, m^2KW^{-1}	Rct, m^2KW^{-1}	Rct, m^2KW^{-1}
1	0.096	0.037	0.010	0.002	0.047	0.033	0.019
2	0.090	0.028	0.035	0.018	0.032	0.025	0.024
3	0.107	0.025	0.031	0.022	0.030	0.020	0.005
4	0.101	0.038	0.014	0.004	0.029	0.029	0.004
5	0.093	0.032	0.029	0.009	0.027	0.019	0.003
6	0.106	0.030	0.040	0.028	0.037	0.016	0.006
7	0.106	0.036	0.014	0.011	0.022	0.023	0.009
8	0.095	0.028	0.028	0.008	0.025	0.023	0.018
9	0.105	0.043	0.044	0.019	0.055	0.024	0.022
10	0.105	0.028	0.015	0.015	0.025	0.028	0.016
11	0.097	0.032	0.018	0.008	0.022	0.020	0.014
12	0.105	0.042	0.042	0.010	0.050	0.028	0.013
13	0.109	0.035	0.017	0.014	0.040	0.033	0.021
14	0.101	0.025	0.009	0.009	0.022	0.019	0.014
15	0.098	0.034	0.037	0.014	0.041	0.025	0.005
16	0.115	0.038	0.032	0.013	0.039	0.036	0.019
17	0.105	0.027	0.016	0.010	0.020	0.022	0.016
18	0.094	0.031	0.024	0.023	0.032	0.018	0.002
19	0.110	0.041	0.034	0.017	0.040	0.024	0.009
20	0.112	0.034	0.025	0.013	0.025	0.028	0.024

Table 1. Thermal insulation of weft knitted sweaters under static and dynamic conditions

Mean thermal insulation values and their standard deviations for the three yarn compositions are given in Table 2. Under both static and dynamic conditions, the highest values were obtained for the 100% acrylic weft knitted sweater, with thermal insulation values of 0.0332 m^2 K W^{-1} under static conditions and 0.0330 m^2 K W^{-1} under dynamic conditions. The 100% cotton weft knitted sweater showed the lowest thermal insulation, with values of 0.0134 m^2 K W^{-1} under static conditions and 0.0125 m^2 K W^{-1} under dynamic conditions. The influence of yarn composition on thermal insulation was statistically significant ($F(2, 38) = 107.586$, $p < 0.001$), as shown in Table 3. Thermal insulation did not differ significantly between static and dynamic measurement conditions ($F(1, 19) = 0.024$, $p = 0.879$). The interaction between measurement conditions and yarn composition was also not significant ($F(2, 38) = 0.129$, $p = 0.879$). Bonferroni-adjusted pairwise comparisons further showed that each yarn composition differed significantly from the other two ($p < 0.001$).

Yarn composition	R_{ct} in static condition (m^2 K W^{-1}) Mean ± SD	R_{ct} in dynamic condition (m^2 K W^{-1}) Mean ± SD
100% acrylic	0.0332 ± 0.0055	0.0330 ± 0.0102
50/50% acrylic/cotton	0.0257 ± 0.0110	0.0247 ± 0.0054
100% cotton	0.0134 ± 0.0065	0.0125 ± 0.0078

Table 2. Thermal insulation of weft knitted sweaters under static and dynamic conditions: mean ± SD, n = 20

Effect	df	Error df	F	p
Measurement conditions	1	19	0.024	0.879
*Yarn composition	2	38	107.586	< 0.001
Measurement conditions × Yarn composition	2	38	0.129	0.879

** Bonferroni-adjusted pairwise comparisons showed significant differences among all three yarn compositions ($p < 0.001$).*

Table 3. Two-factor repeated-measures ANOVA for thermal insulation under static and dynamic conditions

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Figure 5 shows the mean thermal insulation values of sweaters with different yarn fibre compositions under static and dynamic conditions, along with the corresponding standard deviations.

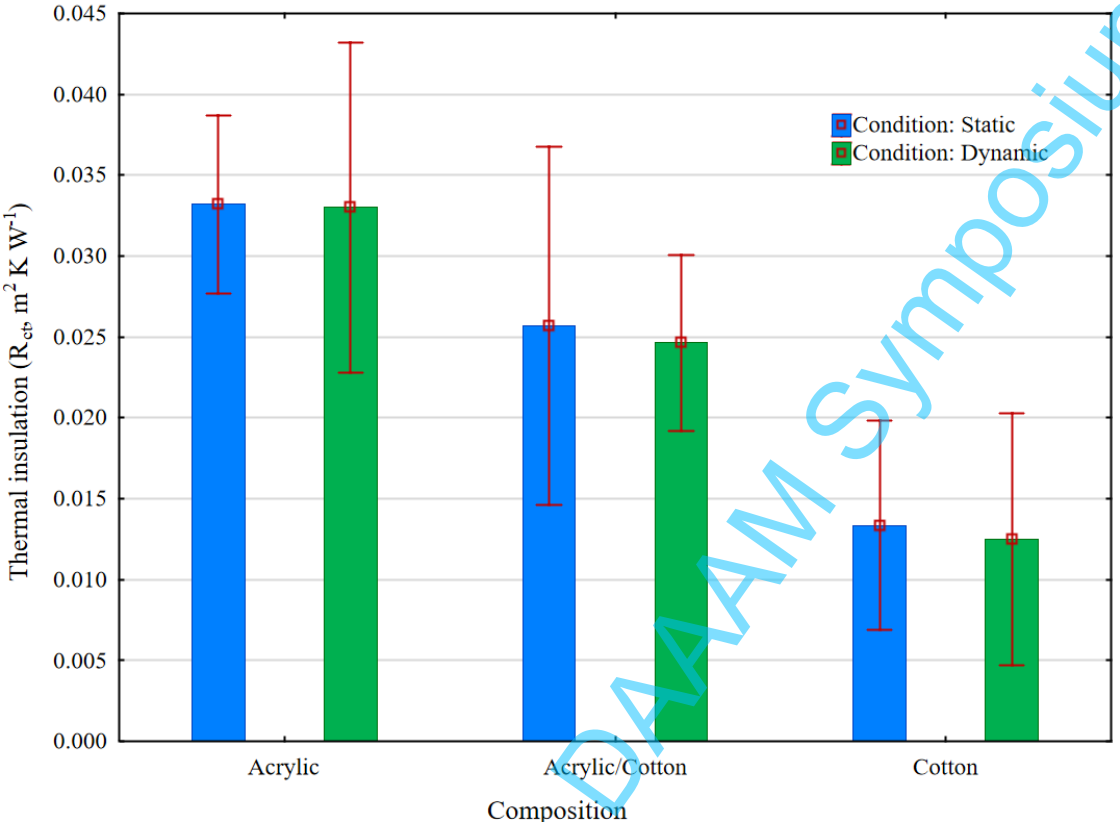

Fig. 5. Thermal insulation of weft knitted sweaters with different yarn compositions under static and dynamic conditions: mean ± SD, n = 20

The electrical power supplied to maintain the set temperature of the thermal manikin measuring surface on which the sweater samples were placed is presented in Table 4. A similar trend, as thermal insulation of weft knitted sweaters under static and dynamic conditions is also evident in the electrical power data, Table 5. Under static conditions, the mean power required to maintain the set thermal manikin surface temperature ranged from 97.5378 W for the 100% acrylic weft knitted sweater to 114.6146 W for the 100% cotton sweater. The values obtained under dynamic conditions were very similar, 98.1343 W for acrylic and 114.9343 W for cotton. Yarn composition also had a significant effect on the required electrical power ($F(1.547, 29.394) = 118.349$, $p < 0.001$), after Greenhouse–Geisser correction, Table 6. No significant effect of measurement conditions was found ($F(1, 19) = 0.097$, $p = 0.769$), and no significant interaction was found between measurement conditions and yarn composition ($F(2, 38) = 0.007$, $p = 0.993$). Bonferroni-adjusted pairwise comparisons showed significant differences among all three yarn compositions ($p < 0.001$). Among the three weft knitted sweaters, the 100% acrylic sweater showed the highest thermal insulation, as the lowest electrical power was required to maintain the defined surface temperature. In contrast, the 100% cotton sweater had the lowest thermal insulation and required the highest electrical power. The results therefore confirm that yarn composition has an important effect on the thermal properties of knitted garments, which is also in agreement with findings reported in previous studies.

The differences observed among the three weft knitted sweaters are consistent with previous studies showing that yarn composition plays an important role in the thermal properties of knitted materials. Abreu et al. [12] reported lower thermal insulation for cotton garments compared with garments made from materials containing synthetic fibres, while Naseer et al. [17] found that acrylic knitted structures provided the highest thermal insulation among the fibre types investigated. The results of the present study show the same general trend. The 100% acrylic sweater had the highest thermal insulation, the 100% cotton sweater the lowest, while the 50/50% acrylic/cotton blend showed intermediate values. This agreement is particularly relevant because the present study evaluated knitted sweaters rather than two-dimensional knitted samples. At the same time, these findings should also be considered in the context of the effects of knit structure reported in previous studies. Mikučionienė and Milašienė [10] showed that knit construction can have a greater influence on thermal properties than yarn type, while Bivainytė et al. [11] identified knit structure as one of the main factors affecting the thermal properties of double-layer knitted fabrics. In the present study, the structural parameters were intentionally kept constant. Therefore, the statistically significant differences observed among the three sweaters can primarily be attributed to yarn composition within the investigated 4 × 4 rib structure.

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No.	H_0, W	Measurements under static conditions (simulated standing)			Measurements under dynamic conditions (simulated walking)		
		Acrylic	Acrylic/ Cotton	Cotton	Acrylic	Acrylic/ Cotton	Cotton
		H, W	H, W	H, W	H, W	H, W	H, W
1	137.489	95.255	117.776	126.979	88.495	97.927	108.844
2	146.505	101.052	96.510	110.083	98.229	103.807	104.776
3	124.026	100.099	98.990	106.537	99.662	108.313	123.260
4	130.620	94.167	113.359	124.646	100.729	100.807	123.922
5	142.932	98.656	101.031	118.391	102.453	108.771	125.290
6	125.442	100.047	92.490	101.469	94.339	111.537	122.005
7	124.557	95.516	113.281	116.849	105.875	105.120	118.839
8	138.635	101.125	101.479	119.505	104.094	105.125	110.343
9	125.995	90.740	90.401	108.880	84.047	104.849	106.787
10	126.245	101.359	112.161	112.740	103.912	101.781	111.531
11	136.708	98.224	109.880	119.464	105.995	107.776	113.781
12	126.734	91.828	91.833	117.234	86.651	101.516	114.271
13	121.135	96.458	110.328	113.370	92.865	97.724	107.604
14	131.234	104.099	119.156	118.557	106.458	108.656	113.052
15	134.641	97.193	94.787	113.682	92.557	103.839	123.276
16	115.005	94.448	98.401	114.271	93.516	95.990	109.000
17	125.667	102.322	111.839	118.021	107.891	106.177	111.260
18	140.724	98.922	104.979	105.885	98.740	109.912	127.016
19	120.802	92.089	96.776	111.026	92.823	105.151	118.682
20	117.823	97.156	103.854	114.703	103.354	101.495	105.146

Table 4. Supplied electrical power required to maintain the set temperature of the measuring surface of the thermal manikin

Yarn composition	Static H (W) Mean ± SD	Dynamic H (W) Mean ± SD
100% acrylic	97.5378 ± 3.7162	98.1343 ± 7.0951
50/50% acrylic/cotton	103.9656 ± 8.9650	104.3137 ± 4.2578
100% cotton	114.6146 ± 6.2442	114.9343 ± 7.2369

Table 5. Electrical power required to maintain the set temperature of the thermal manikin measuring surface: mean ± SD, n = 20

Effect	df	Error df	F	p
Measurement conditions	1	19	0.097	0.769
*Yarn composition	1.547	29.394	118.349	< 0.001
Measurement conditions × Yarn composition	2	38	0.007	0.993

** Greenhouse–Geisser corrected because the assumption of sphericity was not satisfied (Mauchly's test, $p = 0.044$). Bonferroni-adjusted pairwise comparisons showed significant differences among all three yarn compositions ($p < 0.001$).*

Table 6. Two-factor repeated-measures ANOVA for electrical power required to maintain the set temperature of the thermal manikin measuring surface

Figure 6 shows the mean electrical power required to maintain the set surface temperature of the thermal manikin for sweaters with different yarn fibre compositions under static and dynamic conditions, along with the corresponding standard deviations.

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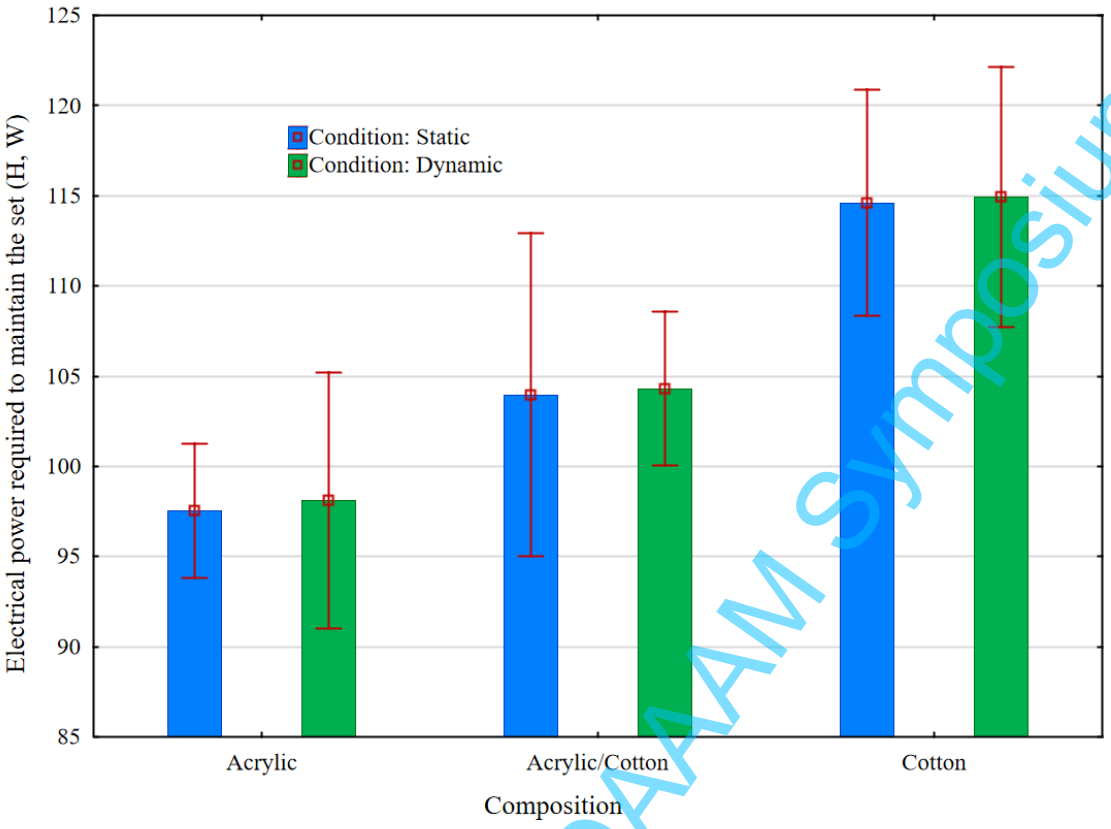

Fig. 6. Electrical power required to maintain the set surface temperature of the thermal manikin: mean ± SD, n = 20

Under the conditions investigated in this study, yarn composition was the main factor influencing the thermal insulation of the weft knitted sweaters. Simulated walking did not significantly affect thermal insulation. Whether the same relationship would be observed with other knitted structures or at higher walking intensities remains to be investigated.

4. Conclusion

Based on the results of this study, it can be concluded that yarn composition has a significant effect on the thermal properties of weft knitted sweaters. The 100% acrylic weft knitted sweater provided the highest thermal insulation and required the least electrical power to maintain the set thermal manikin surface temperature. The 100% cotton weft knitted sweater showed the lowest thermal insulation and required the highest electrical power, while the 50/50% acrylic/cotton weft knitted sweater showed intermediate values.

No statistically significant differences in thermal insulation or required electrical power were found between static and dynamic measurement conditions, and there was no significant interaction between measurement conditions and yarn composition. Under the conditions investigated, yarn composition therefore had a greater influence on the thermal insulation of the weft knitted sweaters than simulated walking.

Future studies should consider different walking speeds, as well as changes in ambient temperature and relative humidity. Sweaters produced at different machine gauges and with other knit structures, such as interlock and single jersey, should also be tested. This would allow the effect of yarn composition to be examined under a wider range of conditions.

5. References

[1] Özdemir, H. (2017). Thermal comfort properties of clothing fabrics woven with polyester/cotton blend yarns. Autex Research Journal, Vol. 17, No. 2, pp. 135–141.

[2] Ogulata, T. (2007). The effect of thermal insulation of clothing on human thermal comfort. Fibres and Textiles in Eastern Europe; Vol. 15, No. 2 (61).

[3] Salopek Cubric, I. & Skenderi, Z. (2010). Approach to the prediction of thermophysiological comfort, Chapter 09 in DAAAM International Scientific Book 2010, pp. 081-088, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-901509-74-2, ISSN 1726-9687, Vienna, Austria DOI: 10.2507/daaam.scibook.2010.09

[4] Huang, J. (2007). Assessment of clothing effects in thermal comfort standards: a review. Journal of Testing and Evaluation, Vol. 35, No. 5, pp. 455-462, doi: 10.1520/jte100707.

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[5] Fan, J. (2006). Simulation of perspiration in sweating fabric manikin-Walter, WIT Transactions on Ecology and the Environment, vol. 87, doi: 10.2495/DN060221.
[6] International Organization for Standardization. (2025). Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria (ISO Standard No. 7730:2025).
[7] Zhang, H.; Wan, X.; Zheng, R.; Chen, Q.; Hu, Z.; Kang, Z.; & Fan, J. (2025). A new model for evaluating dynamic clothing thermal comfort. International Journal of Thermal Sciences, 215, 109946, Vol. 215, p. 109946, doi: 10.1016/J.IJTHERMALSCI.2025.109946.
[8] Jussila, K. (2016). Clothing physiological properties of cold protective clothing and their effects on human experience, Tampere University of Technology, Tampere, Finland, p. 13, 2016.
[9] Rogale, D.; Firšt Rogale, S.; Knezić, Ž.; Jukl, N. & Majstorović, G. (2023). Measurement methods of the thermal resistance of materials used in clothing, Materials, Vol. 16, No. 10, doi: 10.3390/ma16103842.
[10] Mikučioniene, D. & Milašiene, D. (2013). The influence of knitting structure on heating and cooling dynamic, Materials science, vol. 19, no. 2, pp. 174–177, doi: 10.5755/J01.MS.19.2.4434.
[11] Bivainyte, A.; Mikučioniene, D. & Kerpauskas, P. (2012). Investigation on thermal properties of double-layered weft knitted fabrics, Materials Science, vol. 18, no. 2, pp. 167–171, doi: 10.5755/J01.MS.18.2.1921.
[12] Abreu, M. J.; Catarino, A. & Tama, D. (2018). Evaluating the effect of fabric type on thermal insulation properties of sports clothing, IOP Conf. Ser. Mater. Sci. Eng., vol. 460, no. 1, p. 012005, doi: 10.1088/1757-899X/460/1/012005.
[13] Soundri, S. G. M.; Kavitha, S. & Kumar B, S. (2023). Dimensional, moisture, and thermal properties of bi-layered knitted fabric for sportswear application, Research Journal of Textile and Apparel, vol. 27, no. 4, pp. 543–559, doi: 10.1108/RJTA-05-2021-0074.
[14] Buzaite, V.; Repon, R. M. D.; Milasiene, D. & Mikucioniene, D. (2021). Development of multi-layered weft-knitted fabrics for thermal insulation, Journal of Industrial Textiles, vol. 51, no. 2, pp. 246–257, doi: 10.1177/1528083719878811.
[15] Buzaite, V. & Mikucioniene, D. (2022). Effect of inner layer structures of weft knitted spacer fabrics on thermal insulation and air permeability, Textile Research Journal, vol. 92, no. 15–16, pp. 2862–2872, doi: 10.1177/00405175211021452.
[16] Soundri, S. G. M.; Kavitha, S.; Priyalatha, S.; Kalaiselvi, E.; Pachiayappan, K. M. & Prakash, C. (2023). Thermal comfort properties of weft-knitted interlock layered fabrics, Indian J. Fibre Text. Res., vol. 48, no. 2, pp. 174–180, doi: 10.56042/IJFTR.V48I2.58900.
[17] Naseer, R.; Abbas, A.; Sarwar, Z.; Saeed, M. H.; Gul, Z. & Anas, M. S. (2025). Cross-tuck honeycomb based 3D weft knitted auxetic structures with enhanced adaptability/size changing capability & thermo-physiological comfort properties, The Journal of The Textile Institute, vol. 116, no. 7, pp. 1297–1312, doi: 10.1080/00405000.2024.2375490.
[18] Stanković, S. B.; Popović, D. & Poparić, G. B. (2008). Thermal properties of textile fabrics made of natural and regenerated cellulose fibers, Polym. Test., vol. 27, no. 1, pp. 41–48, doi: 10.1016/j.polymertesting.2007.08.003.
[19] International Organization for Standardization. (2004). Clothing - Physiological effects - Measurement of thermal insulation by means of a thermal manikin (ISO Standard No. 15831:2004).

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