CHARACTERIZATION AND STATISTICAL MODELLING OF THERMAL RESISTANCE OF COTTON/POLYESTER BLENDED DOUBLE LAYER INTERLOCK KNITTED FABRICS

by

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The aim of this study was to analyse and model the effect of knitting parameters on the thermal resistance of cotton/polyester double layer interlock knitted fabrics. Fabric samples of areal densities ranging from 310-495 g/m² were knitted using yarns of three different cotton/polyester blends, each of two different linear densities by systematically varying knitting loop lengths for achieving different cover factors. It was found that by changing the polyester content in the inner and outer fabric layer from 40 to 65% in the double layer knitted fabric has statistically significant effect on the fabric thermal resistance. Fabric thermal resistance increased with increase in relative specific heat of outer fabric layer, yarn linear density, loop length, and fabric thickness while decrease in fabric areal density. It was concluded that response surface regression modelling could be successfully used for the prediction of thermal resistance of double layer interlock knitted fabrics. The model was validated by unseen data set and it was found that the actual and predicted values were in good agreement with each other with less than 10% absolute error. Sensitivity analysis was also performed to find out the relative contribution of each input parameter on the air permeability of the double layer interlock knitted fabrics.

Key words: *thermal resistance, response surface regression, modelling, double layer interlock knitted fabric, cotton/polyester*

Introduction

The primary needs of human being include textiles as a major commodity. It comprises all the items used to protect the body from external environment. Textiles are used to cover as well as protect the body. When the external climatic conditions outmatch the body requirements, some specific fabrics are used to provide the optimum body demands for better comfort feelings. Comfort can be defined as *a pleasant state of psychological, physiological, and physical harmony between a human being and the environment* [1]. Clothing plays a vital role in thermoregulatory process as it alters heat loss from the skin and also changes the moisture loss from skin [2].

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Different researchers investigated the effect of fiber, yarn and fabric properties on the thermal comfort performance of different fabrics [3-9]. Cimilli *et. al.* [9] investigated the effect of material type used for thermal comfort properties of plain jersey socks by modal, micro-modal, bamboo, soybean, chitosan, viscose, and cotton fibers. The results obtained suggested that there was statistical significant difference between the fiber type and the thermal resistance of fabrics. Schneider *et al.* [10] investigated the thermal conductivity of different fibers under moist conditions. Wan *et al.* [11], Schacher *et al.* [12], and Ramakrishnan *et al.* [13] explained the effect of fiber fineness on thermal resistance of fabrics. According to them, the micro-denier fiber gives low thermal conductivity and higher thermal resistance. Oglakcioglu *et al.* [14] studied the thermal comfort properties of 1×1 rib knit fabrics with different fiber blend ratios of cotton and angora fiber.

Pac *et al.* [15] studied the effect of fiber morphology, yarn and fabric structure on thermal comfort properties of fabric. Ozdil *et al.* [16] investigated the effect of different yarn parameters on thermal comfort of 1 × 1 rib knitted fabric. They explained that by decreasing yarn linear density and yarn twist, the thermal resistance increases while moisture vapour permeability decreases. Majumdar *et al.* [17] found that by the use of finer yarn for knitted fabric formation of plain, rib and interlock structures by blend of bamboo and cotton fibers, the thermal conductivity of fabric reduces.

Khoddami *et al.* [18] explained that by the use of hollow fiber, the fabric thickness increases which increases the fabric thermal resistance. Greyson [19] and Havenith [20] presented their findings that thermal resistance increases by increasing the air entrapped in the fabric as well as fabric thickness. Ucar and Yilmaz [21] have worked on thermal insulation properties of different rib structures made from cotton. Oglakcioglu and Marmarali [22] have studied the thermal comfort properties of different knitting structures. The structures under considerations were single jersey, interlock and 1×1 rib constructions with polyester and cotton fibers. They explained that interlock structure in both fiber types provide the higher thermal resistance due to more thickness of fabric. Afzal *et. al.* [6] studied the thermal resistance properties of interlock knitted fabrics. They reported that fiber type have statistical significant influence on the thermal resistance of the interlock knitted fabrics.

It is observed that no study has been carried out on the influence of fiber, yarn, and fabric properties on thermal resistance of the double layer interlock knitted fabrics. Therefore, the objective of this study is to determine the effect of fiber type, composition, yarn, and fabric properties on thermal resistance of the double layer interlock knitted fabrics and statistically model them for prediction purposes in future.

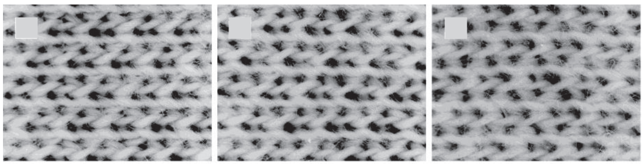
Experimental

Yarns used for knitting

Polyester/cotton blended yarns of 29.5 tex (Ne 20/1) and 24.6 tex (Ne 24/1) with blending ratios of 40:60, 52:48, and 65:35 were used for knitting the double layer fabric samples. The twist multiplier for each yarn linear density of different blend ratios was kept the same *i. e.*, 3.45 and 3.47 for 29.5 tex and 24.6 tex, respectively, with same raw materials and spinning machines setting.

Fabric knitting

The as-spun yarns were used to produce eighteen different double layer interlock fabrics with three different tightness levels (tight, medium, and slack) constituting loop lengths of 3.33 ± 0.03 mm, 3.38 ± 0.01 mm, and 3.68 ± 0.03 mm. The change in fabric structures with different tightness factors is evident from fig. 1. The samples were fabricated in such a construction that polyester content percentage was lower in exterior layer as compared with interior layer of double layer interlock fabric. All the samples were knitted on double cylinder Jacquard circular interlock machine with 18 gauge, 30 inches diameter, 1728 total needle count and a positive yarn feeding system.



(a) (b) (c)

Figure 1. Fabric structures with different tightness factor K; (a) K = 16.24, (b) K = 16.04, and (c) K = 14.73

Fabric processing

The fabric samples were half-bleached for 10 minutes at 110 °C, followed by rinsing. The polyester dyeing was carried out with disperse dye. After dyeing of polyester content, the fabric samples were reduction cleared followed by cotton dyeing with reactive dyes in the presence of anti-crease and washing-off with detergent. After dyeing, the fabric samples were dried and stabilized in compactor at 110 °C temperature and speed of 22 m per minute.

Fabric testing

The samples were pre-conditioned in hot-air oven for four hours before conditioning in standard atmosphere according to ASTM D 1776 [23]. The stitch length of the fabric was calculated from loop length of 150 stitches. The thermal resistance testing was performed on SDL Atlas M259B sweating guarded hotplate [24] according to ISO 11092:2014 [25]. This instrument is also known as skin model used to simulate the mass and heat transfer processes which occur next to the skin surface. The samples were placed on the thermal plate enclosed in a controlled environment. The samples were tested in standard conditions for the thermal resistance which were 20 ± 0.1 °C air temperature, 65 ± 3% RH, 35 ± 0.1 °C thermal guard temperature, 1.00 ± 0.05 m/s air speed, and 35 ± 0.1 °C measuring unit temperature. Total five readings for each fabric sample were obtained and mean value was used.

Table 1. Fabric constructions used for modelling the thermal resistance of double layer interlock knitted fabrics

No.	Pi	Po	Ci	Co	Tt	l	t	m
1	52	40	2.78	3.04	29.2	3.35	1.28	464.6
2						3.39	1.30	449.5
3						3.66	1.30	405.5
4					24.4	3.32	1.19	371.4
5						3.39	1.20	352.2
6						3.70	1.18	316.5
7	65		2.51		29.2	3.33	1.27	470.9
8						3.37	1.28	453.0
9						3.67	1.24	395.5
10					24.4	3.36	1.21	392.2
11						3.37	1.19	372.1
12						3.64	1.17	331.1
13		52		2.78	29.2	3.30	1.28	488.1
14						3.38	1.26	462.7
15						3.66	1.24	403.6
16					24.4	3.32	1.18	393.1
17						3.36	1.18	378.5
18						3.70	1.20	356.5

Results and discussion

The results obtained from the experiments are shown in tab. 1. The Pearson correlation coefficients (PCC) between fabric thermal resistance and different yarn and fabric parameters are given in tab. 2. Initial statistical analyses on the obtained data showed that polyester content percentage in interior layer and exterior layer were highly

Table 2. Correlation between fabric thermal resistance and different yarn and fabric parameters

Parameter	PCC	p-value
Po	–0.644	0.000*
Pi	–0.376	0.000*
Tt	0.050	0.638
l	0.234	0.027*
t	0.059	0.584
m	–0.240	0.023*
Co	0.644	0.000*
Ci	0.376	0.000*

* – statistically significant

correlated with the specific heat of the interior yarn and exterior yarn, respectively. The PCC values for both the parameters were found the same in correlation analysis having p-value less than 0.05 for both of them, which explains their significant effect on the fabric thermal resistance of the double layer knitted fabrics. The reason lies in the fact that these parameters were actually interdependent and are influenced by variation in either variable. Therefore, the polyester content percentage was replaced with the specific heat in this study to explain the influence of both parameters in double layer knitted fabric.

According to the correlation analysis, the relation between the polyester content in interior layer and exterior layer and fab–ric areal density were inversely proportional while yarn linear density, fabric stitch length, fabric thickness, specific heat of interior yarn, and specific heat of exterior yarn were found in direct proportion with the fabric thermal resistance. The p-value obtained for all the parameters except yarn linear density and fabric thickness were less than α value (0.05) expressing statistically significant effect on fabric thermal resistance of double layer knitted fabrics.

In addition, it was observed that yarn linear density have significant correlation with fabric thickness and areal density with PCC value of 0.881 and 0.816, respectively, at p-value of 0.000 for both parameters, while PCC value between fabric thickness and areal density was 0.796 at p-value of 0.000. It is evident from the positive PCC value between yarn linear density and fabric thickness that by increase in yarn linear density, the fabric thickness increases hence increases the fabric areal density.

The measured thermal resistances of the double layer knitted fabrics were within the range of 4.0-19.0 m^{2}K/mW. It was observed from correlation analysis (tab. 2) that specific heat of both sides of yarns were the dominating parameters which highly influenced the thermal resistance of double layer interlock knitted fabrics followed by fabric areal density, fabric stitch length, fabric thickness, and yarn linear density. It was noted that by increment in specific heat of yarn in any fabric layer, the thermal resistance of double layer knitted fabric increases proportionally and vice versa. This effect is also shown in fig. 2. Textile materials have a range of specific heat values, higher to lower. Their usage depends upon the requirement and areas of application. The influence of increase in specific heat of exterior yarn by changing the raw material is more significant than interior yarn as shown by steepness of the surface plot in fig 2. When the specific heat of the yarns is higher, more heat is absorbed by the yarns for per unit increase in their temperature consequently making a barrier between two mediums and thus less heat is transferred across the fabric leading to better thermal resistance results. The specific heat of exterior yarn has more influence on thermal resistance of double layer knitted fabric as compared with specific heat of in-

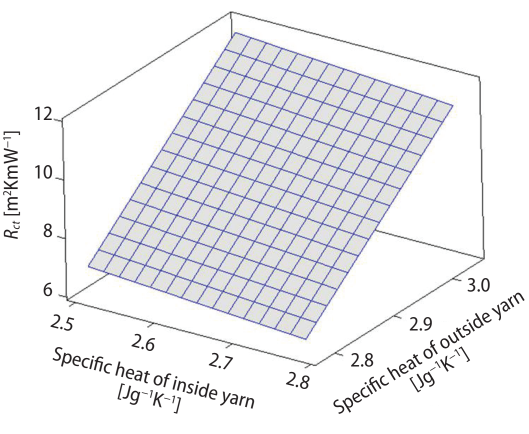


Figure 2. Surface plot of thermal resistance *vs.* specific heat of interior and exterior yarn

terior yarn. The reason may be explained on the fact that interior yarn has direct contact surface with the skin while exterior yarn has no direct contact rather that it has connections with loops of interior yarn. This loop to loop contact surface is far lesser than interior yarn contact surface with skin, which reduces the rate of heat transfer from interior to exterior yarn through conduction mechanism. This structure may help in formation of heat barrier and resultantly increases the thermal resistance by increase in specific heat of exterior layer.

The relation of yarn linear density, stitch length and fabric thickness were in direct proportion with thermal resistance of the double layer knitted fabrics. The relation between thermal resistance of the double layer knitted fabric *vs.* stitch length and yarn linear density is shown in fig. 3. It was noticeable that by increasing the stitch length and yarn linear density, the thermal resistance of the double layer knitted fabric increases. Higher stitch lengths result in bulkier fabrics which entrap higher amount of air, leading to better thermal resistance of the fabric. The double layer structure comprises of two individual fabric layers which are joined by a third group of yarn in between them to form the required structure. By the increase in yarn linear density, the loop stiffness increases which increases the fabric thickness by changing the pore geometry of the structure. This change in pore geometry ultimately increases the fabric thermal resistance.

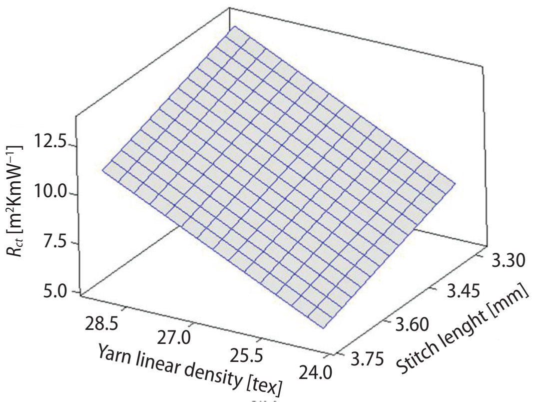


Figure 3. Surface plot of thermal resistance *vs.* stitch length and yarn linear density

The fabric thickness was found in direct proportion with the thermal resistance of double layer knitted fabrics as shown in fig. 4. Thicker fabrics offer more resistance to heat flow across the fabric. Since air is a bad conductor of heat, its presence in the fabric structure results in better thermal resistance.

It is evident that by increase in areal density, the thermal resistance decreases steeply. This might be explained on the fact that by increase in areal density, the conduction mechanism becomes more prominent due to increase in matter and decrease in air-gaps within the structure. Therefore, by the increase in yarn linear density, the areal density and fabric thickness increases but the overall thermal resistance of the double layer knitted structure decreases.

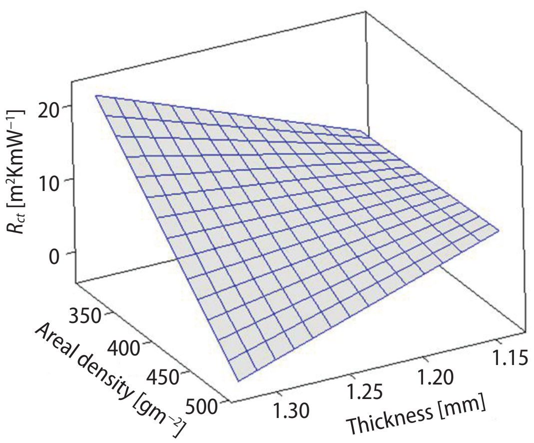


Figure 4. Surface plot of thermal resistance *vs.* fabric thickness and areal density

Development of the prediction models

The total number of datasets consists of 90 input/output patterns comprising 18 individual samples with 5 replicates each. The data was subdivided into two groups, one for the development of the model while the other for the validation of the developed model. The datasets for the validation were randomly selected and were separated for validation of the developed models. Minitab statistical software was applied for data analysis and development of regression models.

In order to make sure that the variables selected for development of model were significant, best subset regression analysis was performed on the data before development of the model. Best subset regression is a statistical tool to sort out the less significant variables from the data and help to develop model with fewer variables. The results of the best subset regression analysis are given in tab. 3.

Table 3. Best subset regression models

No.	V	R^2	R^2 (adj.)	C_p	S	Tt	l	t	m	Co	Ci
1	1	38.6	37.8	19.9	3.0					–	
2	1	7.9	6.7	65.4	3.7				–		
3	2	42.0	40.4	16.9	2.9				–	–	
4	2	41.3	39.7	17.9	3.0		–			–	
5	3	47.3	45.1	11.0	2.8	–			–	–	
6	3	42.8	40.4	17.7	2.9			–	–	–	
7	4	52.5	49.8	5.3	2.7	–	–		–	–	
8	4	47.5	44.5	12.8	2.8	–			–	–	–
9	5	54.1	50.8	5.0	2.7	–	–		–	–	–
10	5	52.6	49.2	7.2	2.7	–	–	–	–	–	
11	6	54.1	50.0	7.0	2.7	–	–	–	–	–	–

V – variables, S – standard deviation, C_p – Mallows C_p

The results of best subset regression analysis suggested that yarn linear density, fabric stitch length, areal density, specific heat of interior yarn, and exterior yarn were the most suitable combination of input variables for the development of thermal resistance model for double layer knitted fabrics, because it showed lowest Mallows C_p and standard deviation while higher values of R^2 and R^2 adjusted values.

Response surface regression analysis was utilized for the development of the models for thermal resistance of the double layer knitted fabrics. Response surface regression is selected instead of multiple linear regressions, because of the fact that the former is a fully capable tool to model linear as well as non-linear relationships of the variables which is not possible with the latter. As suggested by best subset analysis, the yarn linear density, fabric stitch length, areal density, specific heat of interior yarn, and exterior yarn were taken as input parameters to develop first model for the thermal resistance of the double layer knitted fabrics. The quadratic model (M1) developed using these input parameters, can be considered as prediction model for the thermal resistance, R_{ct}, of the double layer knitted fabrics, and is given in eq. (1).

$$R_{ct} = -251.11 + 3.31Tt - 5.93l + 0.52m - 69.36Co + 162.88Ci - 0.01Tt\,m + \\ +0.21m\,Co - 0.41m\,Ci \tag{1}$$

The coefficient of determination, R^2 value (adj.), for the eq. (1) was found equal to 92.26% which explains that approximately 93% variation in the data can be explained by the model. The interactions of input variables which were found non-significant having p-value more than 0.05 were deleted from the final developed model. All the terms in the final developed model have p-value less than 0.05 which confirmed their significant contribution in the model of thermal resistance of double layer knitted fabrics. The regression coefficients in coded units for eq. (1) are given in tab. 4.

Another model was developed based on interaction terms for the prediction of fabric thermal resistance. In this interaction model (M2), only significant terms having p-value less than 0.05 were included and the rest were excluded. This model is given in eq. (2).

$$R_{ct} = -127.04 - 20.00Tt - 134.45t + \\ +1.54m - 46.96Co + 167.72Ci + \\ +16.90Ct - 0.78tm + \\ +0.16mCo - 0.42mCi \quad (2)$$

The fitting of developed model was obtained approximately equal to the previous model, eq. (1), with coefficient of determination, R^2 value (adj.), of 92.82%. The estimated regression coefficients in coded units for this model are given in tab. 5.

Table 4. Estimated regression coefficients in coded units for quadratic based model type

Term	Coefficient	SE coefficient	t-value	p-value
Constant	9.53	0.34	27.84	0.000*
Tt	2.74	0.51	5.42	0.000*
l	–1.29	0.50	–2.56	0.013*
m	–8.09	1.17	–6.93	0.000*
Co	2.06	0.17	12.03	0.000*
Ci	–0.33	0.18	–1.88	0.065
Tt·m	–1.18	0.53	–2.24	0.029*
m·Co	2.45	0.29	8.51	0.000*
m·Ci	–5.13	0.27	–19.11	0.000*

* – statistically significant

Table 5. Estimated regression coefficients in coded units for interaction based model type

Term	Coefficient	SE coefficient	t-value	p-value
Constant	9.07	0.30	30.27	0.000*
Tt	1.90	0.27	6.94	0.000*
t	0.36	0.61	0.60	0.551
m	–5.92	0.50	–11.85	0.000*
Co	2.37	0.15	15.50	0.000*
Ci	–0.27	0.16	–1.70	0.094
C × *t*	3.68	1.08	3.40	0.001*
t × *m*	–6.36	1.28	–4.98	0.000*
m × *Co*	1.88	0.29	6.43	0.000*
m × *Ci*	–5.27	0.25	–20.84	0.000*

* – statistically significant

Validation of the models

The validation datasets which were separated from the main data before the development of the models were used to evaluate the performance of the developed models. The range of the input parameters used for the development and validation of the statistical models of double layer interlock fabrics are given in tab. 6.

It was observed that predicted values were in close approximation with actual values of thermal resistance of double layer interlock knitted fabrics depicting good prediction level of the developed models. The percentage error was calculated to determine the deviation between predicted and actual values using the eq. (3):

Table 6. Range of input parameters used in the statistical model development of double layer interlock fabrics

Parameter	Range
Tt	24.4-29.2
l	3.3-3.7
t	1.14-1.32
m	311.9-492.3
Co	2.78-3.04
Ci	2.51-2.78

$$\text{Percentage error} = \frac{\text{Actual value} - \text{predicted value}}{\text{Actual value}} \times 100 \quad (3)$$

The results of the thermal resistance validation along with the percentage error are given in tab. 7. The average percentage error obtained for quadratic (M1) and interaction (M2) models were 6.5% and 4.1%, respectively. These results confirmed that predictability of the models on unseen data is quite satisfactory. Furthermore, a fitted line plot of all models is shown in fig. 5, which shows good agreement between predicted and actual values of fabric thermal resistance.

Table 7. Predicted and actual values of thermal resistance of double layer interlock knitted fabrics

No.	*Ci*	*Co*	*Tt*	*l*	*t*	*m*	R_{ct} A.V.	M1		M2	
								P.V.	%E	P.V.	%E
1				3.65	1.30	403.4	15.4	12.9	16.1	16.0	3.6
2				3.66	1.30	406.2	14.4	12.5	13.2	15.5	7.8
3	2.782		29.21	3.65	1.30	402.5	15.6	13.0	16.4	16.1	3.2
4				3.67	1.32	409.3	14.6	12.0	17.6	15.8	8.2
5		3.038		3.66	1.30	406.2	13.9	12.5	10.1	15.5	11.6
6				3.37	1.20	372.2	9.9	9.8	1.3	9.8	1.0
7				3.38	1.20	368.3	9.4	9.7	2.8	9.7	2.7
8				3.39	1.20	373.9	9.6	9.6	0.2	9.9	2.7
9				3.37	1.18	371.6	10.0	9.7	2.8	10.0	0.4
10	2.506		24.40	3.36	1.18	374.6	9.7	9.8	1.3	10.2	5.1
11				3.28	1.18	388.5	6.8	7.0	3.2	6.8	0.6
12				3.32	1.18	388.5	7.0	6.8	3.1	6.8	3.5
13		2.782		3.29	1.18	397.3	6.6	6.6	0.5	6.9	3.9
14				3.39	1.18	394.4	6.5	6.1	5.5	6.8	5.0
15				3.31	1.18	396.6	6.7	6.4	3.9	6.8	2.2
Average error %								6.5		4.1	

A.V. – actual value, M1 – 1st model, M2 – 2nd model, P.V. – predicted value, E – error

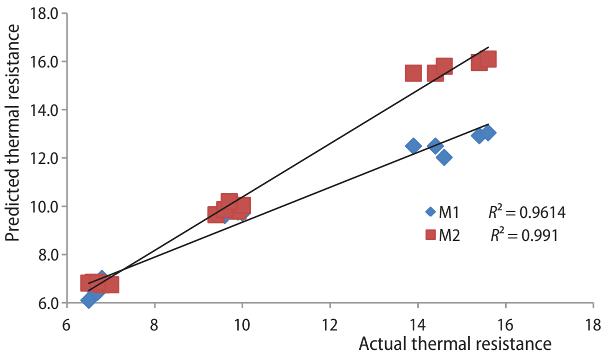


Figure 5. Fitted line plot between predicted and actual values of thermal resistance of double layer interlock knitted fabrics

Sensitivity analysis

Sensitivity analysis was carried out to judge the relative influence of different factors on the thermal resistance of double layer interlock knitted fabrics by using response surface regression based model. The effect of single input variable at maximum and minimum values on thermal resistance was considered ensuring all other input variables at their middle level values. The range of the values of thermal resistance obtained by changing single input variable explained its relative influence on the response variable as percentage of the full range of the thermal resistance values. The levels of the input variables used in the sensitivity analysis are given in tab. 8.

The range of the thermal resistance of data along with minimum and maximum values is shown in tab. 9. The contribution ratios (C.R) of the input variables were calculated by dividing the range of single input variable by the overall range of the thermal resistance data as mentioned in the eq. (4):

$$C.R = \frac{\text{Predicted range of the } R_{ct} \text{ by the variable}}{\text{Overall range of } R_{ct}} \tag{4}$$

The relative C.R percentage (C.R%) of single variable was calculated considering the C.R of each variable with respect to other variables according to the following equation:

$$C.R\left(\%\right) = \frac{C.R \text{ of single variable}}{\text{Sum of all variables } C.R} \times 100 \tag{5}$$

The obtained relative C.R% was plotted in form of pie chart to illustrate the relative influence of the variables in percentage on thermal resistance of double layer fabric structures as shown in fig. 6.

It was evident from the sensitivity analysis that the percentage relative influence of fabric areal density, yarn linear density, specific heat of exterior yarn, stitch length and specific heat of interior yarn on thermal resistance of the double layer knitted interlock fabric structure was 56%, 19%, 14%, 09%, and 02%, respectively. The percentage influence of areal density of the fabric is highest among all the other parameters. The concluded results affirm the established logic that by increasing areal density of the fabric, the air-gaps and fabric thickness deceases. The specific heat of exterior yarn play a pivotal role in determination of thermal conductance and slight variation in it would cause significant change in thermal resistance of the fabric because of change in the exterior heat conductance of the fabric structure. Whenever, the exterior heat conductance is lower, the overall structure thermal resistance ability will be improved. Similarly the yarn linear density and stitch length significantly affects the area of air channel in the fabric structure owing to which its relative importance is significantly high. The quantification of input factors and their relative influence on the thermal resistance can assist for accurate prediction and optimization of the thermal resistance of double layer interlock knitted fabrics.

Table 8. Input parameters along with extreme levels and means for sensitivity analysis

Input variable	Minimum level	Maximum level	Mid-level (mean)
Yarn linear density, [tex]	24.40	29.24	26.82
Stitch length, [mm]	3.28	3.72	3.50
Fabric thickness, [mm]	1.14	1.32	1.23
Areal density, [gm^{-2}]	311.9	492.3	402.1
Specific heat of interior yarn, [Jg^{-1}K^{-1}]	2.51	2.78	2.65
Specific heat of exterior yarn, [Jg^{-1}K^{-1}]	2.78	3.04	2.91

Table 9. Output factor along with extreme levels and means for sensitivity analysis

Output factor	Minimum level	Maximum level	Range
Thermal resistance of double layer interlock fabric, R_{ct}, [m^{2}K mW^{-1}]	4.3	18.9	14.6

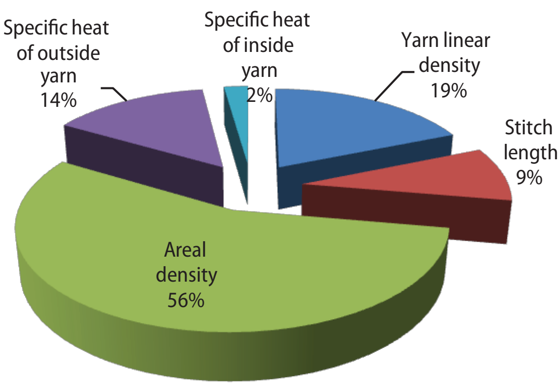


Figure 6. Relative C.R% of input parameters on thermal resistance of double layer interlock knitted fabrics

Conclusions

It was concluded that the change in polyester/cotton blend ratio in inner and outer layer of double layer knitted fabric significantly affect the thermal resistance. The fabric having higher ratio of cotton in exterior layer can provide better thermal resistance owing to higher specific heat value of cotton than polyester. The increase in yarn linear density [tex] results in increase in yarn fluffiness and fabric thickness leading to better thermal resistance. The increase in knitting loop-length results in decrease in number of yarn loops per unit fabric area, leading to lower fabric volume density, and better thermal resistance. The influence of fabric areal density was found significantly higher than other parameters with inverse relation with the thermal resistance of double layer interlock structure. The response surface regression models developed in this study exhibit good predictability of the thermal resistance with a very small absolute error. According to the sensitivity analysis, the relative influence of fabric areal density, yarn linear density, specific heat of exterior yarn, stitch length, and specific heat of interior yarn was found to be 56%, 19%, 14%, 09%, and 02%, respectively. Further work can be carried out on utilizing diversified materials and weave structures for development of generic model with the same technique for all the knitting structures.

Nomenclature

Ci – specific heat of interior yarn, [$Jg^{-1}K^{-1}$]
Co – specific heat of exterior yarn, [$Jg^{-1}K^{-1}$]
l – stitch length, [mm]
m – fabric areal density, [gm^{-2}]
Pi – polyester content in interior layer, [%]
Po – polyester content in exterior layer, [%]
R^2 – coefficient of determination
R_{ct} – fabric thermal resistance, [m^2KmW^{-1}]
Tt – yarn linear density, [tex]
t – fabric thickness, [mm]

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