Evaluation of Permeability Properties of the Fabrics from the Basic Fabric Construction Parameters

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Abstract

This study aims to examine the effect of their construction and yarn properties of single and double layer woven fabrics on fabric air permeability (AP), water vapour permeability (WVP) and thermal resistance (TR) properties. For this purpose, single and double layered cotton/PES fabrics were weaved, and physical performance tests were fulfilled. Permeability properties of all fabrics were analysed with statistically and artificial neural networks, and compared to each other. Useful equations for estimation comfort properties of fabrics before weaving have been obtained by using regression and artificial neural networks.

The focus of this work is to determine the comfort characteristics of the fabrics to be produced from these fibres, which have superior properties and are valuable in terms of Eco-textile before they are produced.

Keywords - *Comfort, air permeability, water vapour permeability, thermal resistance, artificial neural network.*

I. INTRODUCTION

Comfort is easily recognized by the person experience and is a pleasant feeling of being relaxed and free from pain. In terms of textile, comfort can be defined as the psychological effects of the alteration of the heat, moisture and thermal in the body. In their study, Li and Wong indicated that comfort has been related to some senses such as aesthetic, heat, pain and touching. In the light of these explanations, it is stated that comfort can be evaluated in four parts: thermal psychological comfort, skin sensitivity, ergonomic comfort and psychological comfort [1].

In a study on sportswear in 2003, it was stated that it is very difficult to evaluate comfort, because of both subjective and objective factors which should be taken into consideration in evaluating individual comfort. Furthermore, the mechanical, thermal and permeability (air and water vapour) properties of fabrics are stated to be very important in assessing comfort. Fabric parameters that are important for comfort include heat insulation, evaporation heat loss resistance, thermal conductivity, water vapour permeability, water absorption, air permeability, drying rate, wind protection, surface friction coefficient, UV resistance, antimicrobial, antibacterial and anti-odour properties [2].

Rai and Sreenvasan pointed out in their study that the most important parameter affecting sensory comfort has been the frictional property of the fabrics [3]. In the Kawabata's study on evaluating objective handle properties has shown that double and single layered fabrics produced from yarns with different twisted are evaluated and that yarn number is the most effective parameter on the handle characteristics of the fabrics [4]. It was shown that the thermal properties of the fabric depended on the fibre properties (density), yarn properties (fineness, twist), fabric properties (tissue type) and environmental factors [5]. In another study, the thermal properties of the regenerated and natural cellulose fibres depended on the porosity of the fabrics and the voids within the fabric [6]. In a study, it was reported that the effect of fabric structure on the performance of liquid absorbing capacities of socks was high [7]. In a study, the comfort characteristics of fabrics obtained from viloft fibres were examined and it was found that thermal properties of fibres with a high viloft ratio, which was an indented structure, were better [8]. It was reported that the open-end spinning system positively affected the thermal properties [9]. In a study, it was stated that besides the mechanical parameters of the fabric, the moisture of the fabrics also affected the comfort characteristics [10]. In a study with towel fabrics, it was stated that the softness and hydrophilic properties of the towel could be predetermined depending on the performance and mechanical properties of the fabric [11].

In a study, the effect of fibre content, yarn count, fabric density and wash on comfort was examined and it was determined that the fabric has an enhancing effect on water vapour permeability and capillary wetting properties. As the wetting properties increased with decreasing yarn number, drying behaviour decreased with decreasing yarn number [12].

In their study, Gün and Bodur declared that comfortability could be achieved by removing water vapour caused by perspiration. This transmission can also be achieved by water vapour permeability [13].

The comfortable feeling depending on air permeability and absorbed or evaporated sweat forms the basis of the thermal comfort [14,15]. For this reason, human comfort can be characterized by the thermal properties of fabrics, air permeability and water vapour permeability. In many studies, permeability properties of fabric such as air and water vapour permeability and thermal resistance have been investigated depending on fabric and fibre properties [9, 14-16].

Most of the work on comfort features is on knitted fabrics [14, 17-20]. Utkun (2015) conducted a study on the determination of cotton knitted fabrics with optimum comfort characteristics, taking into consideration the cost factor [21].

Various statistical methods such as correlation analysis, regression analysis, factor analysis have been used to determine the relationship between fabric parameters and comfort [22-25]. Artificial neural networks have been used to eliminate constraints arising from non-linear relationships between comfort and fabric parameters in statistical methods [22,26].

Considering the cost factor in this study, it was aimed to estimate the thermal properties, air and water vapour permeability of single and double layered fabrics with different constructions woven from cotton yarns in different numbers, and to estimate the comfort characteristics before fabric production, both regression analyses and artificial neural networks were used.

II. MATERIALS AND METHODS

A. Determination of Sample Technical Properties

The technical properties of the fabrics produced in this study are given in Table 1 and the physical properties are given in Tables 2. The weaving factor (WF) and the fabric densities (d) were calculated according to the following equations.

$$WF = \frac{\frac{D_{warp}}{D_{warp}+NCPWarp}+\frac{D_{weft}}{D_{weft}+NCPWeft}}{2} \quad \text{Eq. 1}$$

$$d = \frac{Weight}{Thickness(cm)*10000} \quad \text{Eq. 2}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(X_H - X_O)^2}{N}} \quad \text{Eq. 3}$$

WF: WeaveFactor

D_{warp}-D_{weft}: Warp or Weft Density

NCP_{warp}-NCP_{weft} : Number of Connection Per Warp or Weft

RMSE: Root Means Squre Error

90 denier 100 % polyester yarns as warp yarn and Ne 16/1, 20/1 and 30/1 100% cotton yarns as weft yarn were used in this study. Within the scope of the study, the fabrics are woven as single layer and double layer by using plain, twill, rips, panama and satin braids. Fabrics were weaved at weft frequencies of 20-60 picks/cm depending on the type of braids and yarn numbers.

Physical and comfort tests were carried out under the standard test conditions specified in TS EN ISO 139. Low stress mechanical properties of all fabrics were measured by FAST evaluation system. All measurements were repeated five times. Density measurements were made according to TS 250 EN 1049-2 standard. While the weighing measurements were made by weighing 100 cm^2 samples on the sensitive scale, thickness measurements were fulfilled with thickness measuring device. The permeability properties of the fabrics such as air permeability, thermal resistance and water vapour permeability were evaluated according to TS 391 EN ISO 9237, TS EN 11902, ASTM E96 standards, respectively. The air permeability tests were conducted with a SDL Atlas Digital Air Permeability tester which has a 20 cm^2 test apparatus. All measurements were repeated five times and smaller value of air permeability showed poorer air permeability. The thermal resistance measurements were made with Sweating Guarded Hotplate tester. All measurements were repeated five times. Water vapour permeability tests were made via cup method. The change in cap weight at certain intervals was recorded as water vapour permeability results.

TABLE I
Technical Properties of all samples

	Code	**Weight**	**Thick.**	**Width**	**WF**
		g/m^2	**mm**	**cm**	**-**
Single-Layered Fabrics	**P101**	150.67	0.355	158	0.5
	P102	137.33	0.352	159	0.5
	P103	118.67	0.35	158.8	0.5
	D101	169.67	0.455	155.5	0.25
	D102	159.67	0.455	155	0.25
	D103	146	0.448	156	0.25
	PA101	166	0.425	156	0.75
	PA102	155.67	0.42	156	0.75
	PA103	145	0.417	157	0.75
	RQ101	157.33	0.463	158	0.625
	RQ102	146.33	0.442	158.5	0.625
	RQ103	130	0.43	158.5	0.625
	S101	162.67	0.48	154	0.87
	S102	169	0.483	153.5	0.87
	S103	180.33	0.49	153.2	0.87
	P104	129.67	0.315	157.5	0.5
	P105	136.67	0.322	157	0.5
	P106	118	0.317	158	0.5
	D104	164.67	0.413	153	0.25
	D105	149.67	0.41	156	0.25
	D106	140	0.408	156.5	0.25
	PA104	149.67	0.4	155.5	0.75
	PA105	143	0.397	156	0.75
	PA106	127	0.395	157	0.75

	RQ104	139.33	0.415	158.2	0.625
	RQ105	131	0.4	158.5	0.625
	RQ106	122.33	0.388	158.8	0.625
	S104	142	0.455	155	0.87
	S105	156.67	0.458	155.6	0.87
	S106	164	0.462	156	0.87
	P107	110.67	0.275	156.5	0.5
	P108	106.67	0.272	157.5	0.5
	P109	99.33	0.268	157.5	0.5
	D107	142.00	0.367	153	0.25
	D108	131.00	0.360	153	0.25
	D109	125.33	0.358	153.5	0.25
	PA107	135.00	0.388	153	0.75
	PA108	128.67	0.377	153	0.75
	PA109	120.27	0.335	154	0.75
	RQ107	124.33	0.348	157	0.625
	RQ108	120.67	0.338	157.3	0.625
	RQ109	110.67	0.335	158	0.625
	S107	124.67	0.392	154.5	0.87
	S108	133.00	0.398	154.6	0.87
	S109	142.33	0.403	155	0.87
Doble-Layered Fabrics	**P201**	211.33	0.6267	153	0.71
	P202	190.87	0.608	155	0.71
	P203	169	0.572	156.5	0.71
	D201	250	0.793	155	0.858
	D202	233.33	0.773	155.2	0.858
	D203	169.33	0.68	156	0.858
	PA201	295	0.92	150	0.724
	PA202	233.33	0.79	153	0724
	PA203	167.33	0.688	155	0.724
	RQ201	286.33	0.728	156	0.71
	RQ202	231.67	0.703	157	0.71
	RQ203	170.67	0.703	157	0.71
	S201	282.33	0.923	151	0.87
	S202	233	0.86	152	0.87
	S203	191	0.797	153	0.87
	P204	191	0.61	152	0.71
	P205	157.33	0.537	153	0.71
	P206	116.33	0.493	156	0.71
	D204	223	0.753	154	0.858
	D205	187	0.712	154.5	0.858
	D206	162.33	0.667	155	0.858
	PA204	259	0.85	150	0.724
	PA205	204.33	0.752	152	0724
	PA206	147	0.608	154	0.724
	RQ204	245.67	0.64	156	0.71
	RQ205	216	0.623	157	0.71
	RQ206	162.67	0.623	157	0.71
	S204	246.33	0.822	150	0.87
	S205	204.67	0.767	152	0.87
	S206	174	0.735	153	0.87
	P207	158.67	0.553	150	0.71
	P208	136.33	0.478	152	0.71
	P209	113.67	0.428	154	0.71
	D207	182.00	0.663	154	0.858
	D208	163.00	0.618	154.3	0.858
	D209	131.67	0.572	155	0.858
	PA207	218.00	0.757	152	0.724
	PA208	172.00	0.673	153.5	0724
	PA209	133.00	0.567	154.5	0.724
	RQ207	213.33	0.523	154	0.71
	RQ208	164.67	0.508	156	0.71
	RQ209	120.33	0.515	157	0.71
	S207	201.67	0.722	152	0.87
	S208	173.67	0.660	153.6	0.87
	S209	144.33	0.618	154	0.87

TABLE II.
Physical properties of single and double layered fabrics

	Code	**Fabric Density**	**Weft**		**Warp**
			Ne	**Den.**	**Den.**
		g/cm^3		**weft/cm**	**warp/cm**
Single-Layered Fabrics	**P101**	0.424	16	25	32.41
	P102	0.391	16	22	32.20
	P103	0.339	16	19	32.24
	D101	0.373	16	30	32.93
	D102	0.351	16	27.5	33.03
	D103	0.326	16	24.2	32.82
	PA101	0.391	16	29.7	32.82
	PA102	0.371	16	26.9	32.82
	PA103	0.348	16	24.3	32.61
	RQ101	0.340	16	27.5	32.41
	RQ102	0.331	16	24.3	32.30
	RQ103	0.302	16	20.9	32.30
	S101	0.339	16	28.2	33.25
	S102	0.350	16	31.1	33.36
	S103	0.368	16	34.4	33.42
	P104	0.412	20	26	32.51
	P105	0.425	20	28	32.62
	P106	0.373	20	23	32.41
	D104	0.398	20	36	33.46
	D105	0.365	20	33	32.82
	D106	0.343	20	30	32.72
	PA104	0.374	20	32.65	32.93
	PA105	0.360	20	29.7	32.82
	PA106	0.322	20	26.9	32.61
	RQ104	0.336	20	30.7	32.36
	RQ105	0.328	20	27.5	32.30
	RQ106	0.315	20	24.87	32.24
	S104	0.312	20	31.94	33.03
	S105	0.342	20	35.85	32.91
	S106	0.355	20	39.02	32.82
	P107	0.402	30	32	32.72
	P108	0.393	30	29	32.51
	P109	0.371	30	26	32.51
	D107	0.388	30	44	33.46
	D108	0.364	30	40.8	33.46
	D109	0.350	30	37.1	33.36
	PA107	0.348	30	41.9	33.46
	PA108	0.342	30	39	33.46
	PA109	0.359	30	36.2	33.25
	RQ107	0.357	30	37.1	32.61
	RQ108	0.357	30	34.4	32.55
	RQ109	0.330	30	31.5	32.41
	S107	0.318	30	39	33.14
	S108	0.334	30	42.5	33.12
	S109	0.353	30	47	33.03
Double-Layered Fabrics	**P201**	0.337	16	39.4	33.46
	P202	0.314	16	34.9	33.03
	P203	0.296	16	30.52	32.72
	D201	0.315	16	50.5	33.03
	D202	0.302	16	40.4	32.99
	D203	0.249	16	30.52	32.82
	PA201	0.321	16	61	34.13
	PA202	0.295	16	45	33.46
	PA203	0.243	16	30	33.03
	RQ201	0.393	16	57	32.82
	RQ202	0.329	16	44.12	32.61

	RQ203	0.243	16	31	32.61
	S201	0.306	16	56.5	33.91
	S202	0.271	16	45	33.68
	S203	0.240	16	34.41	33.46
	P204	0.313	20	44.12	33.68
	P205	0.293	20	34.9	33.46
	P206	0.236	20	23.26	32.82
	D204	0.296	20	56	33.25
	D205	0.263	20	45.88	33.14
	D206	0.244	20	36.31	33.03
	PA204	0.305	20	67.14	34.13
	PA205	0.272	20	50.5	33.68
	PA206	0.242	20	32.65	33.25
	RQ204	0.384	20	60.26	32.82
	RQ205	0.347	20	52	32.61
	RQ206	0.261	20	37.1	32.61
	S204	0.30	20	61.05	34.13
	S205	0.267	20	47.06	33.68
	S206	0.237	20	39.02	33.46
	P207	0.287	30	52	34.13
	P208	0.285	30	41.9	33.68
	P209	0.265	30	32.65	33.25
	D207	0.274	30	68.7	33.25
	D208	0.264	30	55	33.18
	D209	0.230	30	41.5	33.03
	PA207	0.288	30	81.6	33.68
	PA208	0.256	30	61	33.36
	PA209	0.235	30	41.9	33.14
	RQ207	0.408	30	78	33.25
	RQ208	0.324	30	57	32.82
	RQ209	0.234	30	37.1	32.61
	S207	0.280	30	74.4	33.68
	S208	0.263	30	61.1	33.33
	S209	0.233	30	47.1	33.25

B. Statistical Evaluation

SPSS 13 statistical software program was used to examine the effect of technical properties on permeability properties of fabrics. The datasets were analysed by means of stepwise regression analysis. Large R^2 value, small mean square error and p-value were taken into account in the evaluations. However, a linear relationship between thermal resistance and technical properties of produced fabrics could not be determined, and also for water vapour permeability and fabrics properties. For this reason, linearization was applied for both parameters.

The following relations were used to linearize the relationship between the physical properties of the fabrics and the water vapour permeability values.

Inverse of the squared WVP= 1 / WVP^2 =WVPI Eq. 4
Square of the fabric density (M)=$(Fd)^2$
N=$e^{Thickness}$ =e^{Th}
Natural logarithm of weave factor (F)= Ln(WF)

The transformation formulas used to linearize the relationship between the structural parameters of the fabric and the thermal resistance are shown below.

Inverse of the square root of the weft density = $\frac{1}{\sqrt{Ne_A}}$ Eq. 5

C. Devolepment Artificial Neural Network (ANN)

An ANN model contains some layers such as input, hidden and output layers. Input layer covers measurable data affecting the output parameter. One or more hidden layers can be in the different ANN and hidden layer has a lot of neuron having a transfer function such as sigmoid, step or linear transfer functions. Artificial neural networks are applied according to the weight values of each interconnection determined in compliance with the input and output parameters. ANN algorithm was applied for each permeability parameter. Fabric weight, weft count, fabric thickness, fabric density, number of fabric layer, weave factor warp and weft density were used as input parameters for ANN, air permeability, water vapour permeability and thermal resistance properties were calculated, respectively. ANN structures for air permeability, water vapour permeability and thermal resistance of the fabrics are shown in the Figure 1 (A-C), respectively. Sigmoid transfer function was used in the hidden layer. In addition, a neuron is shown in Figure 2.

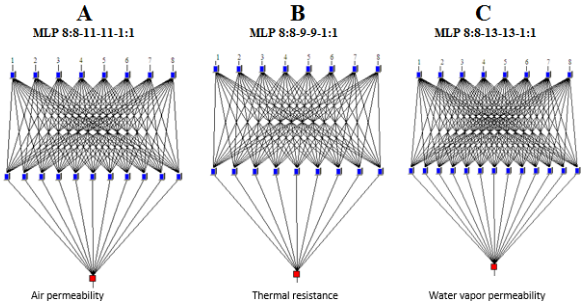

Fig 1: The optimum architecture of neural netwprks for air permeability (A), thermal resistance (B), Water vapour permeability (C)

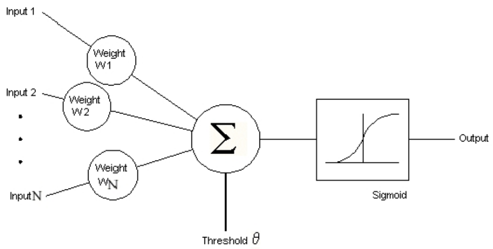

Fig 2: A neuron structure with sigmoid transfer function

III.RESULTS AND DISCUSSION

A. Measurement Results of Fabrics

Air permeability, water vapour permeability and thermal resistance values of the single and double layer fabrics produced in this study are given in Table 3.

TABLE III.
The permeability properties of the single and double-layered fabrics

	Code	**AI**	**WVP**	**TR**
		mm/s	**g/m^2**	**m^2/C/W**

Single-Layered Fabrics	**P101**	225.667	1.8863	0.02570
	P102	399.333	2.0315	0.02410
	P103	686.667	2.2528	0.02140
	D101	147.000	2.0258	0.02860
	D102	245.333	2.2123	0.02770
	D103	500.667	2.4382	0.02690
	PA101	177.000	1.9579	0.02980
	PA102	307.667	2.1194	0.02780
	PA103	430.333	2.2389	0.02600
	RQ101	338.000	2.2556	0.02690
	RQ102	513.333	2.3714	0.02560
	RQ103	783.333	2.6714	0.02280
	S101	112.667	2.1964	0.02937
	S102	162.333	2.3396	0.02967
	S103	281.000	2.4944	0.02723
	P104	400.333	2.1508	0.02173
	P105	276.667	2.0155	0.02087
	P106	223.667	1.9707	0.02037
	D104	323.333	2.5112	0.02630
	D105	196.000	2.4188	0.02430
	D106	103.000	2.1396	0.02246
	PA104	558.667	2.5570	0.02373
	PA105	351.000	2.3406	0.02267
	PA106	244.333	2.1547	0.02212
	RQ104	739.333	2.5040	0.02320
	RQ105	531.000	2.3628	0.02180
	RQ106	370.667	2.2918	0.02120
	S104	368.000	2.4674	0.02630
	S105	253.667	2.2789	0.02470
	S106	135.333	2.2051	0.02270
	P107	303.667	1.9866	0.02004
	P108	395.667	2.0855	0.01851
	P109	581.667	2.2252	0.01738
	D107	106.167	2.1169	0.02162
	D108	192.667	2.3046	0.01919
	D109	316.000	2.3974	0.01873
	PA107	209.000	2.1751	0.02287
	PA108	325.667	2.2156	0.02033
	PA109	395.333	2.2865	0.01947
	RQ107	297.333	2.1430	0.02192
	RQ108	346.667	2.2575	0.02115
	RQ109	595.333	2.4554	0.01917
	S107	210.000	2.2519	0.02163
	S108	301.667	2.3210	0.02093
	S109	411.333	2.4775	0.02042
Double-Layered Fabrics	**P201**	268.667	1.9547	0.02860
	P202	377.333	2.0591	0.02690
	P203	612.667	2.2206	0.02630
	D201	267.667	2.1350	0.03020
	D202	342.667	2.2469	0.02870
	D203	1035.667	2.3310	0.02710
	PA201	196.667	1.9475	0.03150
	PA202	471.000	2.0680	0.02780
	PA203	1083.333	2.3469	0.02530
	RQ201	93.300	1.9345	0.03260
	RQ202	332.000	2.0440	0.02820
	RQ203	861.333	2.2485	0.02697
	S201	329.000	2.0075	0.03050
	S202	604.333	2.2015	0.02770
	S203	1035.333	2.3866	0.02520
	P204	349.333	2.0170	0.02683
	P205	689.000	2.1692	0.02620
	P206	1250.000	2.4466	0.02507
	D204	388.333	2.0195	0.02923
	D205	757.333	2.2577	0.02620
	D206	1088.000	2.4674	0.02570
	PA204	316.333	2.1502	0.03003
	PA205	653.333	2.2335	0.02906
	PA206	1090.667	2.3876	0.02655
	RQ204	162.667	1.8494	0.03010
	RQ205	372.333	2.0779	0.02947
	RQ206	897.000	2.2762	0.02710
	S204	474.667	2.1229	0.03053
	S205	839.333	2.2267	0.02950
	S206	1170.000	2.3187	0.02593
	P207	440.333	2.1313	0.02357
	P208	650.000	2.2318	0.02330
	P209	1059.333	2.5042	0.02287
	D207	650.000	2.3561	0.02570
	D208	865.333	2.4380	0.02420
	D209	1316.667	2.6049	0.02350
	PA207	380.000	2.1229	0.02700
	PA208	905.000	2.2561	0.02580
	PA209	1156.667	2.4712	0.02463
	RQ207	188.333	1.9242	0.02913
	RQ208	604.667	2.2424	0.02547
	RQ209	1310.000	2.5720	0.02387
	S207	639.000	2.2021	0.02750
	S208	928.333	2.3496	0.02667
	S209	1203.333	2.4664	0.02341

B. Stepwise Regression Analysis

In this study, no linear relationship was found between the water vapour results and the fabric production parameters. Statistical linearization was performed according to Eq, 4. Similarly, since the thermal resistance results of the fabrics were not linearly related to the technical properties of the fabrics, statistically linearization was applied according to Eq. 5.

C. The Air Permeability

The air permeability of the fabrics produced from Ne 16, Ne 20 and Ne 30 yarns were evaluated according to technical properties of fabric such as weight, yarn number, thickness. After regression analysis, it has been determined that fabric air permeability can be calculated according to Eq. 6 depending on technical parameters of fabrics.

$$\sqrt{AP} = 14.995 * \frac{1}{\sqrt{D}} - 3.638 * LD_{Warp} - 0.173 * W + 19.920 * e^{T} + 5.104 * NL + 101.646$$

Eq.6

In the Eq.6, AP, D, LD_{warp}, W, T and NL were air permeability, density, linear density of warp yarn, fabric weight, fabric thickness and number of layer, respectively. As you seen in Eq. 6, the most important parameter for air permeability of fabrics has been linear density of warp yarn. The other important parameters have been fabric weight, number of layer, thickness and density, respectively.

Figure 3 shows relationship between measuring and calculating air permeability values.

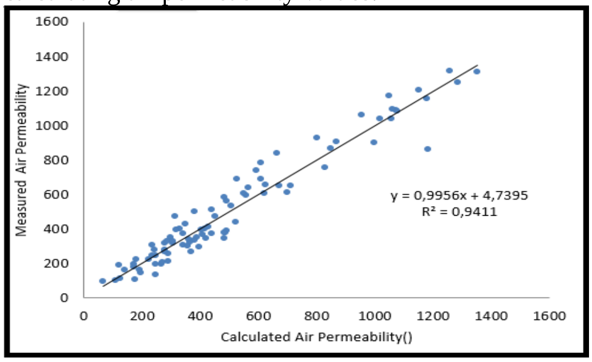

Fig. 3: Measuring and calculating air permeability values

According to the regression analysis results, there is a negative relation between air permeability and fabric density and warp linear density, but there is a positive relationship between thickness and fabric layer count. As the weight of the fabric increased, the air permeability decreased. As the warp linear density values decreases. The most important parameter for air permeability is the number of fabric layers, and as the fabric thickness increases, the air permeability of the fabrics increases. Despite the increase in fabric thickness in double layered samples, the air permeability values are high because the weft and warp densities of two layers are generally lower than single layer fabrics. R^2 value is 0.9411. Regression analysis has high significance level for the fabric air permeability calculated depending on the technical parameters of fabrics and fabric density.

D. Water vapour Permeability

The water vapour permeability of the fabrics produced from Ne 16, Ne 20 and Ne 30 yarns were evaluated according to technical properties of fabric such as weight, yarn number, thickness. After regression analysis, it has been determined that fabric water vapour permeability can be calculated according to Eq. 7 depending on technical parameters of fabrics.

$$WVP = \frac{1}{\sqrt{(1.512 * D^2 + 0.03916 * NL + 0.04846 * e^T - 0.03357 * \ln WF - 0.07173)}}$$

Eq.7

In the Eq.7, WVP, D, WF, T and NL were water vapour permeability, density, weave factor, fabric thickness and number of layer, respectively. As you seen in Eq. 7, the most important parameter for water vapour permeability of fabrics has been density of fabrics. The other important parameters have been fabric weight, number of layer, thickness and weave factor, respectively.

Figure 4 shows relationship between measuring and calculating water vapour permeability values.

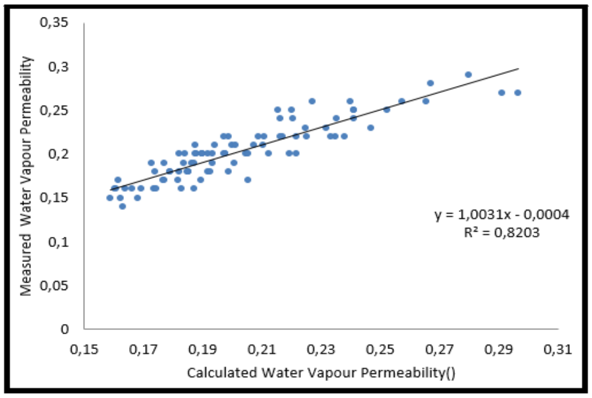

Fig.4: Measuring and calculating water vapour permeability

According to the regression analysis results, there is a negative relation between water vapour permeability and weave factor, but there is a positive relationship between thickness and fabric layer count. The weave factor of fabrics is between 0-1. For this reason, effect of weave factor as Eq. 7 is negative.

Important parameters for water vapour permeability are density, number of layer, thickness and weave factor. R^2 value is 0.8203. Regression analysis has high significance level.

E. Thermal resistance

Thermal resistance depends not only on the properties of the raw material but also on the structural properties of the textile surface. Since the raw material used in the work is the same, the change in thermal resistance depends on the structural properties of the fabric. Eq. 8 has been obtained for thermal resistance depending on fabric properties.

$$TR = \frac{0.0958}{\sqrt{YC_{Weft}}} + 0.00014 * LD_{Weft} + 0.001174 * T + 0.003658 * WF - 0.005763$$

Eq. 8

Eq. 8 has been obtained where TR, YC_{Weft}, LD_{Weft}, T and WF were thermal resistance, weft yarn count, weft linear density, fabric thickness and weave factor. As you shown in the equation, thermal resistance has depended some parameters such as weft yarn count, weft linear density, thickness, number of layer and weave factor. Figure 5 shows fabric thermal resistance properties.

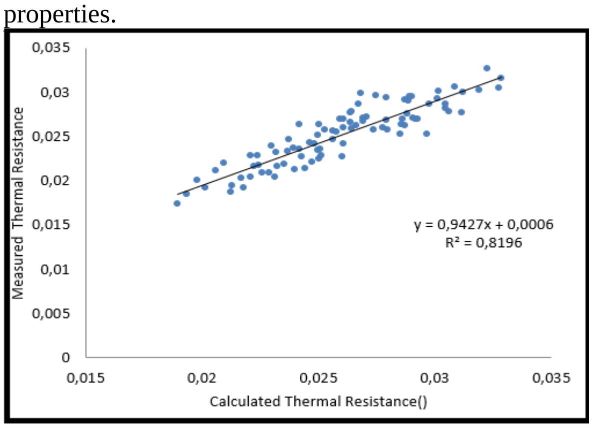

Fig. 5: Fabric thermal resistance

According to the regression analysis results, while yarn count number increases, yarn become finer. For this reason, all parameters have positive influence on thermal resistance. R^2 value is 0.8196. Regression analysis has high significance level.

F. Artificial Neural Networks

In practical application for developing the best material, it is necessary to prepare a database of experimental results large enough to develop ANN. For the optimization, transfer function, training algorithm and other parameters have setted. In this study, sigmoid transfer function was used.

G. Evaluation of the air permeability with ANN

Because air permeability of the fabrics can be evaluated, ANN was fulfilled depending on input parameters. A single-layer artificial neural network was applied as shown in Figure 1-A. The architecture of the ANN was 8:8-11-11-1:1.

The configuration of adopted architecture of the neural network for all fabrics overall air permeability evaluation was shown in Figure 6. The air permeability values calculated using artificial neural networks are close to real values and R^2 value is 0.9982. The average values of the error squares (RMSE) were calculated for linear regression and ANN are 78.4762317 and 13.859542, respectively. The smallest RMSE value is the best value.

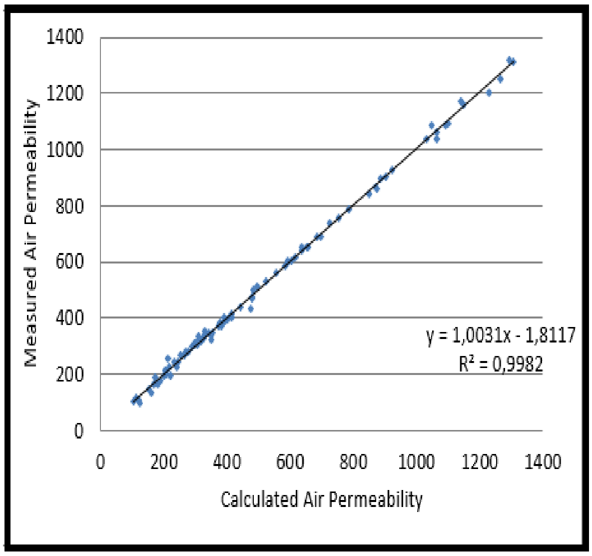

Fig.6: ANN evaluation for air permeability

H. *Evaluation of the water vapour permeability with ANN*

ANN was fulfilled for evaluating water vapour permeability of fabrics. A single-layer artificial neural network was applied as shown in Figure 1-B. The architecture of the ANN was 8:8-9-9-1:1. ANN results for water vapour permeability has shown in Fig. 7.

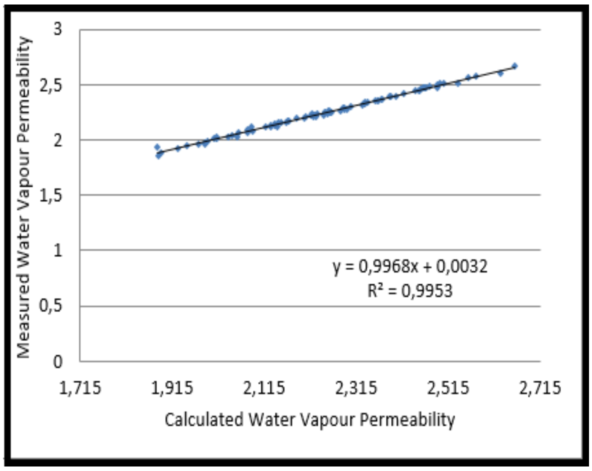

Fig. 7: ANN evaluation for water vapour permeability

As you see in figures, R^2 values for ANN are smaller than linear regression's. At the end of the evaluation made using artificial neural networks, a linear relationship was found between water vapour permeability values calculated with fabric parameters (R^2 = 0,9953 accuracy). The RMSE values for linear regression and ANN are 0.012994 and 0.002905, respectively.

I. *Evaluation of the thermal resistance with ANN*

Because thermal resistance of the fabrics can be evaluated, ANN was fulfilled and fabric weight, weft count, fabric thickness, fabric density, number of fabric layer, weave factor warp and weft density were used as input parameters. Thermal resistance of the fabrics was chosen as output parameter. A single-layer artificial neural network was applied as shown in Figure 1-C. The architecture of the ANN was 8:8-13-13-1:1.

The evaluation results with artificial neural network for all fabrics are shown in Figure 8.

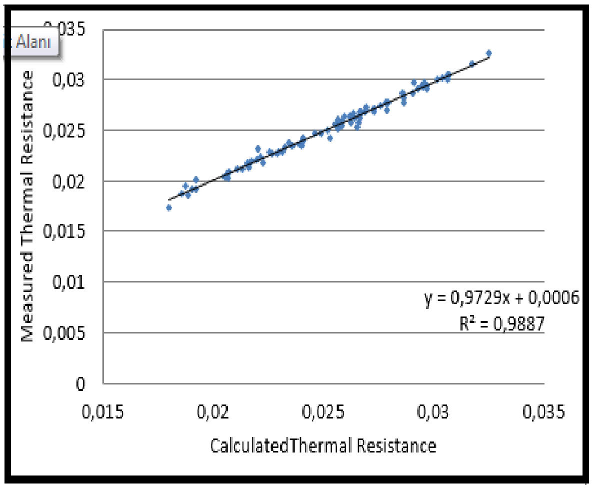

Fig.8: ANN evaluation for thermal resistance

As you see in Figure 10, R2 values for ANN is 0.9887, and smaller than linear regression. The RMSE values for linear regression and ANN are 0.001687 and 0.000386, respectively.

IV. CONCLUSION

1. It has been concluded that the constructional parameters of the fabrics such as warp and weft density, weft yarn number, thickness and weight of the fabrics, weaving factor affects the air permeability results of the fabrics produced in the study. A linear relationship between fabric structure parameters and air permeability could not be determined. Therefore, linearization was made for these parameters. One practical formulas for air permeability was obtained depending on density, linear density of warp yarn, fabric weight, fabric thickness and number of layer as you seen in equation 6. While density, warp linear density and weight have negative influence, thickness and number of layer have positive influence on air permeability.
2. It has been concluded that constructional parameters of fabrics affect water vapour permeability. As you can see in equation 7, the

water vapor permeability affects the weave factor in the negative direction, while thickness and number of layer influence it in the positive direction.

3. It has been determined that the higher thermal resistance values have been obtained by increasing linear weft density, weaving factor, thickness. More thermal resistance can also have obtained with finer yarn. number of fabric layers. After statistical evaluation, equation 8 was obtained for thermal resistance of fabrics.
4. It is determined that artificial neural networks have given higher accuracy results about the comfort properties of the fabrics before fabric production.

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