Thermal resistance of double jersey fabric knitted by different yarn raw material

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Abstract. The research was carried out on five double jersey knitted fabrics, knitted from cotton, Viscose®, Tencel®, Modal® and polyester ring spun yarns finesses of 20 tex. A circular double bed knitting machine gauge of E17 with the same production parameters was used for knitting all the fabrics. A change in all knitted fabric structure parameters was reflected through fabric mass per unit area, which ranged from 142 g m⁻² to 165 g m⁻². The minimum and maximum knitted fabric mass per unit area difference is up to 16 %. The lowest thermal resistance have polyester, while the largest have cotton knitted fabric. Thermal resistance of cotton fabric is higher for 36.7 % related to polyester knitted fabric. Considering basic knitted fabric parameters, knitting with same constructional parameters but different yarn raw materials doesn’t provide knitted fabric with same mass per unit area or thickness, i.e. thickness factor. It can be concluded that beside basic knitted fabric parameters, yarn raw material influence on thermal resistance.

1. Introduction
More and more yarns are being made in the world that will replace classic cotton yarns produced by the ring spinning system. For a number of reasons the increasing number of population does not cause a proportional increase in the production of cotton yarns. Therefore, yarns by different raw materials are manufactured which will replace or complement cotton yarns in different areas of application [1]. Investigations on textile properties carried out by physiologists showed that raw material composition does not significantly affect comfort parameters since humans can not feel the difference between different raw material compositions or type of fabric [2]. Contrary to physiologists, researches done by textile experts indicate that there are relevant differences in heat and water vapour resistance of fabrics made by different raw materials [3]. In research where knitted fabrics produced from cotton and angora fibres in different ratios were analysed, it was indicated that 25 % of angora fibre caused a significant difference in relative water vapour permeability values [4]. In another research, untreated fabric made of spun polyester yarn has higher water vapour resistance than the one made of cotton, where after fabric treatment, the decrease in water vapour resistance for polyester fabric is significant, but it is not for cotton fabric [5]. Recent research showed that different types of fibres and yarns are being used to improve the heat and moisture management, and therefore the comfort of the fabric wearable next to the skin [6]. In most of the studies of thermo-physiological properties, synthetic fibres are compared to natural fibres. Fabrics made by different yarn structure or different fabric parameters where researchers did not manage to produce yarns or fabrics that was identical, differ only in one single factor [7-11]. The present research aim is to analyse knitted fabric parameters and influence on thermal resistance of
double jersey knitted fabrics. The fabrics were made on the same knitting machine with same production parameters by yarn finesses of 20 tex. Yarns were produced in one factory differing only in raw material, namely cotton, Viscose®, Tencel®, Modal® and polyester.

1.1. Knitted fabrics
A circular double bed knitting machine gauge of E17 was used for knitting the fabrics (Figure 1 and Figure 2). It is used to knit plain or plated double knit jersey fabrics, and due to its construction (Table 1), it is recommended to knit single cotton yarns from 12 to 36 tex or ply yarns from 10 tex x 2 to 17 tex x 2.

This type of machine has 8 knitting systems so it was necessary to prepare 8 individual yarn spools for each yarn group (cotton, Viscose®, Tencel®, Modal® and polyester). The tensile force of the yarn fed to the knitting system was regulated with Coni positive feeders.

| Table 1. Construction features of the double bed circular knitting machine. |
|---------------------------------------------------------------|
| Machine gauge, E | Cylinder diameter, mm (in) | Number of knitting systems, S | Number of needles, N_i | Cylinder working speed, rpm |
| 17 | 200 (8") | 8 | 432 x 2 | 60 |

Twenty meters of each sample were knitted. The fabric take-down was performed by two pairs of rollers located 70 cm away from the knitting zone. The fabric was not wound onto a fabric roll but it was plaited down on the tray below the take down rollers. The research work was carried out on five double jersey knitted fabrics, knitted from cotton, Viscose®, Tencel®, Modal® and polyester ring spun yarns finesses of 20 tex.

1.2. Knitted fabric structure parameters
Basic structure parameters such as horizontal (D_h) and vertical fabric density (D_v), fabric thickness (t) and mass per unit area (m) are tested. Based on the fabric thickness and mass per unit area, porosity and fabric thickness cover factor were calculated.

From the width of the knitted fabric and number of needles in the cylinder, horizontal fabric density (D_h, number of loops in course direction) can be determined using following equation:

\[ D_h = \frac{N_i}{S_p} \]
Where: Dh is the horizontal fabric density in cm⁻¹, Ni is the number of needles, Sp is the width of the fabric in cm.

Vertical fabric density (Dv, number of loops in wale direction) was measured on the sample, counting the loops in one course at a certain length. Thickness (t) was measured using the precision Thickness Gauging testing device model 2000-U, from HESS MBV GmbH, according to the standard DIN EN ISO 5084, where the standard recommend to apply pressure of 1 kPa by a stamp of 50.5 mm diameter.

The most important technological and economical parameter of the knitted fabric structure is the fabric mass per unit area (m, g m⁻²). It can be determined by weighing the mass of the fabric (mu) and calculating its surface area (Pu) with this equation:

\[ m = \frac{m_u}{P_u} \quad (2) \]

Where: m is mass per unit area in g m⁻², mu is the weight of the knitted sample in g, Pu is the surface area in m².

Thickness cover factor (Tcf) is calculated with the ratio of mass per unit area (m) and fabric thickness (t):

\[ T_{cf} = \frac{m}{1000 \cdot t} \quad (3) \]

Where: Tcf is thickness cover factor in g m⁻³, m is mass per unit area in g m⁻², and t is fabric thickness in mm.

The porosity of the knitted fabric (P) is analysed as the ratio of the substance mass that makes the fabrics and the yarn volume of the knitwear. For the porosity of knitted fabric, the main data is the average density of fibres (γ) that builds the knitted structure. Porosity was calculated according to the following equation [12]:

\[ P = \frac{\gamma - T_{cf}}{\gamma} \cdot 100 \quad (4) \]

Where: P is porosity, %, γ is the density of the fibre in g cm⁻³ where density of the cotton fibre is 1.52 g cm⁻³; viscose fibre is 1.48 g cm⁻³; tencel fibre is 1.50 g cm⁻³; modal fibre is 1.53 g cm⁻³ and polyester fibre is 1.39 g cm⁻³ [13,14], Tcf is the thickness cover factor, g m⁻³.

1.3. Thermal resistance

Thermal resistance of the knitted fabric were determine by measuring thermal resistance under steady-state conditions using the Sweating Guarded Hot Plate according to standard ISO 11092:2014. The Sweating Guarded Hot Plate simulates the heat and moisture transfer from the body surface through textile fabric to the environment under specified environmental conditions. Standard environment for testing thermal resistance is air temperature of 20 ± 0.1 °C and relative humidity of 65 ± 3%. The thermal resistance of knitted fabric gives quantitative evaluation of fabric as thermal barrier to the wearer. The thermal resistance of knitted fabrics are required to assess the heat exchange of the human body with the environment, and are related to human perceptions of comfort [15].

2. Results and discussion

The results of the knitted fabric parameters, i.e. mass per unit area, knitted fabric thickness, horizontal and vertical knitted fabric density, calculated knitted fabric porosity and thickness cover factor are presented in Table 2. The results of thermal resistance are shown in Table 3. All tested yarns were ring spun yarns with nominal yarn count of 20 tex from 1.3 dtex fibres with a length of 38 mm. Ring-spun yarns were produced using the carding manufacturing process, comprising fibre preparation phases (opening, blending and carding), spinning preparation (drawing, pre-spinning and ring spinning), winding and cleaning. A Zinser 351 ring spinning machine connected to an Autoconer X5 winding machine was used for the ring spinning process [16,17]. The knitted fabrics were made on one machine
and under the same conditions, i.e. without machine operation control. A change in all parameters of knitted fabric structure was reflected through fabric mass per unit area, which ranged from 142 g m\(^{-2}\) (knitted fabric made of polyester ring spun yarn) to 165 g m\(^{-2}\) (knitted fabric made of Viscose\(^\circledR\) ring spun yarn) (Table 2.). The minimum and maximum knitted fabric mass per unit area difference is up to 16 \%.

### Table 2. Basic knitted fabrics properties [18].

| Sample   | m, g m\(^{-2}\) | t, mm | \(D_v\), cm\(^{-1}\) | \(D_h\), cm\(^{-1}\) | P, \%  | \(T_{cf}\), g m\(^{-3}\) |
|----------|----------------|-------|----------------|----------------|--------|----------------|
| Cotton   | 157            | 0.64  | 11.4           | 11.1           | 83.82  | 0.245          |
| Viscose\(^\circledR\) | 165            | 0.63  | 11.8           | 10.9           | 82.26  | 0.262          |
| Tencel\(^\circledR\)   | 152            | 0.63  | 11.8           | 10.8           | 83.93  | 0.241          |
| Modal\(^\circledR\)    | 155            | 0.58  | 11.8           | 10.3           | 82.55  | 0.267          |
| Polyester | 142            | 0.61  | 12.0           | 9.5            | 83.24  | 0.233          |

where: m is the mass per unit area, g m\(^{-2}\); t is the thickness, mm; \(D_h\) is the horizontal fabric density, cm\(^{-1}\); \(D_v\) is the vertical fabric density, cm\(^{-1}\); P is the porosity, \%; \(T_{cf}\) is thickness cover factor, g m\(^{-3}\).

Comparing the knitting fabric thickness, influence of raw material is noticeable. The range of thickness is from 0.58 mm up to 0.64 mm, where knitted fabric made by cotton yarn has higher thickness for 10.3 \% related to the fabric made by Modal\(^\circledR\) yarn. Results have shown the difference up to 14.5 \% in knitted fabric cover factor, which ranged from 0.233 g m\(^{-3}\) for fabric made from polyester yarn to 0.267 g m\(^{-3}\) for fabric made by Modal\(^\circledR\) yarn. Due to the difference in fibre density and knitted fabrics mass per unit area, range of knitted fabric porosity is from 82.26 \% (for the Viscose\(^\circledR\) knitted fabric) to 83.93 \% (for knitted fabric made by Tencel\(^\circledR\) yarn) which is a difference of only 2 \%. Different mass per unit area and thickness of knitted fabrics made by different raw material influenced on the knitted fabric horizontal and vertical density (Table 2.).

The thermal resistance of the knitted fabrics is in the range of 0.019 m\(^2\) °C W\(^{-1}\) to 0.030 m\(^2\) °C W\(^{-1}\) (Table 3.). The smallest thermal resistance value has the polyester knitted fabric, while the largest thermal resistance value has the cotton knitted fabric. Thermal resistance of cotton fabric is higher for 36.7 \% related to polyester knitted fabric.

### Table 3. The knitted fabrics thermal resistance.

| Sample   | \(R_{ct}\), m\(^2\) °C W\(^{-1}\) | SD, m\(^2\) °C W\(^{-1}\) | CV, \% |
|----------|----------------|----------------|--------|
| Cotton   | 0.030          | 0.003          | 11.3   |
| Viscose\(^\circledR\) | 0.022          | 0.002          | 8.3    |
| Tencel\(^\circledR\)   | 0.023          | 0.003          | 12.2   |
| Modal\(^\circledR\)    | 0.023          | 0.001          | 5.3    |
| Polyester | 0.019          | 0.001          | 3.9    |

Where: \(R_{ct}\) is the knitted fabric thermal resistance in m\(^2\) °C W\(^{-1}\), SD is the knitted fabric thermal resistance standard deviation in m\(^2\) °C W\(^{-1}\), CV is the knitted fabric thermal resistance coefficient of variation in \%.

Considering that thermal resistance describes resistance of human body heat passage through knitted fabric to the environment, it can be concluded that cotton knitted fabric will provide better thermal barrier than polyester fabric. Thermal resistance difference of Viscose\(^\circledR\) (13.6 \%), Tencel\(^\circledR\) (17.4 \%) and Modal\(^\circledR\) knitted fabric (17.4 \%) related to polyester is smaller than cotton to polyester thermal resistance difference. Comparing thermal resistance of the knitted fabrics and their basic parameters, it is visible that polyester fabric has the lowest mass per unit area and thickness cover factor, which gives heat an easier pass through fabric, i.e. gives the smallest resistance heat to pass (Figure 3 and 4). Considering basic knitted fabric parameters, highest mass per unit area doesn’t provide the greatest
thickness, i.e. greatest thickness factor. It can be concluded that beside basic knitted fabric parameters, different yarn raw material influence on thermal resistance.

3. Conclusion
Based on the conducted research, it can be concluded that knitting with same yarn finesses and machine production parameters but different yarn raw materials do not provide knitted fabrics with the same constructional characteristic. Knitting with different raw materials namely, cotton, Viscose®, Tencel®, Modal® and polyester, gives mass per unit area in range of 142 g m⁻² (knitted fabric made of polyester ring spun yarn) and 165 g m⁻² (knitted fabric made of Viscose® ring spun yarn), which is different to up to 16 %. Beside mass per unit area, influence of raw material on knitted fabric is noticeable through thickness (from 0.58 mm for knitted fabric made by Modal® yarns up to 0.64 mm made by cotton yarns) and cover factor (from 0.235 g m⁻³ for fabric made by polyester yarn up to 0.267 g m⁻³ for fabrics made by Modal® yarn). The polyester has the lowest thermal resistance, while the cotton knitted fabric has the largest. Thermal resistance of cotton fabric is higher by 36.7 % related to polyester knitted fabric. Knitting with same yarn finesses and knitting machine production parameters but different yarn raw materials will give knitted fabrics different basic constructional parameters, which will influence on thermal resistance.

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