(REFEREED RESEARCH)

PREDICTION OF THERMAL RESISTANCE OF THE KNITTED FABRICS IN WET STATE BY USING MULTIPLE REGRESSION ANALYSIS

ISLAK HALDEKİ ÖRME KUMAŞLARIN ISIL DİRENÇLERİNİN ÇOKLU REGRESYON ANALİZİ İLE TAHMİNLENMESİ

Z. Evrim KANAT[1], **Nilgün ÖZDİL**[2], **Arzu MARMARALI**[2]

[1] Namık Kemal University, Department of Textile Engineering, Tekirdağ, Turkey
[2]Ege University, Department of Textile Engineering, İzmir, Turkey

Received: 06.03.2014 Accepted: 13.06.2014

ABSTRACT

Thermal properties of fabric depend on fabric construction parameters such as fiber and yarn type, fabric thickness etc. and also moisture content present. As the moisture content of the fabrics increase thermal properties of the fabrics vary. Thermal resistance is one of the main parameters of thermal comfort of fabrics. Thermal resistance of fabric decreases as the fabric moisture content increases. In this study the thermal resistance of knitted fabrics produced from cotton, polyester, modal and acrylic fibers in different moisture content is predicted from construction parameters by using two different regression analyses. The findings show that specific heat of fiber, fiber density, fabric thickness and loop density are the most important factors for thermal resistance of the fabric and thermal resistance of the fabric in different moisture content can be predicted by using regression analysis successfully.

Key Words: Knitted fabrics, Thermal resistance, Moisture content, Regression analysis, Prediction

ÖZET

Kumaşların ısıl özellikleri lif ve iplik tipi, kumaş kalınlığı gibi kumaş konstrüksiyon parametrelerinin yanında kumaşta bulunan nem oranına da bağlıdır. Kumaşın nem oranı arttığında ısıl özellikleri değişmektedir. Isıl direnç kumaş ısıl konforunun temel parametrelerinden birisidir. Kumaş ısıl direnci, kumaşın nem oranı arttığında azalmaktadır. Bu çalışmada pamuk, poliester, modal ve akrilik liflerinden üretilmiş örme kumaşların farklı nem oranlarındaki ısıl direnci iki farklı regresyon analizi ile tahminlenmiştir. Sonuçlar lifin özgül ısısı, lif yoğunluğu, kumaş kalınlığı ve ilmek yoğunluğunun kumaş ısıl direnci için en önemli özellikler olduğunu ve kumaşların farklı nem oranlarında ısıl dirençlerinin regresyon analizi ile tahminlenebileceğini göstermektedir.

Anahtar Kelimeler: Örme kumaş, Isıl direnç, Nem oranı, Regresyon analizi, Tahminleme.

Corresponding Author: Nilgün Özdil, nilgun.ozdil@ege.edu.tr, Tel: +90 232 311 16 06

1. INTRODUCTION

It is expected from a garment to help to protect thermal balance of the body, and maintain the body temperature and humidity. Garments serve as a barrier to conserve body temperature of a human being in different atmospheric conditions (1-2). Thermal properties of fabrics are influenced by fiber, yarn and fabric properties such as structure, density, humidity, material and properties of fibers, type of weave, surface treatment, filling and compressibility, air permeability, surrounding temperature and other factors (3).

Thermal resistance is the ability of a material to resist the flow of heat. Many researchers investigated the effect of fiber, yarn and fabric construction parameters on thermal properties of fabrics. Stanković et al. compared thermal properties of fabrics made of natural and regenerated cellulose fibres (4). Çil et al. investigated the comfort properties of cotton/acrylic knitted fabrics (5). Čiukas et al. studied the thermal resistance of socks knitted from stretch yarns (6). Behera et al. and Kane et al., investigated the effect of spinning systems on the comfort related properties of the fabrics (7-8). Özdil et al. studied thermal properties of knitted fabrics by using various yarns of different properties like yarn count, yarn twist (2). The effect of yarn count on comfort properties of the fabrics were discussed by Majumdar et al. and Vigneswaran et al.(9- 10).

The effect of fabric construction parameters on the comfort properties of the fabrics were studied thoroughly (8-9; 11-18). Thermal resistance of the fabric increase linearly with thickness (16) and tightness factor of the fabric (17). The studies show that there is a high correlation between thermal resistance of the fabric with thickness, weight, cover factor and porosity of the fabric. Then it can be said that the air enclosed in the fabric is the significant factor for thermal resistance (18).

During heavy activities, due to sweat sorption the moisture content of the fabric increases. With the increasing moisture regain, thermal resistance of the fabric changes due to displacement of the enclosed air by water. Chen et al. showed that the thermal resistance of the fabric decreased with sweating (19). Hes and Araujo investigated the effect of air layers between the skin of the wearer and the cotton fabric in wet state (20). Oğlakçıoğlu and Marmaralı studied thermal properties of knitted fabrics with different yarn types in dry and wet state. They found that the wetted fabrics indicate lower thermal resistance and cooler feeling (21).

There are also some studies related with prediction models of the thermal properties of the fabrics. Ziegler and Kucharska-Kot, determined the heat transfer coefficient of the woven fabrics using thermal conductivity and thickness values of fabrics (22). Dias and Delkumburewatte, developed a theoretical model to predict thermal conductivity of knitted structures with respect to porosity, thickness and moisture content. They found that thermal conductivity of dry fabric decreases when the porosity increases. However with the increased water content, thermal conductivity increases when the porosity increases (23). Militky and Křemenáková, developed a simple mechanical model for prediction of fabric thermal conductivity from basic fabric properties as yarn diameters, weft and warp sett, planar weight and thickness of fabric (24). Bhattacharjee and Kothari presented a mathematical model to predict thermal resistance of woven fabrics. They depicted all the basic weaves by a system of porous yarns, interlacements between warp and weft yarns and air pores. Thermal resistance of the fabric was predicted with the help of these parameters. The total thermal resistance was validated with actual values obtained from a standard thermal resistance measuring instrument (25).

Hes and Loghin, modeled thermal resistance of wetted woven fabrics and they suggested the following equation.

$$\lambda_{RES} = (\lambda_T + U\,\lambda_W)/(1 + U)$$

$$R_{RES} = 1/\lambda_{RES}$$

where λ_{RES} is total thermal conductivity, U is weight part (%) of dry textiles, λ_T is thermal conductivity of dry fabric, λ_W is thermal conductivity of water. They concluded that with increasing fabrics humidity their thermal resistance can even significantly decrease. This is caused by substitution of the air in pores by water with higher thermal conductivity (3).

Mohammadi et al. predicted the effective thermal conductivity of multilayered nonwoven structures by using regression analysis. The important parameters of the model were fabric weight, thickness, porosity, structure and the applied temperature. They concluded that the effective thermal conductivity of needled nonwoven structures can be predicted with greater than 88% accuracy (26).

Banks- Lee et al. were used multiple regression analysis to determine effective thermal conductivity coefficient of the needled nonwoven structure from the specific air permeability. They found the relationship between effective thermal conductivity and air permeability:

$$k^*_{etc} = 0,02669\,k^*_{fp} + 0,00023\,L - 0,01255\,\varepsilon + 0,01211$$

where k^*_{etc} is the predicted effective thermal conductivity, k^*_{fp} is the specific air permeability, L is the sample thickness, and ε is the sample porosity (27).

In this study, thermal resistance of the fabrics which have different moisture content was predicted from fiber, yarn and fabric properties by using regression analysis. One of the important points of this study is the sensitivity of the resulting regression equations obtained from the samples which produced under controlled conditions in wide range of yarn count from Ne 16 to Ne 60.

2. MATERIALS AND METHODS

In this study cotton (CO), polyester (PET), modal (CMD) and acrylic (PAN) fibers which are mostly preferred for sportswear were used. Cotton, polyester and modal fibers were spun into yarns on Rieter Model G30 ring spinning machine at α_e=3,6 twist coefficient; acrylic fiber were spun on Zinser Model 319 ring spinning machine at α_m=85 twist coefficient. Plied yarns produced on Saureer Allma doubling machine. All the samples were knitted in single jersey structure. Samples that in Ne 16 and Ne 32/2 yarn counts which are the thickest yarns among the others were produced Mesdan Labknitter (4,5", 140 needles) in two different tightness as tight and loose. The other samples produced on a 28 gauges and 16" diameter Terrot circular knitting machine using three different tightness levels as tight, medium and loose. The production plan of the study was given in Table 1. The fabrics were washed according to suitable washing procedure to remove the foreign substances from fabric.

Table 1. Production plan of the experiment

Material	Yarn Count	Fabric tightness
CO, PET, CMD	Ne 24, Ne 48/2, Ne 30, Ne 40, Ne 50, Ne 60, Ne 60/2	Tight, Medium, Loose
CO, PET, CMD, PAN	Ne 16, Ne 32/2	Tight, Loose
PAN	Ne 20, Ne 30, Ne 40, Ne 40/2, Ne 50	Tight, Medium, Loose

Yarn count, yarn diameter, wales per cm (wpc), course per cm (cpc), loop density, loop length, fabric thickness, fabric weight per unit area and air permeability parameters measured. The diameter of the yarns was measured by USTER Tester 5. The loop density was determined based on the results of courses and wales per unit length (TS EN 14971). Fabric weight determined according to TS EN 12127. The porosity of the fabrics was calculated using following formula:

$$\varepsilon = 1 - \frac{\rho_a}{\rho_b}$$

where ρ_a is the fabric density (g/cm^3) and ρ_b is the fiber density (g/cm^3). Fabric density was calculated as the fabric weight per unit area divided by fabric thickness. The air permeability tests were conducted using the Tex-test FX3300 Air Permeability Tester at a test pressure drop of 100 Pa for 20 cm² test area (TS 391 EN ISO 9237).

The thickness of the fabrics and thermal resistance of the fabrics in different moisture content were measured by ALAMBETA Sensora device at 200 Pa. The Alambeta simulates the dry human skin and its principle depends in mathematical processing of time course of heat flow passing through the tested fabric due to different temperatures of bottom measuring plate (22°C) and measuring head (32°C). When the specimen is inserted, the measuring head drops down, touches the fabrics and the heat flow levels are processed in the computer and thermo-physical properties of the measured specimen are evaluated (3).

In order to obtain absolutely dry fabrics, all the samples were dried in drying oven at 105 °C for 4 hours. Then the fabric weights were immediately measured and dry weight was determined. Fabrics were dipped in water then excessive water was removed by filter paper. Then the samples were left at standard atmospheric conditions for drying. During drying process wetted weight of the samples under %100, %75, %50, %25 moisture content determined, and thermal resistance of the fabrics were measured in these conditions by using ALAMBETA Sensora device.

3. RESULTS AND DISCUSSION

Thermal resistances of the cotton, polyester, modal and acrylic fabrics in different moisture content were given in Figures 1-4 respectively.

Test results showed that thickness has an important effect on the thermal resistance of the fabrics and thermal resistance increases as the fabric thickness increases similar to the literature. When the tightness increases thermal resistance decreases due to decreased thickness. Thermal resistance of the fabric increased due to increased thickness for coarser yarns. Polyester fabrics have highest thermal resistance values whereas modal fabrics have the lowest. It is thought that the difference depends on mainly the fabric thickness. Also thermal resistance of the fabric decreases when the moisture content increases for all types of the fabrics. The difference between the thermal resistance of the fabrics knitted with single yarns and the fabrics knitted with plied yarns is not statistically significant at %95 confidence interval.

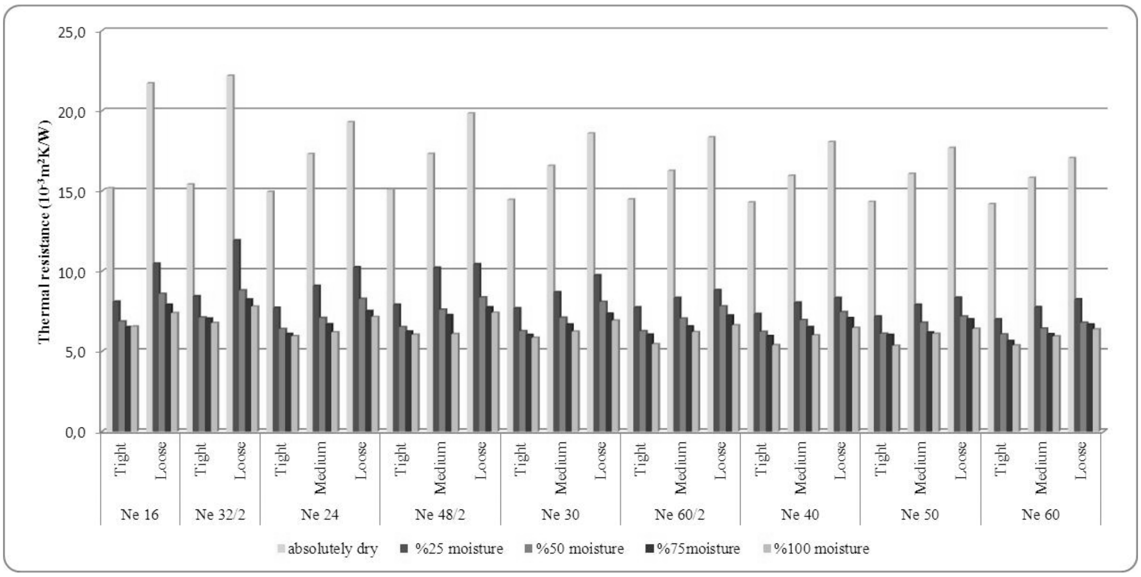

Figure 1. Thermal resistance of the cotton fabrics in different moisture content

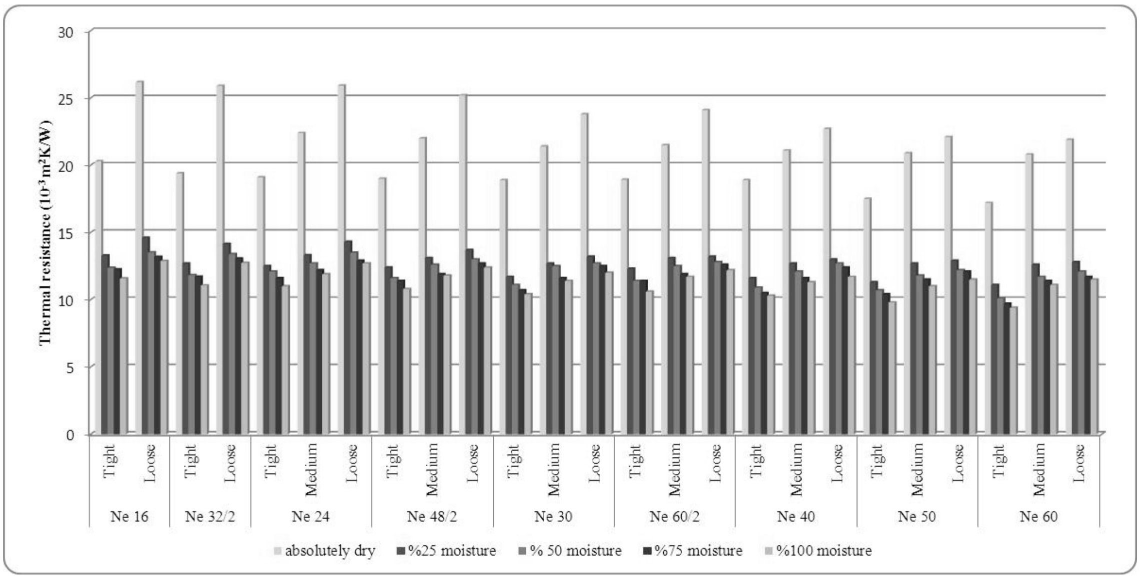

Figure 2. Thermal resistance of the polyester fabrics in different moisture content

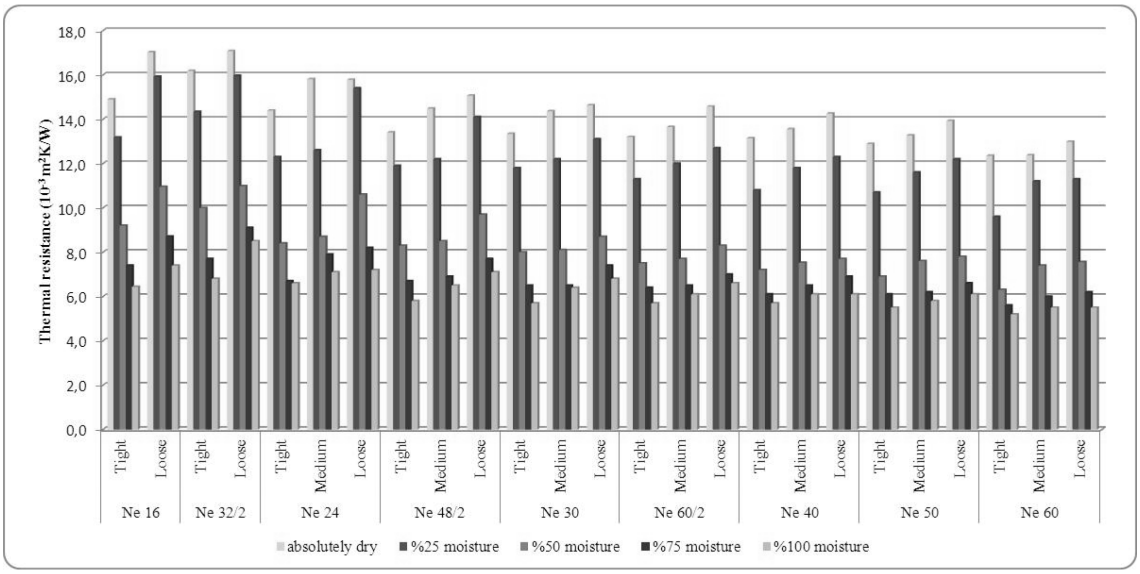

Figure 3. Thermal resistance of the modal fabrics in different moisture content

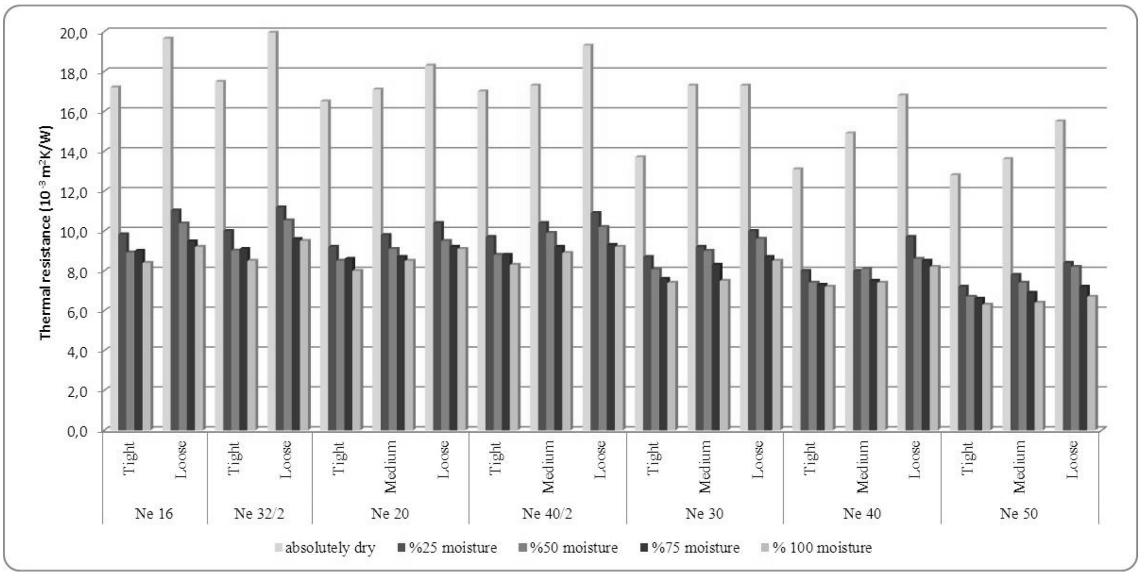

Figure 4. Thermal resistance of the acrylic fabrics in different moisture content

Thermal resistance values of the fabrics in different moisture content were predicted using by two different regression analyses. Fiber density, fiber conductivity, specific heat, yarn count, yarn diameter, fabric weight, thickness, wpc, cpc, loop density, loop length, porosity and air permeability values were chosen as the independent variables in both analyses. Correlation analysis is performed between these properties and the results suggested that there is a strong correlation between some parameters. Therefore some of the highly correlated independent variables were neglected from the analyses. A linear multiple regression analysis method was chosen. According to the performed correlation analysis, specific heat, fiber density, fabric thickness and loop density were used as independent variable in both two analyses. Statistical analysis indicated that there was a nearly linear relationship between these parameters and thermal resistance. Moisture content of the fabric was added to these parameters in first analysis. In the second analysis the thermal resistance of the fabric in given moisture contents was predicted individually (28). Statistical analyses were performed using SPSS 16.0 software. In order to see whether one parameter is significant in all regression equations, the p values of each independent variable were investigated. If p≥ 0,05, then the independent variable was not so significant in the equation and can be omitted (29).

The linear multiple regression analysis equation given below was obtained as the moisture content was taken account as independent variable.

$$R_{fabric} = (-169,899 + 80,893 * \text{Specific heat (J/gK)} + 50,004 * \text{Fiber density } (d_f)\ (g/cm^3) + 11,570 * \text{Fabric thickness (h) (mm)} - 8,437 * \text{Moisture content (\%)}) \quad \mathbf{(1)}$$

Due to loop density of the fabric was not significant at the 95% confidence interval; it was removed from the equation. It can be seen in the equation that fiber type (specific heat and fiber density), fabric thickness and moisture content are the main factors affecting thermal resistance value of the fabrics. Thermal resistance increases when thickness increases, and moisture content decrease. Figure 5 shows the scatter plot of predicted values versus experimental values and regression line of Equation 1.

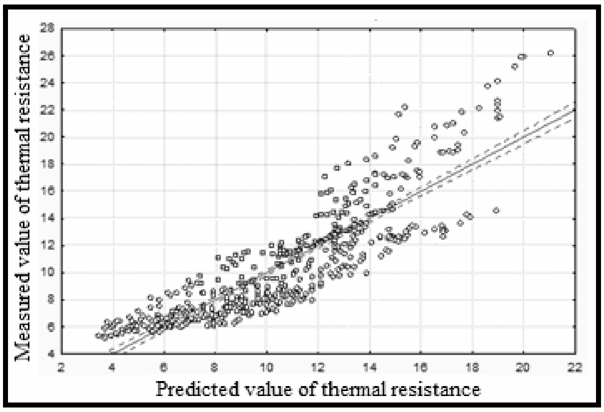

Figure 5. Predicted and measured value of thermal resistance (R^2= 0,763)

The linear multiple regression analysis equations to predict thermal resistance of the fabric in different moisture content from absolutely dry to 100 % moisture content individually were given below as Equations 2 to 6:

$$R_{(absolutely\ dry)} = (-100,617 + 49,867 * \text{Specific heat (J/gK)} + 29,166 * \text{Fiber density } (d_f)\ (g/cm^3) + 17,298 * \text{Fabric thickness (h) (mm)} - 0,003 * \text{Loop density (number of loop/cm}^2\text{)}) \quad \mathbf{(2)}$$

$$R_{(\%25)} = (-261,426 + 118,012 * \text{Specific heat (J/gK)} + 80,006 * \text{Fiber density } (d_f)\ (g/cm^3) + 7,357 * \text{Fabric thickness (h) (mm)} - 0,003 * \text{Loop density (number of loop /cm}^2\text{)}) \quad \mathbf{(3)}$$

$$R_{(\%50)} = (-189,664 + 87,877 * \text{Specific heat (J/gK)} + 53,949 * \text{Fiber density } (d_f)\ (g/cm^3) + 10,368 * \text{Fabric thickness (h) (mm)}) \quad \mathbf{(4)}$$

$$R_{(\%75)} = (-160,473 + 74,917 * \text{Specific heat (J/gK)} + 44,037 * \text{Fiber density } (d_f)\ (g/cm^3) + 11,270 * \text{Fabric thickness (h) (mm)} + 0,002 * \text{Loop density (number of loop /cm}^2\text{)}) \quad \mathbf{(5)}$$

$$R_{(\%100)} = (-153,549 + 71,868 * \text{Specific heat (J/gK)} + 41,552 * \text{Fiber density } (d_f)\ (g/cm^3) + 11,381 * \text{Fabric thickness (h) (mm)} + 0,003 * \text{Loop density (number of loop /cm}^2\text{)}) \quad \mathbf{(6)}$$

It can be seen from Equation 2 to 6 that fiber density, specific heat, loop density and fabric thickness are the factors determining the thermal resistance value. With increasing specific heat and fiber density, thermal resistance of the fabric increases. Thermal resistance of the fabric increase when the fabric thickness increased in all moisture level, due to the linear relationship between the resistance and the fabric thickness. Figure 6- 10 show the scatter plots of predicted values versus experimental values and regression line of Equation 2-6.

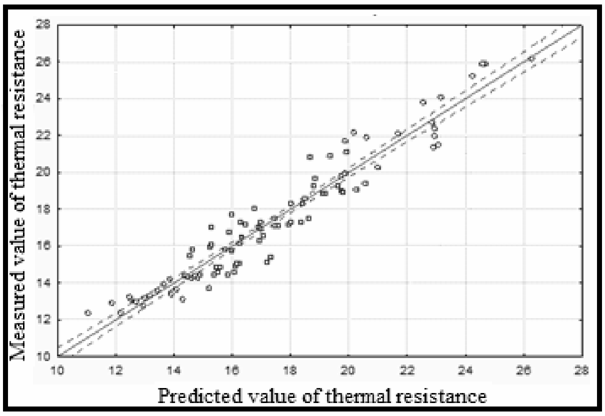

Figure 6. Predicted and measured value of thermal resistance (absolutely dry) (R^2= 0,925)

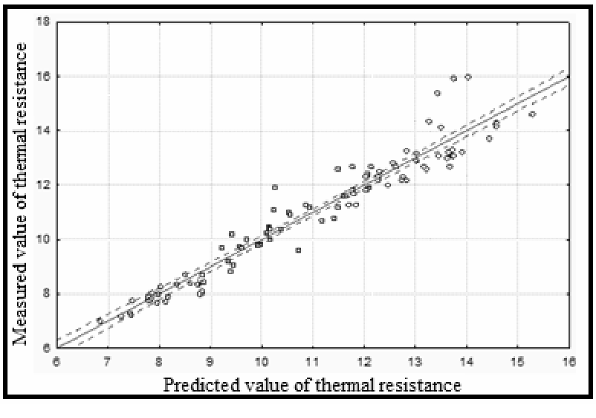

Figure 7. Predicted and measured value of thermal resistance (%25 moisture) (R^2= 0,927)

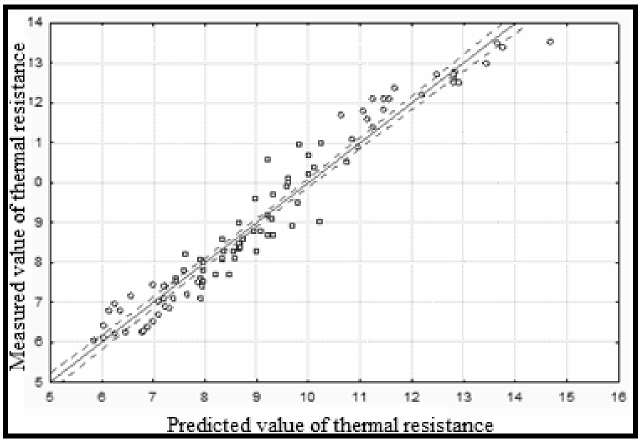

Figure 8. Predicted and measured value of thermal resistance (%50 moisture) (R^2= 0,927)

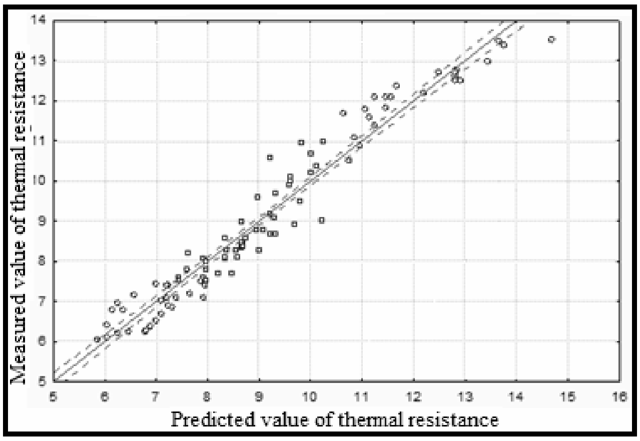

Figure 9. Predicted and measured value of thermal resistance (%75 moisture) (R^2= 0,958)

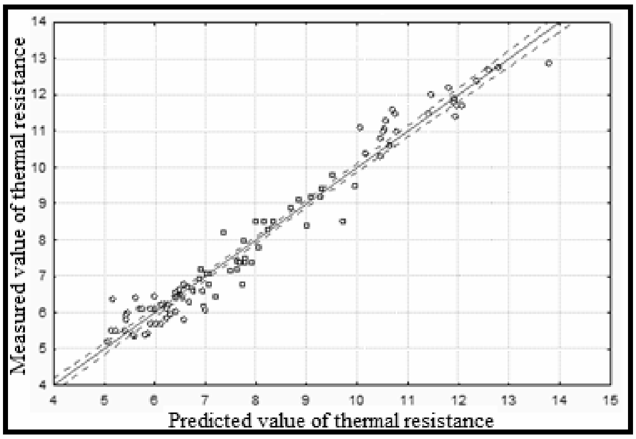

Figure 10. Predicted and measured value of thermal resistance (%100 moisture) (R^2= 0,961)

The relation between the thermal resistance and loop density was negative in Equation 2 and 3, whereas in Equation 5 and 6 the relation was positive. With decreasing loop density, fabric becomes looser, yarn amount in the unit area decreases and air amount in the fabric increases as well. Due to greater air amount of lower loop density fabric, thermal resistance of the fabric increases for absolutely dry and the fabric in 25% moisture content. At 50% moisture level (Equation 4), loop density of the fabric was not significant at 95% confidence interval, so it was omitted. As the loop density of the fabric increase fabric will have less air, so for 75% and 100% moisture level, less air will replace with water, therefore thermal resistance will increase.

Table 5 shows the R, R^2, adjusted R^2 and p- values (%95 confidence interval) of all models. As it can be seen from the Table 5 the R^2 values of the equations are quite high, the models are significant at %95 confidence interval ($p \leq 0{,}05$). So the equations are convenient for explaining the thermal resistance of the fabric in different moisture content.

Table 5. R, R^2, adjusted R^2 and p- values

	R	**R^2**	**Adj. R^2**	***p- value***
$R_{(fabric)}$	0,873	0,763	0,760	0,000
$R_{(absolutely\ dry)}$	0,962	0,925	0,922	0,000
$R_{(\%25)}$	0,963	0,927	0,924	0,000
$R_{(\%50)}$	0,974	0,927	0,924	0,000
$R_{(\%75)}$	0,979	0,958	0,956	0,000
$R_{(\%100)}$	0,980	0,961	0,959	0,000

4. CONCLUSION

In this study, the differences between the thermal resistances of the single jersey knitted fabrics produced from % 100 cotton, polyester, modal and acrylic fibers in different moisture content were exhibited and the thermal resistances of the fabrics in these conditions were predicted from fabric construction parameters by using regression analysis. Two different regression analyses were performed in the study. In addition to the constructional parameters of the fabrics water content of the fabric also was selected as independent variable in the first analysis. In the second analysis, thermal resistance of the fabric in determined moisture content was predicted individually.

Results show that, specific heat, fiber density, fabric thickness and loop density are the main parameters affecting thermal resistance of the fabric. Thermal resistance of the fabric increase when the fabric thickness increased in all moisture level, due to the linear relationship between the resistance and the thickness. But loop density has different effect on the thermal resistance of the fabrics in different moisture content. With increasing loop density of the fabric, yarn amount in the unit area increases and air amount in the fabric decreases as well. At higher moisture level, fewer airs replaces with water in high loop density fabric. But thermal resistances of lower loop density fabric are higher at lower moisture content due to the higher air content of the fabrics.

Although the regression coefficients of both regression analyses are quite high, the second analysis which predicts the thermal resistance of the fabric at different moisture level individually is better. Equations show that, the structural parameters of the fabric influence the thermal resistance in different moisture content distinctively.

The predicted and the measured values were found very close to each other, and the error values were quite small. It was determined that regression analysis can be used for the prediction of thermal resistance of the single jersey fabrics in different moisture content.

REFERENCES

1. Li, Y., 2001, "The Science of Clothing Comfort", *Textile Progress*, The Textile Institute International, UK. 138p.
2. Özdil, N., Marmaralı, A. and Dönmez Kretzschmar, S., 2007, "Effect of Yarn Properties on Thermal Comfort of Knitted Fabrics", *International Journal of Thermal Sciences*, Vol: 46, pp: 1318–1322.
3. Hes, L. and Loghin, C., 2009, "Heat, Moisture and Air Transfer Properties of Selected Woven Fabrics in Wet State", *Journal of Fiber Bioengineering and Informatics*, Vol: 2 (3), pp: 141 - 149.
4. Stanković, S. B., Popović, D. and Poparić, G. B., 2008, "Thermal Properties of Textile Fabrics Made of Natural and Regenerated Cellulose Fibers", *Polymer Testing*, Vol: 27, pp: 41–48.
5. Çil, M.G., Nergis, U.B. and Candan, C., 2009, "An Experimental Study of Some Comfort-Related Properties of Cotton--Acrylic Knitted Fabrics", *Textile Research Journal*, Vol: 79(10), pp: 917–923.
6. Čiukas, R., Abramavičiūtė, J. and Kerpauskas, P., 2011, "Investigation of the Thermal Properties of Socks Knitted From Yarns with Peculiar Properties. Part II: Thermal Resistance of Socks Knitted from Natural and Stretch Yarns", *Fibres & Textiles in Eastern Europe*, Vol: 19(3(86)), pp: 64-68.
7. Behera , B. K., Ishtiaque, S. M. and Chand, S., 1997, "Comfort Properties of Fabrics Woven from Ring-, Rotor-, and Friction-Spun Yarns", *Journal of The Textile Institute,* Vol: 88(3), pp: 255-264.
8. Kane, C. D., Patil U. J. and Sudhakar, P., 2007, "Studies on the Influence of Knit structure and Stitch Length on Ring and Compact Yarn Single Jersey Fabric Properties", *Textile Research Journal*, Vol: 77(8), pp: 572–582.
9. Majumdar, A., Mukhopadhyay, S. and Yadav, R., 2010, "Thermal Properties of Knitted Fabrics Made from Cotton and Regenerated Bamboo Cellulosic Fibres", *International Journal of Thermal Sciences*, Vol: 49, pp: 2042-2048.
10. Vigneswaran, C., Chandrasekaran K. and Senthilkumar, P., 2009, "Effect of Thermal Conductivity Behavior of Jute/Cotton Blended Knitted Fabrics"*, Journal of Industrial Textiles*, Vol: 38(4), pp: 289-306.
11. Wang, F., Zhou, X. and Wang, S., 2009, "Development Processes and Property Measurements of Moisture Absorption and Quick Dry Fabrics", *Fibres & Textiles in Eastern Europe*, Vol: 17(2 (73)), pp: 46-49.
12. Zhang, W., Li , J., Chen, W. and Long, S., 1999, "Wetness Comfort of Fine Polypropylene-Fibre Fabrics", *Journal of The Textile Institute*, Vol: 90(2), pp: 252-263.
13. Bedek, G., Salaün, F., Martinkovska, Z., Devaux, E. and Dupont, D., 2011, "Evaluation of Thermal and Moisture Management Properties on Knitted Fabrics and Comparison with a Physiological Model in Warm Conditions, *Applied Ergonomics*, Vol: 42, pp: 792-800.
14. Uçar, N. and Yılmaz, T., 2004, "Thermal Properties of 1×1, 2×2, 3×3 Rib Knit Fabrics", *Fibres & Textiles in Eastern Europe*, Vol: 12 (3), pp: 34-38.
15. Oğlakçıoğlu, N. and Marmaralı, A., 2007, "Thermal Comfort Properties of Some Knitted Structures", *Fibres & Textiles in Eastern Europe*, Vol: 15(5 - 6 (64 - 65)), pp: 94-96.
16. Celcar, D., Meinander, H. and Geršak, J., 2008, "A Study of the Influence of Different Clothing Materials on Heat and Moisture Transmission Through Clothing Materials, Evaluated Using a Sweating Cylinder", *International Journal of Clothing Science and Technology*, Vol: 20 (2), pp: 119-130.
17. McGregor, B.A. and Postle, R., 2008, "Mechanical Properties of Cashmere Single Jersey Knitted Fabrics Blended with High and Low Crimp Superfine Merino Wool", *Textile Research Journal*, Vol: 78(5), pp: 399-411.
18. Cubric, I. S., Skenderi , Z., Mihelic-Bogdanic, A. and Andrassy, M., 2012, "Experimental Study of Thermal Resistance of Knitted Fabrics", *Experimental Thermal and Fluid Science*, Vol: 38, pp: 223-228.
19. Chen, Y.S., Fan, J. and Zhang, W., 2003, "Clothing Thermal Insulation During Sweating", *Textile Research Journal*, Vol: 73(2), pp: 152-157.
20. Hes, L. and Araujo M. De, 2010, "Simulation of the Effect of Air Gaps Between the Skin and a Wet Fabric on Resulting Cooling Flow", *Textile Research Journal*, Vol: 80(14), pp: 1488–1497.
21. Oğlakçıoğlu, N. and Marmaralı, A., 2010, "Thermal Comfort Properties of Cotton Knitted Fabrics in Dry and Wet States", *Tekstil ve Konfeksiyon*, Vol: 3, pp: 213-217.
22. Ziegler, S. and Kucharska-Kot J., 2006, "Estimation of the Overall Heat-Transfer Coefficient Through a Textile Layer", *Fibres & Textiles in Eastern Europe*, Vol: 14 (5 (59)), pp: 103-106.
23. Dias, T. and Delkumburewatte, G. B., 2007, "The Influence of Moisture Content on the Thermal Conductivity of a Knitted Structure"*, Measurement Science and Technology*, Vol: 18, pp: 1304–1314.
24. Militky, J. and Křemenáková, D., 2008, "Thermal Conductivity of Wool/Pet Weaves", *HEFAT2008, 6th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics*, 30 June- 2 July 2008, Pretoria, South Africa
25. Bhattacharjee, D. and Kothari, V. K., 2009, "Heat Transfer Through Woven Textiles", *International Journal of Heat and Mass Transfer*, Vol: 52, pp: 2155–2160.
26. Mohammadi, M., Banks-Lee P. and Ghadimi, P., 2003, "Determining Effective Thermal Conductivity of Multilayered Nonwoven Fabrics", *Textile Research Journal*, Vol: 73(9), pp: 802-808.
27. Banks-Lee, P., Mohammadi M. and Ghadimi, P., 2004, "Utilization of Air Permeability in Predicting the Thermal Conductivity", *INJ,* Vol: Summer 2004, pp: 28-33.
28. Kanat, Z. E., 2013, A Study on Prediction and Modellling of Thermal Resistance of Knitted Fabrics in Different Moisture Content, PhD Thesis, Ege University Graduate School of Natural and Applied Science, Turkey, 150 p.
29. Ergün, M., 1995, "Application of Statistics in Scientific Research: SPSS for WINDOWS", pp: 107-109.