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Investigation of the Effects of Embroidery Parameters on Physical Properties and Thermal Comfort

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ABSTRACT

Embroidery is the process of transferring a pattern to the textile surface by sewing. Embroidery, which increases the value-added of the product with ornamentation technique, is indispensable for clothing manufacturers that particularly care about the brand image. With the development of computerized sewing machines, embroidery, which is a traditional ornamentation technique, can be performed using different methods and materials in multi-needle and multi-head embroidery machines. As a result of technological developments and the effect of fashion, embroidery has become an important field of ornamentation on textile surfaces, especially for industrial branches such as clothing, home textile and footwear.

Since the primary aim of embroidery is pattern transfer, special attention has been paid to visual quality, while the quality factors related to usage have remained in the background. This research studies the effects of embroidery on clothing comfort in terms of embroidery parameters. Growing embroidery sizes, because of the reasons such as emphasizing the brand image and the fashion trends, enrich the product visually. However, growing embroidery sizes affect the physical and clothing comfort properties. In this study, the main two embroidery parameters, which add visual richness to the product, the embroidery stitch length and the weight of the fusing paper are used. The fusing paper increases the stability of the embroidery by remaining between the lower thread and the fabric. By using the same yarn on two types of fabric, single jersey and pique, the effects of embroidery stitch length and fusing paper properties on physical and thermal comfort properties are analyzed. As a result of this study, it has been observed that embroidery affects the clothing comfort properties of a garment. The increase in the weight of the fusing paper used and the increase in the needle penetration number affect the thermal behavior. As an outstanding conclusion, when the same fusing paper is used, the increase in needle penetration number relatively decreases the thermal and water vapour resistance, due to the increased number of needle holes.

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1. INTRODUCTION

Thermal comfort is a thermal condition that occurs because of the mechanical interaction between the skin and the textile surface. It involves heat and moisture conduction properties of textile surfaces during different activities [1].

It can be said that optimal clothing comfort can be ensured with conscious and correct selection of fabrics to be used in clothes, preparation of production patterns by considering the anatomical body features and the principles of ergonomics, and at the final phase, correct determination/ application of machines, sewing material and stitch types to be used in production [2]. Besides, the subsidiary processes used to ornament the cloth should also be evaluated in terms of thermal comfort.

The embroidery process has accommodated itself to increasing production quantities to support brand image, fashion factor through ornamentation with the use of advanced technologies and has taken its place among the subsidiary garment processes. The embroidery process,

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which can be performed using different methods and materials, provides value-added for the product, especially in terms of visuality.

The main principle of embroidery is based on sewing the inside or periphery of a figure with a certain density or edge-to-edge sewing. In order to improve the quality of the embroidery, every production parameter, especially the machine to be used in embroidering, should be selected correctly. Factors such as proper adjustment of the machine settings and correct material selection directly affect the quality [3]. Different types of stitches can be preferred for the embroidery process. However, the most common one used in the market is double lockstitch type 301. In embroidery, when the value of the stitch density decreases, the pattern becomes dense since the length between the stitches shortens, and when the value increases, the pattern becomes sparse since the length will also increase [4]. When the length between the needle penetrations decreases, more needle penetrations are needed to obtain the same embroidery. Changes in parameters related to sewing, such as stitch density, also affect the thermal comfort and physical properties of embroidery.

Fusing papers are used by being stretched under the fabric during the needle strokes to prevent the fabric from contracting and straining, and to ensure that the embroidery turns out proper. The fusing paper to be used is chosen according to their weight and whether it can be torn easily, while considering the quality of the embroidery, stitch density and properties of the fabric [4]. Fusing paper, which must be used in the embroidery process, increases the weight and thickness of the fabric in the area where it is used, and therefore, affects the thermal comfort and physical properties of the product.

It is possible to find studies examining the effects of fabric-related parameters, such as raw materials and fabric construction, on thermal comfort of the garment; however, resources available at the apparel phase are limited.

The studies on thermal comfort usually analyze the effects of fiber and yarn properties [5 - 11] and fabric structure [7, 12 - 16] on thermal comfort. The results of these studies show us several facts. Cotton fabrics have more heat resistance than fabrics containing regenerated cellulose fiber, tencel fabrics have higher water vapour permeability and viscose fabrics have higher air permeability [5]. In terms of moisture transfer, the fabric structure with polypropylene on the inside and cotton on the outside has the best thermal comfort value [7]. Compared to 100% wool and 100& bamboo fabrics, wool/polyester or wool/bamboo blends improve the moisture management properties of the fabrics [10]. Use of acrylic yarns do not have an important effect on thermal resistance, thermal conductivity, thermal absorptivity and air permeability of the fabrics; weaving type has an effect on thermal resistance, thermal conductivity and heat absorptivity; etamine weave fabrics have higher thermal resistance and air permeability, and lower thermal absorptivity than plain weave fabrics; etamine fabrics are expected to give more warm feeling; the thickness of fabric is also a parameter affecting the thermal comfort properties of fabrics; as the thickness of fabrics increases, thermal resistance and thermal conductivity also increases and thermal absorptivity decreases; fabric density has an effect on thermal comfort and water vapour management properties of the fabrics, decreasing the fabric density increases the thermal resistance, thermal conductivity and air permeability of fabrics, however, it decreases thermal absorptivity and moisture management capacity [8]. For all knitted fabric structures, as the density value increases, the thermal absorptivity value increases and the values of thermal resistance, water vapour and air permeability decrease; using elastane yarn improves the thermal isolation property [13]. Each knitted structure tends to have quite different thermal comfort properties; interlock and 1×1 rib fabrics have a significantly high thermal conductivity and thermal resistance value; single jersey fabrics have higher relative water vapour permeability values than 1×1 rib and interlock fabrics, and they give a warmer feeling with lower thermal absorptivity values [14]. As the fabric thickness increases, thermal resistance value increases and the values of water vapour and air permeability decrease, thermal comfort properties of different knitted structures significantly alter, and single jersey, rib and interlock knitting, respectively, while the thermal resistance and thermal absorptivity values increase, the water vapour permeability decreases [15 - 17]. When moisture transfer properties of fabrics with different wool/polyester blend ratios are investigated, it has been revealed that as the fiber diameter decreases and the fiber percentage increases, moisture management properties improve, and as the yarn number and polyester fiber percentage increase, the overall moisture management value decreases [18].

Apart from the studies conducted on these fiber and fabric structures, some studies, although fewer, also investigate the effect of stitch types, stitch and yarn properties on comfort properties. The results of the study carried out by Oğlakçıoğlu et al. (2013) reveal that flatlock stitch provides higher thermal conductivity than overlock stitch; overlock stitch has higher thermal isolation than flatlock stitch; flatlock stitch is more advantageous than overlock stitch in terms of water vapour permeability; overlock stitch has higher air permeability than flatlock stitch [19].

In the literature, no studies have been found on the effect of ornamentation tools that provide value-added to the product, especially embroidery, on the thermal comfort and physical properties of the garment. Growing embroidery sizes, because of the reasons such as emphasizing the brand image and the fashion trends, enrich the product visually. However, growing embroidery sizes affect the physical and clothing comfort properties. This research studies the effect of embroidery, which is used for patterning certain areas of the product, on physical properties and clothing comfort in terms of embroidery parameters. In this research, by using the same yarns on two types of fabric, single jersey and pique, the effects of embroidery stitch length (needle penetration number) and the weight of fusing paper on physical properties and thermal comfort are analyzed. It is believed that the data obtained in this study will also guide the positioning of embroidery on cloth in such a way as to create minimum discomfort on the body.

2. MATERIAL AND METHOD

2.1 Material

In this study, the effects of embroidery fabric type, stitch length and fusing paper on clothing comfort are analyzed and other parameters are kept constant. The same upper thread and lower thread are used throughout the embroidery processes. Coats Sylko tkt no. 120, 27 tex trilobal polyester thread is used as the upper thread (needle thread), tkt no. 75, 40 tex cotton thread is used as the lower thread, both widely used in the embroidery applications. In order to simulate the fabric textures, pique fabric weighing 199,4 gr/m^2 and single jersey fabric weighing 148,5 gr/m^2, both made with 30/1 Ring 50% Co - 50% PES yarn is used.

As one of the parameters analyzed within the scope of this study, super-tear airlaid embroidery fusing papers with three different weights are used (Table 1). While the fusing paper outside the embroidered area is removed from the fabric, the fusing paper inside the embroidered area remains between the lower thread and the fabric thus can’t be removed. In this way, the embroidery looks more stable, but it also thickens the embroidered area. Beside the embroidery, the unremoved fusing paper has an additional increase in the thermal resistance values.

Table 1. Weight in grams of fusing papers

Fusing paper code	Weight in grams (g/m²)
FP1	35
FP2	40
FP3	50

Tajima DG16 by Pulse software is used to change the embroidery stitch lengths and create the pattern according to the widest sample size that covers the measurement areas of the testers. The embroideries are transferred to the fabric with Tajima SAI embroidery machine.

Figure 1. Tajima SAI embroidery machine

To determine the pTahysical properties of the base fabric and the samples prepared, precision scale, Textest FX 3300 air permeability tester and Wira thickness meter are used. Thermal comfort measurements are carried out on the SDL Atlas Sweating Guard Hotplate.

2.2 Method

In this research, 12 experimental groups are formed to determine the effect of the variables, which are 2 embroidery stitch lengths and 3 fusing papers, on physical properties and thermal comfort for both single jersey and pique fabrics (Table 2). The all tests are also conducted for base ground fabrics to determine effect of embroidery parameters. The embroidered samples are prepared on a square area of 20 cm*20cm (400 cm^2), complex fill embroidery type is used which fully covers the area. The reason of determination of the embroidery area as 20 cm*20cm is the measuring range of the tester, based on the Sweating guard hotplate sample size (the largest sample size).

Embroidery stitch length is determined as 0.4 cm and 0.5 cm in order not to cause fabric damage and not to affect the embroidery image quality adversely. Fabric damage may occur below 0.4 cm stitch length, and the embroidery image begins to deteriorate above 0.5 cm stitch length. The ground fabric is appearing between the stitches with a stitch length of 0.5 cm and above. This affects the visual quality of embroidery negatively (Fig. 2).

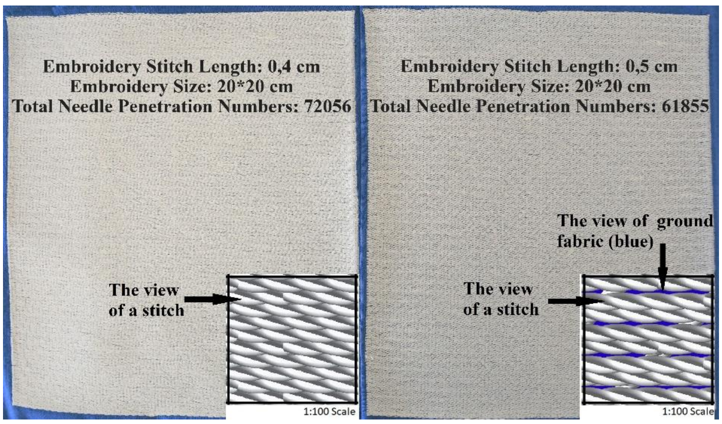

Figure 2. Embroidery stitch length samples (0.4cm/0.5cm) and the embroidery densities’ visuals taken on Pulse software (1:100 Scale)

Table 2. Experimental groups

Fabric Type	Experimental group	Fusing paper code	Embroidery stitch length (cm)
Pique	Base fabric (BF)	none	none
	1	FP 1	0.4
	2	FP 1	0.5
	3	FP 2	0.4
	4	FP 2	0.5
	5	FP 3	0.4
	6	FP 3	0.5
Single Jersey	Base fabric (BF)	none	none
	1	FP 1	0.4
	2	FP 1	0.5
	3	FP 2	0.4
	4	FP 2	0.5
	5	FP 3	0.4
	6	FP 3	0.5

Embroidery densities are automatically determined by Pulse software according to the embroidery stitch length. There are 72056 needle penetrations in the sample with 0.4 cm stitch length, and 61855 needle penetrations in the sample with 0.5 cm stitch length in the total embroidery areas.

After the preperation of the embroidered and base fabric samples; the weight in grams is measured according to the TS EN 12127 standard with 5 repetitions, the fabric thickness is measured according to the TS 7128 EN ISO 5084 standard using fabric thickness enstrument with 5 repetitions, the air permeability values are measured according to the TS 391 EN ISO 9237 standard using Textest FX 3300 air permeability tester with 10 repetitions, thermal resistance and water vapour resistance tests are carried out according to the TS EN ISO 11092 standard using SDL Sweating guarded hotplate with 3 repetitions.

3. RESULTS AND DISCUSSION

3.1 Results

The average results of all tests are presented in Table 3.

Within the scope of statistical analysis, test of normality is applied according to Shapiro-Wilk method to determine the compatibility of fabric type, fusing paper and embroidery stitch length parameters to physical properties and thermal resistance effects. It is determined that all values did not show normal distribution ($p \leq 0.05$), therefore, the Kruskal-Wallis test method is applied to all values. Kruskal-Wallis test is a very popular nonparametric test for comparing more than two independent samples [20].

Kruskal-Wallis test results are presented in Table 4, Table 5, Table 6 and Table 7. Regarding the results presented in Table 4, applying embroidery significantly affected all evaluated parameters for both pique and single jersey fabrics ($p \leq 0.05$).

Afterwards, to determine the effect of embroidery process separately for fabric types, the Kruskal-Wallis tests are conducted on sub-groups for all parameters. The results in Table 5 show that, the embroidery process has significant effect on fabric type sub-groups ($p \leq 0.05$).

After comparing the embrodeired and base fabrics, the Kruskal-Wallis tests are also conducted on all data obtained from only the embroidered samples. Table 6 shows the results regarding the effect of fabric type, fusing paper and embroidery stitch length parameters on weight, air permeability, thickness, water vapour resistance and thermal resistance values. It is determined that, all parameters are statistically significantly affected by embroidery stitch length parameters ($p \leq 0.05$). However, fabric type parameter shows a statistically significant effect on weight, thickness and water vapour resistance values ($p \leq 0.05$), whereas air permeability and thermal resistance are not statistically significantly affected ($p > 0.05$). Likewise, fusing paper does not show statistically significant effect on weight ($p > 0.05$).

Moreover, in order to determine the effect of fusing papers, the post-hoc tests are performed (Table 7). According to the results, the used three fusing papers do not statistically significantly change the weight in grams of the samples ($p > 0.05$). Similar impact could also be seen on fabric thickness, only the difference between FP1 and FP3, which are the lightest and the heaviest fusing papers in grams, respectively, is statistically significant ($p \leq 0.05$). regarding the air permeability test results, the differences between FP1 and FP2 as well as between FP1 and FP3 are statistically significant ($p \leq 0.05$), whereas the difference between FP2 and FP3 is not statistically significant ($p > 0.05$). The thermal resistance and the water vapour resistance values between FP1 and FP2 are not statistically significant ($p > 0.05$). However, the resistance values are statistically significant ($p \leq 0.05$) between FP1 and FP3 as well as FP2 and FP3.

Table 3. Average results

Fabric type	Experimental group	Weight in grams (g/m²)		Thickness (mm)		Air permeability (l/m²/s)		Thermal resistance Rct (m²/K/W)		Water vapour resistance Ret (m²/Pa/W)	
		Average	Std. Deviation	Average	Std. Deviation	Average	Std. Deviation	Average	Std. Deviation	Average	Std. Deviation
Pique	BF	199.4	1.259	0.82	0.0051	771	3.768	0.0176	0.00033	3.2	0.1304
	1	299.1	2.411	1.76	0.0313	122	4.827	0.025	0.00055	6	0.1581
	2	295.2	1.427	1.68	0.0278	136	4.183	0.032	0.00077	6.2	0.1871
	3	323.3	2.167	1.81	0.0246	101.3	2.793	0.026	0.00071	6.1	0.0639
	4	307.2	3.150	1.72	0.0190	116.3	5.541	0.0324	0.00007	6.2	0.0894
	5	332.3	2.484	1.9	0.0475	99.7	2.280	0.03	0.00039	6.2	0.0548
	6	314.6	1.377	1.79	0.0560	114.7	4.827	0.0326	0.00026	6.4	0.1140
Single jersey	BF	148.5	1.890	0.43	0.0078	737.2	1.031	0.0078	0.00063	1.9	0.0817
	1	265.3	0.929	1.44	0.0329	104	1.333	0.0181	0.00059	5.6	0.0639
	2	245.1	1.110	1.36	0.0318	122	0.648	0.0298	0.00035	5.7	0.0912
	3	266.3	0.540	1.5	0.0126	97.5	0.385	0.0192	0.00019	5.8	0.1009
	4	248	0.653	1.43	0.0247	115.2	0.642	0.0316	0.00022	5.9	0.0743
	5	267.6	1.791	1.55	0.0274	92.6	0.654	0.0268	0.00028	6.2	0.0932
	6	252.9	2.285	1.48	0.0116	110.4	0.884	0.0346	0.00020	6.4	0.0713

Table 4. Kruskal-Wallis test results of embroidery process effect for all fabric types

		Weight in grams	Air permeability	Thickness	Thermal resistance	Water vapour resistance
Embroidery process effect	Kruskal-Wallis H	25.354	25.359	25.353	24.366	25.508
	df	1	1	1	1	1
	Asymp. Sig.	0.000	0.000	0.000	0.000	0.000

Table 5. Kruskal-Wallis test results of embroidery process effect on fabric type sub-groups

		Weight in grams	Air permeability	Thickness	Thermal resistance	Water vapour resistance
Base single jersey-embroidered single jersey	Kruskal-Wallis H	12.500	12.516	15.502	12.525	12.768
	df	1	1	1	1	1
	Asymp. Sig.	0.000	0.000	0.000	0.000	0.000
Base pique-embroidered pique	Kruskal-Wallis H	12.509	12.502	12.502	12.521	12.585
	df	1	1	1	1	1
	Asymp. Sig.	0.000	0.000	0.000	0.000	0.000

Table 6. Kruskal-Wallis test results for all parameters

		Weight in grams	Air permeability	Thickness	Thermal resistance	Water vapour resistance
Fabric type	Kruskal-Wallis H	44.268	5.052	44.265	2.600	11.776
	df	1	1	1	1	1
	Asymp. Sig.	0.000	0.025	0.000	**0.107**	0.001
Fusing paper	Kruskal-Wallis H	5.386	20.311	7.235	10.775	27.527
	df	2	2	2	2	2
	Asymp. Sig.	**0.068**	0.000	0.027	0.005	0.000
Embroidery stitch length	Kruskal-Wallis H	6.695	26.786	5.457	41.120	4.999
	df	1	1	1	1	1
	Asymp. Sig.	0.010	0.000	0.019	0.000	0.025

Table 7. Kruskal-Wallis test results of fusing paper sub-groups

		Weight in grams	Air permeability	Thickness	Thermal resistance	Water vapour resistance
FP1-FP2	Kruskal-Wallis H	3.690	12.949	2.336	1.654	3.378
	df	1	1	1	1	1
	Asymp. Sig.	**0.055**	0.000	**0.126**	**0.198**	**0.066**
FP2-FP3	Kruskal-Wallis H	1.230	1.905	2.678	5.876	19.746
	df	1	1	1	1	1
	Asymp. Sig.	**0.267**	**0.168**	**0.102**	0.015	0.000
FP1-FP3	Kruskal-Wallis H	3.535	15.710	5.927	8.698	19.141
	df	1	1	1	1	1
	Asymp. Sig.	**0.060**	0.000	0.015	0.003	0.000

3.2 Discussion

When the embroidery stitch length decreases, the needle penetration number increases. The needle penetration numbers are directly proportional to the number of lower thread - upper thread joints. Therefore, the amount of thread used increases, the average weight in grams and fabric thickness values relatively increase (Fig. 3).

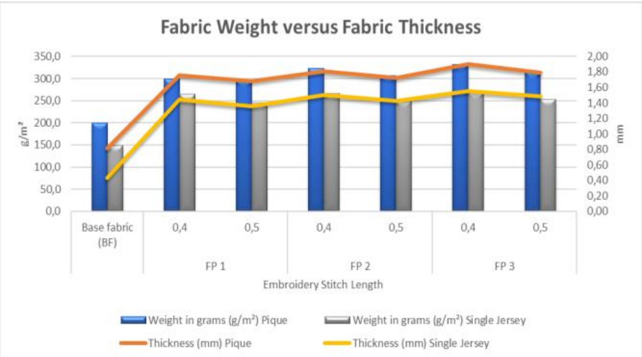

Figure 3. Fabric weight vs. fabric thickness

According to the statistical analysis results, all values are statistically significantly affected by embroidery stitch length parameters for pique and single jersey fabrics ($p \leq 0.05$). These results show the pique and single jersey samples prepared by different embroidery stitch lengths have significantly different test values in terms of weight in grams, air permeability, fabric thickness, thermal resistance and water vapour resistance.

An increase in the weight and thickness of the fabric decreases in the value of air permeability. When the base fabric and the embroidered fabrics are compared, it is observed that the increase in weight causes a significant decrease in air permeability values. When the same fusing paper is used, it is observed that the increase in the number of lower thread - upper thread joints also increase the weight and thickness, thus partially decreases the air permeability value (Fig. 4). This situation similarly happens for both pique and single jersey fabrics, however, due to the honeycomb structure of pique fabric; the base fabric has higher air permeability results. Moreover, fusing paper has a significant effect on air permeability values of pique and single jersey fabrics ($p \leq 0.05$). However, fabric type has a statistically significant effect on air permeability values of samples prepared using fusing paper 1 (FP 1) ($p \leq 0.05$) whereas air permeability values of samples prepared using FP 2 and FP 3 are not statistically significantly affected ($p>0.05$).

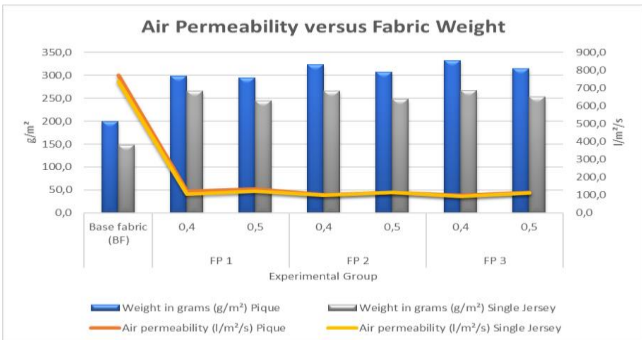

Figure 4. Air permeability vs. fabric weight

The increase in fabric weight and thickness enhances the thermal and water vapour resistance. When the base fabric and embroidered fabrics are compared, thermal resistance and water vapour resistance value significantly increase. Additionally, at fixed stitch length, the increase in weight and thickness of embroidery with the increase in fusing paper weight causes the thermal resistance and water vapour resistance to increase. However unexpectedly, when the same fusing paper is used, since the increase in needle penetration number also increases the needle holes on the fabric and thus relatively decreases the thermal and water vapour resistance (Fig. 5 and Fig. 6). The statistical analysis proves this situation, as air permeability, thermal resistance and water vapour resistance values are statistically significantly affected by embroidery stitch length parameters for all fusing papers ($p \leq 0.05$).

The obtained results also prove that embroidery using the same fusing paper with different types of fabrics has effects on the thermal properties of the garment ($p \leq 0.05$). However, in the statistical analysis performed for all fusing paper parameters in terms of fabric types, it is seen that, the fabric type doesn't statistically significantly affect the thermal resistance value for all fusing papers ($p>0.05$). in other words, changing the fusing paper has a greater effect regarding fabric type.

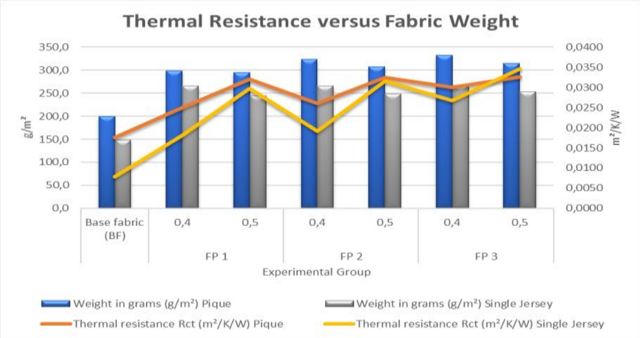

Figure 5. Thermal resistance vs. fabric weight

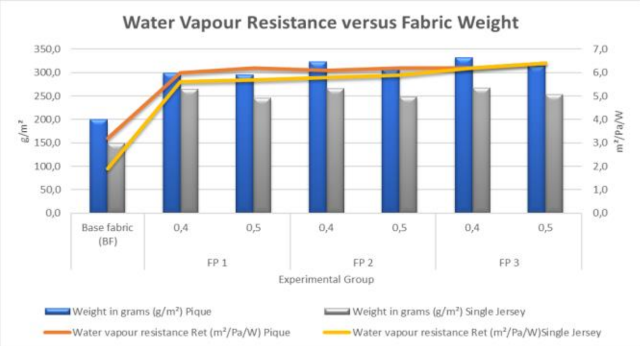

Figure 6. Water vapour resistance vs. fabric weight

4. CONCLUSION

The effect of different stitch types on clothing comfort is studied by Oğlakçıoğlu [17]. However, no study conducts an intense sewing or even investigates the fusing paper and embroidery stitch length factor together on clothing comfort. As a result of this study, it has been observed that embroidery affects the clothing comfort properties of a garment. The increase in the weight of the fusing paper used and increase in the needle penetration number affect the thermal behavior. As an outstanding conclusion, when the same fusing paper is used, the increase in needle penetration number relatively decreases the thermal and water vapour resistance, due to the increased number of needle holes. Considering these data, it is revealed that embroidery has significant effects on the clothing comfort; therefore, it should be used on a minimum area of the clothing and especially outside the sweating areas of the body. Keeping the weight of the fusing paper, which is used to ensure stability in the embroidered area, at the minimum level (according to quality criteria) will reduce the negative effects on clothing comfort.

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