Modelling thermal resistance of woven fabrics in wet state

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ABSTRACT – REZUMAT

Modelling thermal resistance of woven fabrics in wet state

In this study, a simple mathematical model based on conductive heat transfer is suggested for predicting the thermal resistance of wet woven fabric. For this purpose, cellulosic fabrics produced in two different weave types with different moisture content were investigated. Fabric is considered a system of a porous structure consisting of fibre, air and if present, water. The thermal resistance of fabric was calculated according to the proportion of these components. It was considered that the water's location could have changed the resistance values. The assumption was the capillary water was arranged serially with fibres and air when it was located in the yarns, and it was arranged parallel with the air when it was located between the yarns. Calculated values were compared with the measurement values obtained from ALAMBETA. When the results were evaluated, the obtained values were quite good except for the absolute dry fabric. Serial arrangement of fibre and air was better fitted for dry fabric. So, it is thought that the air acts as a single block in absolute dry fabrics. Additionally, for comparison, Maxwell-Eucken2 (ME-2) was also used. The new model's R^2 value is a little higher than *the other model as 0.9017. Furthermore, MSSD and MSAD values were 0.0000013 and 0.0007878 for this model, respectively. As a result of the study, it can be said that the suggested model is useful for predicting the thermal resistance of woven fabrics with different moisture content. Besides this, analyses of fabric porosity can be useful to manage the thermal resistance of wet fabrics.*

Keywords: *thermal resistance, woven fabric, weave type, modelling, wetting*

Modelarea rezistenței termice a țesăturilor în stare umedă

În acest studiu este prezentat un model simplu matematic bazat pe transferul de căldură conductiv, pentru preconizarea rezistenței termice a țesăturii în stare umedă. În acest scop, au fost investigate țesături celulozice produse cu două tipuri diferite de legături cu conținut diferit de umiditate. Țesătura este considerată ca un sistem de structură poroasă constând din fibre, aer și, dacă este prezentă, apă. Rezistența termică a țesăturii a fost calculată în funcție de proporția acestor componente. S-a considerat că locația apei ar fi putut modifica valorile rezistenței. S-a analizat apa supusă influenței capilare dispusă în serie cu fibrele și aerul atunci când este situată în fire și cea dispusă paralel cu aerul când se află între fire. Valorile calculate au fost comparate cu valorile măsurate obținute cu ALAMBETA. La evaluarea rezultatelor, valorile obținute au fost destul de bune, cu excepția țesăturii complet uscate. Aranjarea în serie a fibrei și aerului a fost mai potrivită pentru țesătura în stare uscată. Deci, se preconizează că aerul acționează ca un singur bloc în țesăturile complet uscate. În plus, pentru comparație, a fost utilizat și Maxwell-Eucken2 (ME-2). Valoarea R^2 a noului model este puțin mai mare decât cea a celuilalt model, cu 0,9017. În plus, valorile MSSD și MSAD au fost de 0,0000013 și, respectiv, de 0,0007878 pentru acest model. Ca rezultat al studiului, se poate spune că modelul sugerat este util pentru preconizarea rezistenței termice a țesăturilor cu conținut diferit de umiditate. Pe lângă aceasta, analizele porozității țesăturilor pot fi utile pentru a gestiona rezistența termică a țesăturilor în stare umedă.

Cuvinte-cheie*: rezistență termică, țesătură, tip de legătură, modelare, umezire*

INTRODUCTION

Clothing helps to keep the body temperature in the comfort zone by creating a thermal barrier between the human body and the environment. For this aim high thermal resistance is expected from clothing in cold weather, whereas in hot weather thermal resistance must be low. Thus, thermal resistance is considered one of the important comfort-related properties [1].

Fibre, yarn, and fabric parameters have a significant effect on the thermal properties of the fabrics. Many studies investigated the relationship between these parameters and the thermal characteristics of the fabrics. A high correlation between the thermal resistance of the fabric with thickness, weight, cover factor and porosity of the fabric was determined with these studies. The study by Cubric et al. indicates that the air enclosed in the fabric is a significant factor in thermal resistance [2]. Also, some researchers suggested prediction models for the thermal properties of the fabrics. For the prediction of thermal resistance of woven fabrics, Bhattacharjee & Kothari developed a mathematical model. Their model consists of heat transfer by conduction, radiation through air and radiation through yarns [3]. Matusiak developed a model of the thermal resistance of woven fabrics in the function of their structure [4]. Wei et al. established a structural model to predict the thermal resistance of fabrics [5]. Yang et al. described four different regions in fabric and suggested a predicting model using the arrangement of thermal resistance of yarn and thermal resistance of air serial, parallel or hybrid [6].

Due to sweat sorption in the fabric or due to rainy climate, the air enclosed in the fabric replaces with water although the proportion of water and air in the fabric will change. As a result, the thermal properties of the fabric change due to the moisture content of the fabric since the thermal conductivity of water is 25 times higher than the thermal conductivity of air. The thermal performance of fabric in wet conditions is more complex and it is affected by fabric thickness, porosity and fibre type [7]. Some researchers investigated the fabric's thermal properties in wet conditions [8–10]. Several studies used statistical models to investigate the relationship between fabric parameters and thermal properties [11–15].

Conduction, radiation, convection, and ventilation are dry heat transfer mechanisms, when wet heat transfer occurs evaporation, wicking, sorption and desorption, wet conduction (additional conductive heat transfer due to the clothing being wet), and condensation of moisture are added [16]. Modelling of the thermal properties of the fabrics in a wet state is investigated in some studies.

Dias and Delkumburewatte developed a mathematical model for the porosity of plain knitted fabrics based on the unit cell of stitch. Then they suggested a thermal conductivity model for wetted fabric. In this model, they assumed that the wet fabric consists of material, water, and air with different volume fractions. Their theoretical values were quite higher than the experimental values. However, theoretical values obtained from this model and experimental values have a similar pattern [17].

Hes and Loghin assumed that the thermal resistance of textiles is linked parallel to the thermal resistance of water, and they suggested a mathematical model for the thermal conductivity of wetted fabric [18]. Mangat et al. suggested a model for predicting the thermal resistance of wet denim fabrics by using mean porosity [19]. Mangat and Hes predicted the thermal resistance of denim fabrics at different moisture content. They considered wet fabric as a system of fibre, air, and water. They calculated the resistance values of wet fabric with eight different arrangements of the thermal resistance of fibre, air, and water. They suggested the model that gives the best results [20]. Similarly, Mangat et al. used this approach to predict the thermal resistance of selected fabrics in the wet state [21].

Mansoor et al. predicted the thermal resistance of wet socks by using the thermal conductivity of wet polymer. They have compared the models in the literature with the experimental data and developed two new mathematical models on modifications of the Maxwell Eucken-2 and Militky models for the prediction of thermal resistance of plain socks in the wet state [22]. Mansoor et al. also suggested another model with assumed that fabric density is changing with wetting [16]. Mansoor et al. used image analysis to obtain the porosity values of the socks and compared the experimental values of heat transfer of wet socks with theoretical values obtained from 3 different mathematical models [23].

Wu et al. improved the models based on Mangat's prediction models, by replacing the original moisture content with water content saturation. The results of their studies showed that air resistance and water resistance were connected in parallel, followed by serial arrangement with fibre resistance gave the best results with $R^2 \geq 0.955$. The modified model gave better results with R^2 values ranging from 0.95 to 0.99. [7]. Joshi et al. modelled both heat and mass transfer of layered fabrics [24]. Wu et al. classified into five levels of thermal absorptivity of wet fabrics with fuzzy comprehensive evaluation and compared with subjectively classified using participant evaluations [25].

Also, artificial intelligence is used for predicting the thermal properties of fabrics in wet states. Kanat and Özdil predicted the thermal resistance of knitted fabrics in the wet state by using an artificial neural network (ANN) [26]. Mandal et al. developed multiple linear regression and ANN models to predict the thermal protective and thermo-physiological comfort performances of fabrics used in firefighters' clothing [27]. Also, ANN was used by Li et al. to predict thermal resistance and water vapour resistance of wet knitted double jersey fabrics [28].

In this study thermal resistances of the woven fabrics with different moisture content are predicted from thermal resistances of fibre, air, and water. There are four different types of water held within fibres and fabrics as defined below [29].

- internal water, which is absorbed into fibres,
- capillary water, which is located in the capillary pores between fibres,
- surface water, which is located between the yarns,
- dripping water, which is located on the fabric and is transported downwards due to gravity.

This study aims to estimate the wet thermal resistance of woven fabrics using fabric geometric parameters. Different from the previous study, the suggested model uses the location of water, which existed in the fabric to calculate the thermal resistance of the fabric as well as volume fractions of fibre, air, and water. For this purpose, the porosity of the fabrics was analysed first, and the thermal resistance model was constituted by considering the position of water.

MATERIALS AND METHODS

Fabric properties

The proposed model to predict the thermal resistance of wetted woven fabric is experienced on three different cellulosic fibres cotton, viscose and Tencel™. 36 Ne yarns were used in all fabrics both for warp and weft. 3/1 (Z) twill fabrics were manufactured with all three yarns and with cotton yarns also plain fabrics were produced. Two different weft densities (23 and 27 picks/cm) were used for all fabrics [30].

In this study thermal resistance of wet woven fabrics is predicted by using their geometrical properties. For this purpose, warp and weft density, fabric weight and fabric thickness were determined experimentally. Other parameters used such as porosity and cover factor of the fabrics were calculated by using these measurement results.

All measurements were performed under the standard atmospheric conditions (20 ± 2°C temperature, 65% ± 4 relative humidity). The number of threads per unit length was determined according to TS 250 EN 1049-2. All fabric samples were dried at 105°C for 4 hours to obtain absolute dry fabrics. Fabric weights per unit area were determined according to TS EN 12127 at this stage. Fabric thicknesses were determined with the ALAMBETA instrument at thermal resistance measurement which is expressed in Testing Procedure. The measured properties of the fabrics are given in table 1.

The porosity and cover factor of the fabrics was calculated using equations 1 and 2 respectively [31, 32]:

$$\varepsilon = 1 - \frac{\rho_f}{\rho_{fb}} \quad (1)$$

$$CF = (P_1 \times d_1 + P_2 \times d_2 - d_1 \times d_2) / (P_1 \times P_2) \quad (2)$$

In equation 1, ρ_f is the fabric density (ρ_f = fabric weight per unit area/fabric thickness) (g/cm^3) and ρ_{fb} is the fibre density (g/cm^3). In equation 2, 1 and 2 are indices for warp and weft, respectively. *d* indicates the diameters of the yarns and *P* indicates the density of the yarns (figure 1).

To calculate the fabric cover factor firstly yarn densities were determined with Pierce's packing factor expressed as in equation 3 [33]:

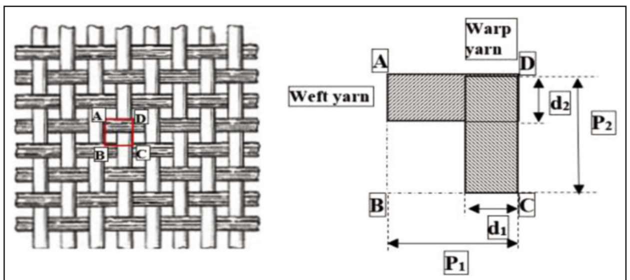


Fig. 1. Diagram of the weave structure

$$\textit{Packing factor} = \frac{\rho_y}{\rho_{fb}} \quad (3)$$

In Pierce's equation, the packing factor is constant at 0.59 and ρ_y is the yarn density (g/cm^3) and ρ_{fb} is the fibre density (g/cm^3). According to the literature, fibre densities were taken as 1.55 g/cm^3 for cotton, 1.52 g/cm^3 for viscose [34] and 1.50 g/cm^3 for Tencel^{TM} [35] to calculate both porosity and packing factor. Also yarn diameter was calculated by using equations 4 and 5 is [33]:

$$V_y = \frac{1}{\rho_y} \quad (4)$$

$$V_y = \pi \frac{R^2}{4} Nm \cdot 100 \quad (5)$$

where *R* is the diameter of the yarn (cm), V_y is the specific volume of the yarn (cm^3/g), *Nm* is the yarn number (m/g).

Testing procedure

Thermal resistances of absolute dry fabrics were measured by using the ALAMBETA instrument at first (equivalent to ISO 8301). Fabrics were wetted with distilled water then the samples were left to dry at standard atmospheric conditions. At the drying stage, the wetted weight of the samples at 100%, 75%, 50% and 25 % moisture content according to dry weight was determined and the thermal resistance of the fabrics was measured at these conditions also.

When measuring thermal properties with ALAMBETA Instrument, the sample is placed on the measuring plate at 22°C and the measuring head at 32°C drops down and touches the sample. The thickness of the fabric is determined by measuring the difference between the levels of the measuring plate and the measuring head. Due to temperature difference heat flow occurs and the heat flow is processed on the computer and thermo-physical properties of the measured sample are evaluated [17, 36].

Since the water content of the fabric changes over time, the measurement time is important for this study. ALAMBETA Instrument was preferred in this study because the measurement is performed in a few minutes.

Table 1

FABRIC PROPERTIES				
Fabric type	**Warp density (ends/cm)**	**Weft density (picks/cm)**	**Thickness (mm)**	**Fabric weights (g/m^2)**
Cotton/Plain/23	49	24	0,37	122.27
Cotton/Plain/27	50	28	0,34	130.99
Cotton/Twill/23	52	25	0,41	124.22
Cotton/Twill/27	53	28	0,37	132.03
Viscose/Twill/23	53	24	0,38	123.70
Viscose/Twill/27	53	28	0,34	130.73
Tencel^{TM}/Twill/23	50	24	0,37	121.88
Tencel^{TM}/Twill/27	51	28	0,34	129.17

The obtained resistance values from the suggested model are compared with the experimental values which are observed by using ALAMBETA Instrument.

Theoretical model

In this study, referring to the studies of Farnworth [37] and Hes and Stanek [38] heat transfer by convection and radiation was neglected. Farnworth [37] did not find any evidence of convection heat transfer through fabrics. Hes and Stanek [38] explained that the proportion of radiation heat transfer is less than 20% of the total heat transfer of the fabric. Therefore, only conducted heat transfer was considered.

The air gaps in the fabric were analysed at first, and then the thermal resistance values were calculated on this basis. The woven fabrics can be considered as a system consisting of fibre, air and if present, water. The thermal resistance of the wet fabric is calculated according to this system. Assumptions of this system are as follows:

- Thickness of the fabric does not change with wetting.
- Yarn diameter is constant throughout its length.

Dry fabric comprises two components fibre and air. Porosity expresses the air ratio in the fabric. So $(1-\varepsilon)$ is the fibre ratio within the fabric. Air gaps in the fabric are examined in two parts. One of these parts is the gap between yarns and the other is the gap between fibres in the yarns. Porosity consists of these two gaps. The covering factor refers to the part of the fabric covered with yarns. Thus $(1-CF)$ is the gap between yarns. Therefore, $\varepsilon-(1-CF)$ is the gap between fibres. The ratio of the gaps in the fabrics was calculated and the values were given in the following table.

By using these ratios and the thickness values of the fabrics; thicknesses of fibre in the yarn, air in the yarn and water in the yarn were calculated according to equations 6–8 [16]. The air and water thickness values change by water amount due to air being replaced with water. Since the wetting process was carried out according to the weight of the fabric, the water content was determined according to the volumes to calculate the thicknesses.

$$h_f = h \times p_f \quad (6)$$

$$h_w = h \times p_w \quad (7)$$

$$h_a = h \times p_a \quad (8)$$

In these equations, h indicates the thicknesses of the fabrics and p indicates the percentages of fibre, water, and air in the yarn. f, w indices refer to fibre, water and air, respectively (table 3).

According to literature, firstly small pores fill with wetting, and then the water moves to large pores [39]. Thus, the water molecules fill in the gaps between fibres, and the gaps between yarns, respectively. The thickness of the air between yarns is regarded as the thickness of the fabric since there was no water in these gaps in this study. Therefore, the resistance of the gaps of the fabric is calculated with equation 9.

$$R_{gaps} = \frac{h}{\lambda_a} \quad (9)$$

After that, the resistance of each part of the system in the yarn is calculated by using equations 10–12:

$$R_a = \frac{h \times p_a}{\lambda_a} \quad (10)$$

$$R_f = \frac{h \times p_f}{\lambda_f} \quad (11)$$

$$R_w = \frac{h \times p_w}{\lambda_w} \quad (12)$$

where R is the resistance of the material and λ is the conductivity of the material. The conductivity of fibre material is 71 $mWm^{-1}K^{-1}$ [37] of the air is 24 $mWm^{-1}K^{-1}$ and of the water is 600 $mWm^{-1}K^{-1}$ [19]. Since all fibres were cellulosic, the conductivities of the fibres were regarded the same as cotton fibre.

In this study, only the heat flow from the surfaces of the fabric was considered. While the yarn resistances were calculated, it was assumed that resistances of fibre, air and water were arranged serial (figure 2, *a*). Then the fabric resistances were calculated, and it was assumed that the resistance of yarn and air gaps were arranged parallel (figure 2, *b*).

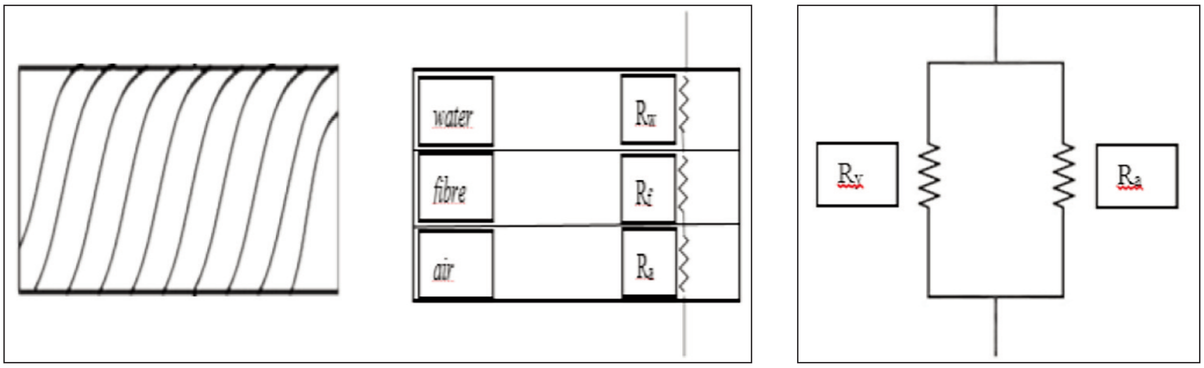
With this assumption resistance of the yarn and fabric was calculated by using equations 13 and 14.

$$R_{yarn} = R_a + R_f + R_w \quad (13)$$

Table 2

FRACTION OF THE GAPS IN THE ABSOLUTE DRY FABRICS

Fabric type	CoverFactor (CF)	Porosity (ε)	1–CF	1–ε	ε–(1–CF)
Cotton/Plain/23	0.8304	0.7869	0.1696	0.2131	0.6173
Cotton/Plain/27	0.8550	0.7481	0.1450	0.2519	0.6031
Cotton/Twill/23	0.8625	0.8022	0.1375	0.1978	0.6647
Cotton/Twill/27	0.8811	0.7679	0.1189	0.2321	0.6490
Viscose/Twill/23	0.8765	0.7844	0.1235	0.2156	0.6609
Viscose/Twill/27	0.8883	0.7474	0.1117	0.2526	0.6357
Tencel™/Twill/23	0.8624	0.7821	0.1376	0.2179	0.6444
Tence™l/Twill/27	0.8849	0.7445	0.1151	0.2555	0.6294



a *b*

Fig. 2. Thermal resistance system of: *a* – yarn; *b* – fabric

Table 3

FIBRE, WATER, AND YARN THICKNESSES IN THE YARN ACCORDING TO WATER CONTENT (MM)

Water content acc. to weight	0%			25%			50%			75%			100%		
Fabric type	h_f	h_w	h_a	h_f	h_w	h_a	h_f	h_w	h_a	h_f	h_w	h_a	h_f	h_w	h_a
Cotton/Plain/23	0.0950	0	0.2751	0.0950	0.0368	0.2383	0.0950	0.0736	0.2015	0.0950	0.1104	0.1647	0.0950	0.1472	0.1279
Cotton/Plain/27	0.0988	0	0.2367	0.0988	0.0383	0.1984	0.0988	0.0766	0.1601	0.0988	0.1149	0.1218	0.0988	0.1532	0.0835
Cotton/Twill/23	0.0929	0	0.3122	0.0929	0.0360	0.2762	0.0929	0.0720	0.2402	0.0929	0.1080	0.2042	0.0929	0.1440	0.1682
Cotton/Twill/27	0.0967	0	0.2704	0.0967	0.0375	0.2329	0.0967	0.0749	0.1955	0.0967	0.1124	0.1580	0.0967	0.1498	0.1205
Viscose/Twill/23	0.0928	0	0.2846	0.0928	0.0353	0.2493	0.0928	0.0706	0.2140	0.0928	0.1058	0.1788	0.0928	0.1411	0.1435
Viscose/Twill/27	0.0968	0	0.2437	0.0968	0.0368	0.2069	0.0968	0.0736	0.1701	0.0968	0.1104	0.1333	0.0968	0.1472	0.0965
Tencel™/Twill/23	0.0942	0	0.2786	0.0942	0.0353	0.2433	0.0942	0.0707	0.2080	0.0942	0.1060	0.1726	0.0942	0.1413	0.1373
Tence™l/Twill/27	0.0973	0	0.2397	0.0973	0.0365	0.2032	0.0973	0.0730	0.1667	0.0973	0.1095	0.1302	0.0973	0.1460	0.0937

$$R_{fabric} = \frac{R_{gaps} \times R_{yarn}}{R_{gaps} + R_{yarn}} \quad (14)$$

For comparison, some of the models which gave good results in the literature were used. One of these models was the Modified Maxwell-Eucken2 (ME-2) model, which was expressed in Mansoor et al.'s study with best fitting. It was stated that this model can be convenient for the effective thermal conductivity of a two-component material with simple physical structures [22] (equations 15 and 16). In equation 15 λ_{fab}, λ_a and $\lambda_{wet\ polymer}$ are thermal conductivities of fabric, air and wet fibre, and F_a and $F_{wet\ polymer}$ are volume fractions of air and wet fibre, respectively.

$$\lambda_{fab} = \frac{\lambda_a F_a + \lambda_{wet\ polymer} F_{wet\ polymer} \dfrac{3\lambda_a}{2\lambda_a + \lambda_{wet\ polymer}}}{F_a + F_{wet\ polymer} \dfrac{3\lambda_a}{2\lambda_a + \lambda_{wet\ polymer}}} \quad (15)$$

$$R_{fab} = \frac{h_{fab}}{\lambda_{fab}} \quad (16)$$

Other two models Model 5 and Modified Model 5 were described in Wu et al.'s study. The saturation level was used instead of the ratio of water. In Model 5, water resistance and air resistance were connected parallel, fibre resistance was connected serial to them [7].

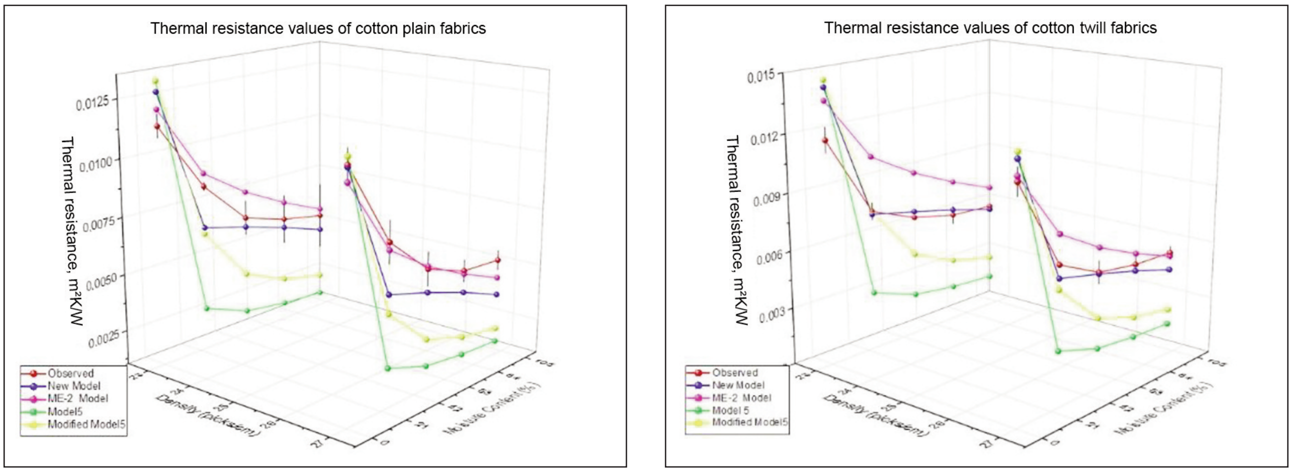
RESULTS AND DISCUSSION

The predicted values were quite good except for the values of absolute dry fabrics. For evaluating the predicted values, the sum of squares deviations (SSD) and the sum of absolute deviations (SAD) were used.

$$MSSD = \frac{1}{n} \Sigma_{i=1}^{n} (R_{tm,i} - R_t)^2 \quad (17)$$

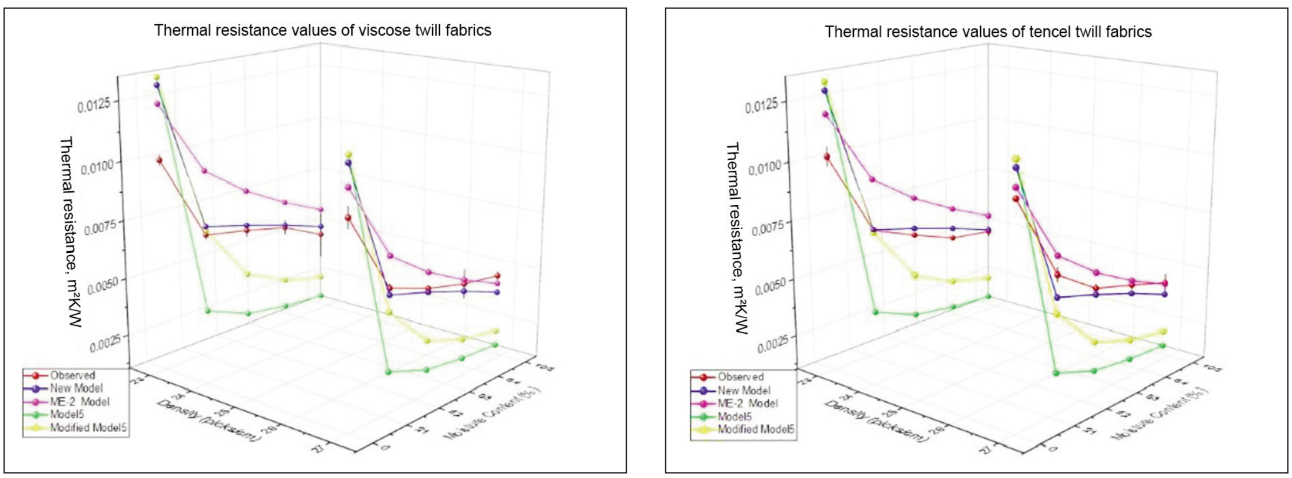
$$MSAD = \frac{1}{n} \Sigma_{i=1}^{n} |R_{tm,i} - R_t| \quad (18)$$

In these equations, R_{tm} is the measurement thermal resistance value and R_t is the calculated thermal resistance value. These mean values of SSD and SAD are 0.0000036 and 0.002007, respectively. These values are quite good but when compared with the literature [29] a little high. This difference



a *b*

Fig. 3. Comparison of predicted and observed resistance values of cotton fabrics with: *a* – plain; *b* – twill



a *b*

Fig. 4. Comparison of predicted and observed resistance values of: *a* – viscose twill fabrics; *b* – Tencel^{TM} twill fabrics

results from the values of absolute dry fabrics deviations. If the absolute dry fabric values are left out of the calculations *MSSD* and *MSAD* values rise to 0.00000070 and 0.000631531, respectively. These values are better than the literature.

However, when the fibre and air resistances are arranged with serial for the absolute dry fabrics as suggested by Dias and Delkumburewatte the predicted values better fitted with measured values. This can be explained by the fact that the air in the fabric acts as a single block when there is no water in the structure. Furthermore, this block is broken with water molecules. *MSSD* and *MSAD* values were calculated with this approach and were obtained at 0.0000013 and 0.0007878, respectively.

The predicted values obtained from both the ME-2 model, Model 5, Modified Model 5 and new model vs. observed values of thermal resistance of the fabrics at different moisture content were shown in figures 3 and 4.

The coefficient of determination (R^2) and mean values of SSD and SAD values of these four models are given in table 4. All these models were quite good. Although modified Model 5 has the highest R^2 value, when considering SSD and SAD values new model was quite good also. It can be seen in the graphs that according to these results, using the location of water in predicting the thermal resistance of wet woven fabrics could give the closest values to actual resistance.

Table 4

R^2, MSSD AND MSAD VALUES OF THE MODELS

Model	R^2	MSSD	MSAD
New Model	0.902	0.00000130	0.00078780
ME-2 model	0.847	0.00000180	0.00109540
Model 5	0.885	0.00001307	0.00348515
Modified Model 5	0.930	0.00000541	0.00215592

CONCLUSION

Thermal resistance of fabrics is one of the most important properties of clothing comfort. Higher thermal resistance values provide better protection from cold. Steady air in textile structures increases thermal resistance and it is useful for cold-weather clothing. However, wetting the fabric means replacing the air in the fabric with water. Since the thermal conductivity of water is 25 times higher than the thermal conductivity of air, the resistance value of fabric decreases dramatically. Considering thermal comfort, predicting the thermal resistance of wet fabrics is crucial for textile designs.

In this study, the thermal resistances of wet woven fabrics were predicted with their geometrical properties. The location of water can be different in the textile structure such as internal, capillary, surface and dripping, and it was assumed that wetting of the structure comes into existence in this order.

It was considered that the location of the water could change the resistance values of the fabrics. For this reason, the air gap percentages between the yarns (surface gaps) and in the yarns i.e., between the fibres (capillary gaps) were calculated. The thermal resistances of the yarns were determined by assuming that resistances capillary water, fibres and air between the fibres arrange serial. The yarn resistance is arranged parallel with the resistance of air between the yarns.

In this study, there was no water between the yarns, although fabrics were wetted up to their own weight. In addition to this, in absolute dry fabrics air in the fabric acts as a single block and air and fibre arranged serial at this moment.

The predicted values were quite close to the actual values. R^2 was 0.9017 for this new model. MSSD and MSAD values were 0.0000013 and 0.0007878, respectively. Also, the results were compared with the obtained results from some of the models in the literature that gave good results. It was found that the new model's prediction is quite good. According to these results, it can be said that the distribution of fabric porosity is effective for managing the thermal resistance of wetted fabrics.

Also, this model can be applied easily since it uses only basic geometrical and physical parameters. Other fibre types and fabrics having different construction parameters and also higher moisture content could be examined in further studies.

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