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Neuro-fuzzy Modelling and Experimental Study of the Physiological Comfort of Green Cotton Fabric Based on Yarn Properties

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A B S T R A C T

In textile and garment industry, the physiological comfort of fabric as one of the important parameters, can be improved by the fabric finishing treatment. Nevertheless, the toxic chemicals produced in this process leads to the pollution of the environment. Therefore, this study aims to improve the physiological comfort of the cotton fabric without applying the finishing process as green technology. Accordingly, air permeability and moisture transfer as two important parameters of the fabric physiological comfort are evaluated with the structural parameters of the cotton yarn using experimental and theoretical procedures. For theoretical evaluations, a novel neuro-fuzzy network (ANFIS) is proposed and used for modelling and estimation. The structural parameters of yarn are the yarn linear density, yarn twist and fineness of fibers, which are defined as inputs and air permeability and moisture transfer of the cotton samples are considered as the outputs of developed ANFIS model. According to the experimental and modeling results, the fiber fineness, yarn linear density (Ne) and yarn twist have the same effect on the output parameters. It is also found that both parameters of the physiological comfort sensory can be improved effectively without finishing process. Simulation results show the novel proposed ANFIS that has high learning capability, fast convergence and accuracy greater than 99% and negligible error value smaller than of 1% can be reasonably used in textile industry. In addition, for the winter garments, the optimum points of turns per meter (T.P.M) coefficient, English count of yarn, and fibers fineness are 4.5, 25 and 3, respectively.

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1. INTRODUCTION

Nowadays, the environmental pollution concerns are important topics for academic studies and there are many researches in the open literature, accordingly [1-3]. In textile industry, the toxic materials have been used in different processes such as bleaching, sizing, de-sizing, scouring, dying, printing, finishing, anti-static, and anti-wrinkling. Recently, the famous brands of clothing industry have attempted to develop their products based on "Green Technology Methods". In the textile and clothing industry, the green technologies can be applied with the fiber preparation, yarn production, fabric production, dyeing and printing and finishing processes [4]. In garment industry, the clothing comfort as an important parameter is improved by finishing process. The effect of weaving pattern and number of the picking sequences on the wetting, wicking and air permeability (AP) properties of the samples were analyzed.

The effect of moisture finisher on the comfort sensory of woven fabrics was also studied by the researchers [5]. The moisture finishing parameters were analyzed to optimize the sportswear' comfort. The results revealed that when the ethylated alcohol was synthesized as wetting agent with the recipe containing amino silicone polyether copolymer and hydrophilic polymer in the ratio of 1:2 with pH of 5.5 at 600-700 °C temperature, better comfort properties for sportswear is obtained. Hermophysiological comfort and mechanical properties of cotton fabrics for lady's summer apparel were

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evaluated by fabric weight characteristic (number of the warp / weft yarns per inch and yarn count) [6]. The weight of the cotton samples studied in that research was 50 to 80 g/m^2. The main target of that work was to make a balance between two parameters of the yarn count and number of ends and picks per inch in fabric to achieve the appreciate fabric comfort and strength. The results showed that the fabric samples with 60 Ne warp count, 50 Ne weft count, 90 ends/in as warp density and 50 pick/in as weft density have suitable air permeability and mechanical properties [6]. Water vapor resistance and thermal resistance of commercial apparel as comfort parameters were studied based on the fabric structural parameters and fiber type by regression analysis [7-8].

Adaptive neuro-fuzzy inference system (ANFIS) and image processing method as the well-known soft computing techniques have been used in various applications of the function approximation and control in different scopes for the last two decades. [9-11]. There are many published works in the literature about applying ANFIS in the different areas of on-line approximation applications in the textile industry [12-13]. For example, ANFIS was used to predict the bending rigidity of woven fabrics [14]. For this purpose, a set of cotton fabrics used in the clothing industry was de-sized, scoured and relaxed. The weight and thickness and cover factor of fabric were selected as input parameters and the bending rigidity of fabric was considered as the model output.

In the present study physiological comfort is developed based on the new yarn parameters without environmental pollution as a result of finishing treatment elimination. In addition, the improvement of physiological comfort by the yarn parameters is studied here for the first time. the linear density, twist yarn and fineness of fiber are the parameters used in this study as structural parameters of cotton yarn for experimental evaluation of the air permeability and moisture transfer as physiological comfort properties.

Finally, the theoretically analysis was done by an improved ANFIS technique. In this model the linear density, twist yarn and fineness of fibre are input parameters and moisture transfer and air permeability are model outputs .A brief review on the novelties of methodology and ANFIS modeling performed in the present research can be listed as follows:

- A novel ANFIS with fuzzy coefficient in consequent part
- A new parameter learning method with fast convergence
- The new parameters concerning the yarn structure used to evaluate the physiological comfort of fabric.

2. METHODOLOGY

In this research we developed the cotton fabrics with the plain weave structures and different thicknesses by using the cotton yarns with the characteristics presented in Table 1. The characteristics of yarn are measured by an experimental instrument that its name is electronic twist tester (Figure 1). Twist in yarn is essential to hold the fibers together and is added to the spinning and plying processes. In this study, the yarn twist is determined by T.P.M coefficient. In the textile industry the English count of yarn is an indirect method of expressing the size of a cotton yarn. In this system by increasing the yarn number or count, the weight of yarn length decreases. Another parameter is thickness of fabric (mm). This parameter is measured by the thickness gauge presented in Figure 2.

TABLE 1. Characteristics of the cotton yarns used in fabrics

Moisture transfer rate (g/cm^2.h)	Air permeability (ml/cm^2)	Linear density (Ne)	T.P.M coefficient	Fineness (micron)	sample
2.00	26.0	20	4.5	3.2	1
2.10	27.0	20	4.7	3.2	2
2.15	27.0	20	4.8	3.2	3
2.01	26.5	20	4.5	4.2	4
2.20	26.0	20	4.7	4.2	5
2.25	27.7	20	4.8	4.2	6
2.30	27.0	20	4.5	5.3	7
2.20	27.1	20	4.7	5.3	8
2.25	26.9	20	4.8	5.3	9
2.15	27.0	30	4.5	3.2	10
2.17	30.0	30	4.7	3.2	11
2.20	32.0	30	4.8	3.2	12
2.22	31.0	30	4.5	4.2	13
2.19	31.5	30	4.7	4.2	14
2.20	35.0	30	4.8	4.2	15
2.25	35.5	30	4.5	5.3	16
2.22	36.0	30	4.7	5.3	17
2.28	37.0	30	4.8	5.3	18
2.29	37.0	40	4.5	3.2	19
2.30	38.0	40	4.7	3.2	20
2.20	45.0	40	4.8	3.2	21
2.31	33.0	40	4.5	4.2	22
2.30	35.0	40	4.7	4.2	23
2.33	38.0	40	4.8	4.2	24
2.30	37.0	40	4.5	5.3	25
2.37	38.0	40	4.7	5.3	26
2.39	45.0	40	4.8	5.3	27
2.40	37.0	50	4.5	3.2	28
2.39	40.0	50	4.7	3.2	29
2.45	43.0	50	4.8	3.2	30

2.42	43.0	50	4.5	4.2	31
2.41	45.0	50	4.7	4.2	32
2.42	44.0	50	4.8	4.2	33
2.44	46.0	50	4.5	5.3	34
2.46	48.0	50	4.7	5.3	35
2.49	50.0	50	4.8	5.3	36
2.50	65.0	70	4.5	3.2	37
2.49	70.0	70	4.7	3.2	38
2.51	69.0	70	4.8	3.2	39
2.60	70.0	70	4.5	4.2	40
2.58	71.0	70	4.7	4.2	41
2.55	69.0	70	4.8	4.2	42
2.61	73.0	70	4.5	5.3	43
2.62	75.0	70	4.7	5.3	44
2.62	74.0	70	4.8	5.3	45

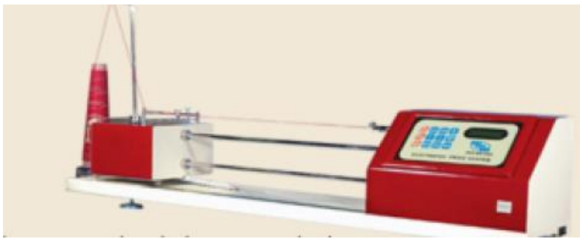

Figure1. Electronic twist tester

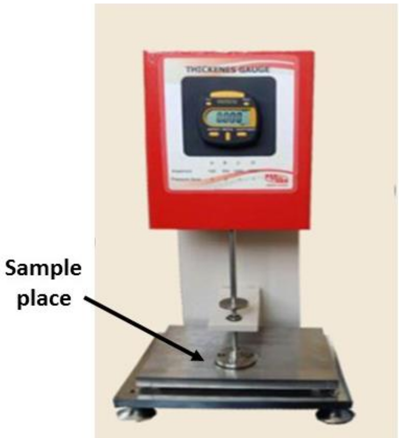

Figure 2. Thickness gauge

The final parameter is Fiber fineness which this parameter is determined by measuring the diameter of a single fiber of yarn using microscope in micron. The two main parameters are used for expressing the physiology comfort of garment. First parameter is "air permeability".

This parameter expresses air transferring through the fabric. Second parameter is "moisture transition" that indicates the transfer of moisture through the fabric. It should be noted that the air permeability and moisture transition parameters have a great importance for the summer clothes. Figure 3 shows the method applied for measuring the moisture transfer of fabric. In this method the sample of fabrics were cut as the specific dimensions of the circular metal containers, then put the fabric firmly on the dish containing 50 ml distilled water, and tighten the container thoroughly with adhesive to allow water vapor to pass through the surface of the fabric, and reweight the set. Then weight the set for every two hours during 6 hours for measuring the amount of discharged steam. The measuring results are presented in Table1.

During the movement due to the rise in metabolic heat, the body begins to sweat; therefore, the quick transferring the steam of the water through the fabric. This property greatly affects the ability of fabric breath and exhausts the excess heat by the fabric. It should be noted that the environment and water temperature is hold at 23ºC and the relative humidity is about 35%. The instrument for measuring the air permeability is presented in Figure 4.

This device is based on the air vacuuming through the sample of the fabric by a vacuum pump. The flow rate of the air passed through the sample is in 20 cm^2 of the surface area of sample, in which the volume of air passed through the sample is determined at a certain pressure. The result of air permeability measuring of samples are showed in Table 1.

In summer, the high metabolic heat is produced in the body and the considerable air permeability in the fabric

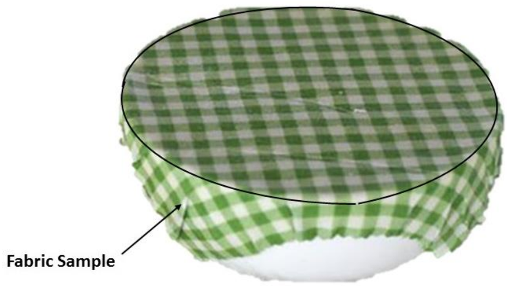

Figure 3. Test method for the moisture transfer measuring of fabric

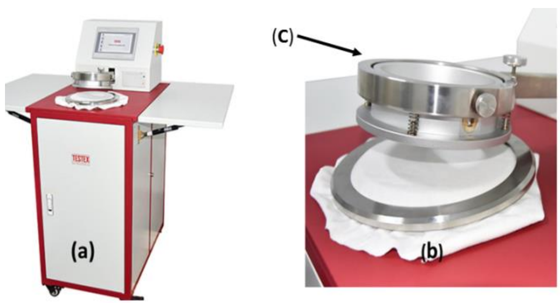

Figure 4. Air permeability tester: (a) Main body of tester, (b) fabric specimen, (c) interchangeable test head

is required in order to allow air flow in clothing for providing the respiratory function in the fabric and keep the person cool. However, in the winter clothes this parameter should be restricted. Due to the high diffusion of the air into the cloth causes a drop of air temperature inside the garment that results the person feels cold in the cloths, which it is a negative factor in the winter for the body comfort.

2. 1. Adaptive Neuro-Fuzzy Inference System

In this section, we introduce our new Adaptive Neuro-Fuzzy Inference System (ANFIS). The fuzzy rules of the proposed ANFIS are as follows:

$R^1: if\ u_1\ is\ \tilde{A}_1\ and\ u_2\ is\ \tilde{B}_1\ then\ \tilde{y}_1 = \tilde{r}_1 + \tilde{p}_1 u_1 + \tilde{q}_1 u_2$

$R^2: if\ u_1\ is\ \tilde{A}_2\ and\ u_2\ is\ \tilde{B}_2\ then\ \tilde{y}_2 = \tilde{r}_2 + \tilde{p}_2 u_1 + \tilde{q}_2 u_2$

where $\boldsymbol{u_1}$ and $\boldsymbol{u_2}$ are network inputs, $\tilde{\boldsymbol{A}}_1$, $\tilde{\boldsymbol{A}}_2$, $\tilde{\boldsymbol{B}}_1$ and $\tilde{\boldsymbol{B}}_2$ are type-1 fuzzy sets. $\tilde{\boldsymbol{y}}_1$ and $\tilde{\boldsymbol{y}}_2$ are the network output. $\tilde{\boldsymbol{r}}_1$, $\tilde{\boldsymbol{p}}_1$ and $\tilde{\boldsymbol{q}}_1$ are the coefficient of the consequent part, that all of them are type-1 fuzzy sets. Figure 5 shows the proposed ANFIS.

All parameters and layers of the proposed ANFIS are the same as traditional ANFIS except the consequent layer. The calculation of the consequent layer in this paper is as follows (General form):

$$\hat{y}_1 = \frac{\sum_{k=1}^{n} \overline{W}^k \left(m_{r_k}\sigma_{r_k} + m_{p_k}\sigma_{p_k} u_1 + m_{q_k}\sigma_{q_k} u_2 \right)}{\sum_{k=1}^{n} \overline{W}^k \left(\sigma_{r_k} + \sigma_{p_k} + \sigma_{q_k} \right)} \qquad (1)$$

where $\boldsymbol{m_{r_k}}$, $\boldsymbol{m_{p_k}}$ and $\boldsymbol{m_{q_k}}$ are the means of Gaussian type-1 fuzzy sets $\tilde{\boldsymbol{r}}_1$, $\tilde{\boldsymbol{p}}_1$ and $\tilde{\boldsymbol{q}}_1$, respectively. Also, $\boldsymbol{\sigma_{r_k}}$, $\boldsymbol{\sigma_{p_k}}$ and $\boldsymbol{\sigma_{q_k}}$ are the variances of Gaussian type-1 fuzzy sets $\tilde{\boldsymbol{r}}_1$, $\tilde{\boldsymbol{p}}_1$ and $\tilde{\boldsymbol{q}}_1$, respectively. The output of one layer before consequent layer from k-th fuzzy rule is shown by $\overline{\boldsymbol{W}}^{\boldsymbol{k}}$. More details of feedforward and learning phase of the proposed ANFIS can be found elsewhere [15].

2. 2. Applying ANFIS for Fabric Physiological and Comfort Sensory Modelling

A mathematical relationship between two (or more) variables or parameters can be obtained by neuro fuzzy networks. For example, if the parameter x affects the y parameter, the mathematical relationship between x and y by applying x as input to the neural network and also y as the desired output can be found. In addition, if the system is dynamic from x to y, we can use the past moments y as input and next to x. In this study, the experimental data extracted from the test results have been used for the proposed ANFIS training and testing. For ANFIS training, there are some steps that have been fully followed, such as data pre-processing, deletion of discarded data, deletion of unimportant fuzzy membership functions, unimportant fuzzy rules and so on.

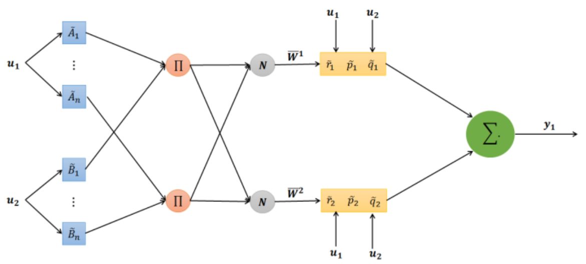

Figure 5. The proposed ANFIS

3. RESULTS AND DISCUSSION

Fabrics woven by fine fibers are softer than those with coarseness fibers and have a relatively smooth surface. In fabrics where the fineness of the fiber is lower in the yarn, the stiffness of the fabric is higher. Therefore, handmade of fabric is not appropriate. Figures 6 and 7 show that there is a relationship between the fineness of fibers produced the fabric and the parameter of air permeability and humidity transfer of the sample. Based on the results, with increasing the fiber diameter, the air permeability and humidity transfer of the fabric are increased. In other words, there are reverse relation between fineness of the fiber and air permeability and humidity transfer of the fabric woven by these fibers.

Fabrics woven from the yarn with linear density of 40 and 50 Ne mainly are used in women's garments. This type of fabric has a high softness. This fabric gets better

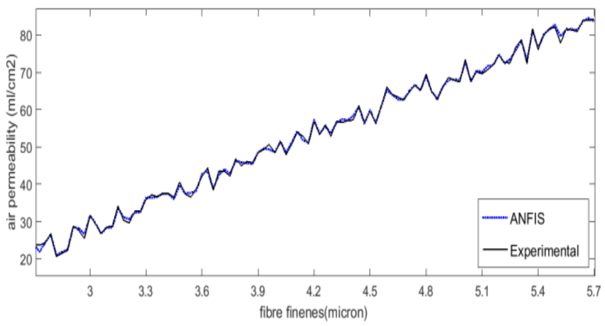

Figure 6. The relation between fiber fineness and air permeability of fabric

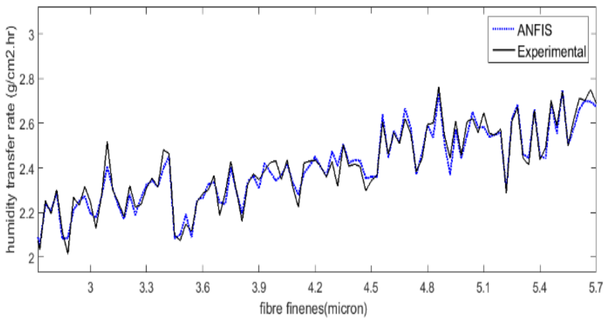

Figure 7. The relation between fiber fineness and humidity transfer rate of fabric

hand value when it is used from finer fibres to reach a higher English count yarn (Ne) and use a number of twist in a suitable way for the yarn. By increasing the English count of yarn, the empty space within the yarn structure are increased and the empty spaces between yarns in fabric structure are increased. As a result, air diffusion is low in the case of fabrics woven from coarse yarn (Figure 8).

According to Figure 9, by increase of the yarn linear density (Ne) or yarn English count, the rate of humidity transfer increases. by increasing the linear yarn density (yarn english count) the rate of humidity transfer increases. Yarn count expresses the coarseness or fineness of a yarn.There are two systems of expressing yarn number or yarn count: 1) Direct yarn numbering system that is defined by weight per unit length of yarn and 2) Indirect yarn numbering system which is defined by length per unit weight. English yarn count refers to the indirect system. In this system by increasing the yarn number or count, the weight of yarn in length decreases. By decreasing of the linear weight of the yarn, the empty spaces between yarns in fabric structure increase Therefore, based on the mentioned increasing behavior, the humidity transfers through the fabric increases.

The stiffness of the fabric increases when the yarn with high twist in fabric has been used. As a result, in this type of fabric the hand value is not suitable. In the yarn with high value of twist the empty space in yarn structure is decreased. According to this fact, the empty space in the fabric structure is increased. Figures 10 and 11 show that by increasing the empty space in the fabric structure, both the air permeability and transfer humidity rate increase. Figures 6 to 11 show that the proposed neuro fuzzy network (ANFIS) is capable of estimating textile' parameters, reasonably. The simulation results show that the system theory analysis is completely correct and can be inferred in the future.

3. 1. Evaluation of Optimum Point or Pointing Stability of Parameters

Physiological comfort of fabric depends on the end using. For the summer garments, the high values of air permeability and humidity transfer are appreciated, while, for the winter garments both mentioned parameters should be decreased to achieve the physiological comfort. Therefore, the pointing stability or the optimum points of yarn structural parameters (yarn twist, yarn English count and fiber fineness) depend on the end use of the fabric. From Figures 6-12, for the winter garment the optimum values of T.P.M coefficient and English count of yarn and fineness of fibers are 4.5, 25 and 3, respectively. Because in these points the air permeability and moisture transfer of fabric have their minimum values.

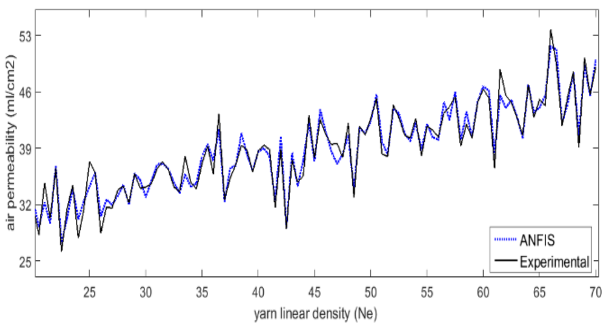

Figure 8. The relation between the yarn English count and the air permeability of fabric

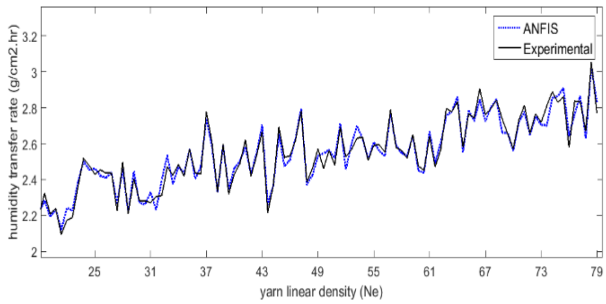

Figure 9. The relation between the yarn English count and the humidity transfer rate of fabric

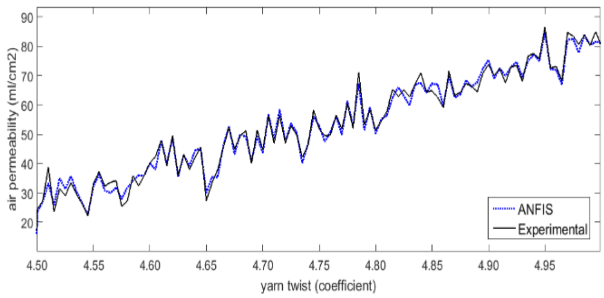

Figure 10. The relation between the yarn twist and the air permeability of fabric

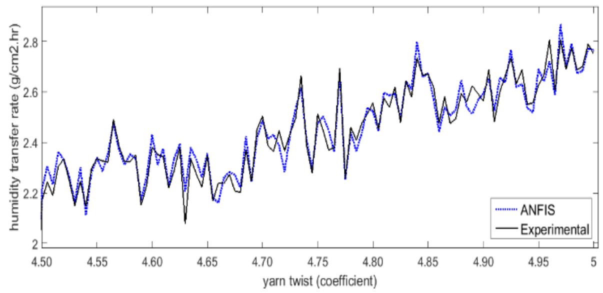

Figure 11. The relation between the yarn twist and the humidity transfer rate of fabric

4. CONCLUSION

In this article the effects of structural parameters of the cotton yarn on the physiological comfort of fabric were studied by experiments and intelligent method of neuro-fuzzy network (ANFIS). The fabric comfort was improved according to the structural parameters of yarn instead of using finishing treatment. The result of this study is useful for green textile industries.

The physiological comfort parameters such as air permeability and moisture transfer of the garment were strongly affected by the characteristics of the yarn and fibers such as fiber fineness, yarn twist and English count of yarn. The modeling and experimental results showed that by increasing the diameter of fibers and English count of the yarn and yarn twist both comfort parameters increase. The theoretical analysis was performed by the new smart model, i.e. improved ANFIS, developed in this work. In the model the linear density, twist yarn and fineness of fibre were input parameters and moisture transfer and air permeability were outputs. Simulation results show the novel proposed ANFIS has high learning capability, fast convergence and accuracy greater than 99% and negligible error value smaller than of 1%. It was also found that both parameters of the physiological comfort sensory, namely, the air permeability and humidity transfer can be improved effectively without finishing process. Finally, the physiological comfort for the winter garment can be achieved at optimum values of 4.5, 25 and 3 for T.P.M coefficient, English count, and fineness of yarn, respectively.

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Persian Abstract

چکیده

اخیراً با افزایش آلودگی های زیست محیطی ، استفاده از فناوری های سبز در زمینه های مختلف صنایع نساجی و پوشاک همانند فرآیند تکمیل به طور جدی توسعه یافته است. در این خصوص یکی از مهمترین پارامترهای موجود در صنعت پوشاک که می¬تواند تحت عملیات تکمیل پارچه بهبود یابد راحتی فیزیولوژیکی پارچه می¬باشد. اما متاسفانه مواد شیمیایی سمی تولید شده در این فرآیند منجر به آلودگی زیست محیطی می¬شود. بنابراین در این تحقیق ، بهبود راحتی فیزیولوژیکی پارچه پنبه¬ای بدون استفاده از عملیات تکمیل به عنوان هدف اصلی این مقاله محسوب می¬گردد. برای این منظور ، خواص نفوذپذیری هوا و انتقال رطوبت که به عنوان دو پارامتر مهم راحتی فیزیولوژیکی پارچه می¬باشد به صورت تجربی و نظری و بر اساس پارامترهای ساختاری نخ پنبه¬ای مورد ارزیابی قرار می¬گیرد. علاوه بر این، بمنظور بررسی تئوری، یک شبکه عصبی- فازی جدید (ANFIS) جهت مدل سازی پیشنهاد شده است. در مقاله حال حاضر ، پارامترهای ساختاری نخ که عبارتند از چگالی خطی نخ، تاب نخ و ظرافت الیاف نخ به عنوان پارامترهای ورودی مدل و عوامل نفوذپذیری هوا و انتقال رطوبت پارچه بعنوان خروجی مدل مورد استفاده قرار می¬گیرند. با توجه به نتایج تجربی و مدل سازی دو عامل ظرافت الیاف و چگالی خطی نخ تأثیر یکسانی بر روی دو پارامتر خروجی مدل داشته و از طرفی تاب نخ اثر معکوس بر روی آنها دارد. نتایج بررسیهای انجام شده در این مقاله نشان می¬دهد که راحتی فیزیولوژیکی پارچه می¬تواند بطور مطلوبی بر اساس پارامترهای ساختاری نخ و بدون انجام عملیات تکمیل بهبود یابد. نتایج شبیه سازی نشان می دهد که مدل پیشنهادی از توانایی یادگیری بالا ، همگرایی سریع، دقت بالای ۹۹٪ و خطای قابل اغماض کوچکتر از ۱٪ برخوردار است. نقاط ٤.٥، ۲۵ و۳ بعنوان مقادیر پارامترهای ضریب تاب و نمره انگلیسی نخ و ظرافت الیاف نخ بعنوان نقاط اپتیمم پارامترهای نخ برای لباسهای زمستانی می باشند.