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Dependence of warm or cold feeling and heat retention ability of knitwear from digital print parameters

ABSTRACT

Textile materials are increasingly being subjected to the process of printing. The printing process with its parameters significantly affects the properties of textile materials and clothes made from these materials. This paper examines the effect of the parameters of digital printing on thermo-physiological characteristics of printed textile materials. As the essential print parameters were selected tone value and a different number of passes. In this research were used knitted fabric materials of 100% cotton fibers (100% CO), 100% polyester fibers (100% PES) and their mixture (50%CO/50% PES). The influence of print parameters to thermo-physiological properties of the material is evaluated through a warm or cold feeling and heat retention ability. Results of the research demonstrated that, in addition to material composition, the printing process with its parameters have a significant influence on the thermo-physiological characteristics of textile materials.

KEY WORDS
digital printing, textile materials, thermo-physiological comfort, warm or cold feeling, heat retention ability

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Introduction

The rise of the living standards of individuals conditioned a major shift of the textile and clothing manufactures because the demands of customers today are higher than they used to be. For today's customers is not enough that clothes meets only basic functions, such as body protection and functionality, but also from clothing is expected to meet the aesthetic fashion requirements, so on that way it can better depict the personal character and lifestyle of the individual (Grujić, 2010). Increase of the aesthetic value of textile materials, and therefore the clothes, is more often carried out with printing process. Textile printing can be best described as the art and science of decorating a fabric with a colourful pattern or design (Tippett, 2002). Some estimates indicate that more than 27 billion m^2 of textile material substrates are printed every year (Provost, 2009). Also, it is considered that printing of textile materials has annual growth of 2% (Momin, 2008). Printing on the textile substrates can be achieved using variety of different techniques and machines (Novaković et al, 2010). The most suitable printing techniques for textile substrates are: screen printing, digital ink-jet printing and thermal transfer printing (Stančić et al, 2014). Today, the most dominant textile printing technique is screen printing, although digital ink jet printing is rapidly expanding in the textile markets. The efficacy of ink jet printing as a flexible ink transfer method is primarily based on its cost and time saving for small print runs (Kašiković et al, 2012). What more, this printing technique enables achieving better visual effects, far more flexible formats, besides with the repeated printing process better reproducibility and consistent quality is achieved (Owen, 2003; Xue et al, 2006). The world of textile printing is rapidly changing and digital textile printing technology supports the industrial trends: integration in a digital workflow, qualitative and short runs, fast turnaround orders, reduced stock risks, exclusive, unique designs and personalized textile, demanding an ability to supply rapidly (Onar Çatal et al, 2012). Also, digital printing technologies are considerably cleaner than conventional ways of applying colour to textiles (Tyler, 2005).

The man practically wears clothes twenty-four hours a day, and needs to feel comfortable, attractive and relaxed. Wearing comfort is one of the crucial quality characteristics of certain clothing on the basis of which buyer decides whether it fits or not, or whether it feels good or bad (Mecheels, 1991). What man in general registers as wearing comfort, mainly consists of three components, every of them should for itself be optimized for textiles and clothing construction and those are: thermo-physiological, ergonomic and mechanical wearing comfort. That is, the clothes have a task to satisfy three functions: aesthetic, ergonomic and physiological (Mecheels, 1992).

Whether clothing meets the aesthetic and ergonomic requirements, one can easily judge while it wears certain clothes for the first time, however, it is different with physiological function. Clothing with good thermo-physiological characteristics have to allow users thermo-physiological balance of the body with minimal effort at different climatic conditions and different physical activities, it means that man in this clothes feel neither cold nor heat, but thermo-physiological comfort (Grujić, 2010). Clothing is an obstacle to the free circulation of heat, ie. boundary layer between the body and the environment (Umbach, 1978). Clothing must allow a certain thermal insulation, a high degree of moisture permeability and good ventilation to maintain optimal thermal regulation of the human body. The result of balanced interaction in the system „man- climate- clothing“ is expressed in human comfort when wearing clothes.

Earlier studies have indicated that the thermo-physiological characteristics of clothing depend on the composition of fibers, spinning technology, weaving or knitting, the yarn thickness, density fabrics and knitwear, surface mass and surface structure, and finishing processes (Mecheels & Umbach, 1976). For further knowledge in this paper the impact of the printing process, as a means of achieving aesthetic function of clothing, has been tested on the thermo-physiological characteristics of textile materials. To that end, was analyzed the dependence of warm or cold feeling and heat retention ability from the print parameters: the tone value and the different number of passes.

Methods and materials

Research of the effect of tone value and a different number of passes on warm or cold feeling and heat retention ability was performed on three types of textile knitwear, of approximately the same surface mass and surface structures but different material composition. Material characterization was done according to following parameters: material composition (ISO 1833), fabric weight (ISO 3801) and thread count (ISO 7211-2). Characteristics of the materials are presented in Table 1.

Table 1

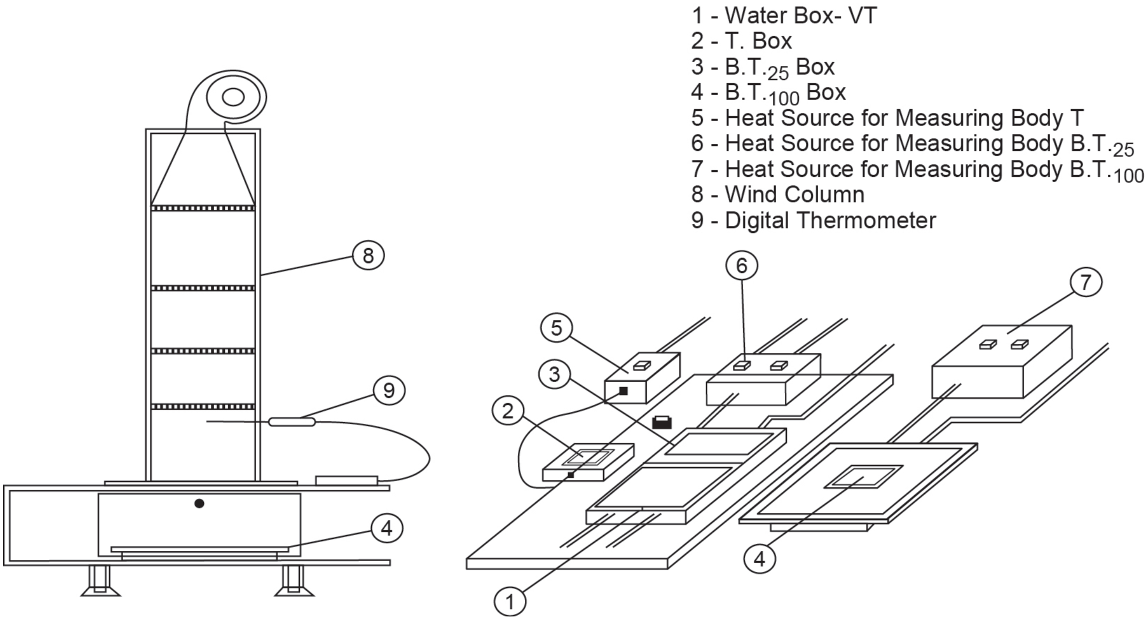
Characteristics of materials used in research

Sample	Material type	Type of weaves	Material composition (%)	Fabric weight (g/m^2)	Thread count (cm^{-1})
PCO	Knitwear	Single	Cotton 100 %	111.89	Dv = 17 Dh = 17
PPES	Knitwear	Single	Polyester 100 %	114.12	Dv = 12 Dh = 20
PCO/PES	Knitwear	Single	Cotton 50 % Polyester 50 %	128.50	Dv = 14 Dh = 20
Method			ISO 1833	ISO 3801	ISO 7211-2

For this study it was created a special test image using Adobe Illustrator CS5 software. Test image contained 200 x 200 mm patches, with 10 %, 50 % and 100 % tone values of black process colour.

Samples were printed by ink-jet printing system Polyprint TexJet. Samples were printed in one, three and five passes, resolution 720 x 720 dpi. It was printed with water-based inks (Artisti Pigment Ink- P5400 Black). Because of a need for a low viscosity, inks contain demineralised water (51%), the appropriate pigment (1-5%), poly (oxyethylene) (14%), ethane-1.2-diol (12%), 1-methyl-2-pyrrolidone (15%), poly (1-hydroxyethylene) (3%), tris(2-hydroxyethyl)amine (1%), biocide (0.1%) and buffer (0.3%). Ink Fixation is performed at a temperature of 130 ^{O}C for 120 seconds.

Examination of warm or cold feeling and heat retention ability of knitwear is performed with KES-F7 (Thermo Labo II) measuring device. Measuring device Thermo



» **Figure 1:** *Components of measuring deviceKES-F7 Thermo Labo II*

Labo II for analyzing thermal properties is consisted of next components (Figure 1.): Measuring body T, used for measuring warm or cold feeling; Measuring body BT, used for measuring constant thermal conductivity; Larger measuring body BT, used to measure heat loss, to determine the thermal resistance, resistance to the flow of water vapour and to determine the ability to retain heat; Measuring body with water VT, used to maintain a constant temperature while measuring warm or cold feeling and the coefficient of thermal conductivity; and Wind column, where was constant air flow rate of 1 ms^{-1} at a constant air temperature of 20 ^{0}C ± 2 ^{0}C. The wind column measure heat loss ie. heat flow, which is used for the determination of heat retention ability, heat resistance and resistance to the flow of water vapour.

Warm or cold feeling represents the transfer of heated measuring body to the sample which has lower temperature. The peak value of the transferred heat, which is reached for 0.2 seconds from the moment of contact, is warm or cold feeling-qmax [W/cm^2]. To determine the warm or cold feeling were used: BT plate with a heat source, heated to the temperature of 32 ^{0}C, simulating a human skin temperature, measuring body T and the measuring body with water VT, on which is deposited the 50 x 50 mm sample. On preheated BT board is laid measuring body T, heated to the temperature of 32 ^{0}C. When the measuring body T reached a desired temperature of 32 ^{0}C, it was placed on the sample that lay on the measuring body with water of the air temperature of 20 ^{0}C, and the value which appears on the display after about two seconds is qmax. The values of qmax may be higher or lower depending on the tested material, ie. if the obtained values are higher, it says that clothes made of that material give a feeling of cold and vice versa. Coefficient of heat retention ability is determined by the wind column. The BT plate is heated to a temperature of 35 ^{0}C and the heat loss ie. heat flow is measured. In wind column is present a constant air flow rate of 1 ms^{-1}, with a constant air temperature of 20 ^{O}C ± 2 ^{O}C. Constant air flow is achieved by switching the fan. Loss of heat flow can be determined by the following methods: dry contact method, dry contactless method, wet contact method, wet contactless method. In presented studies is used a dry contactless method. From the obtained values of the loss of heat flow is determined the heat retention ability, which is expressed with the coefficient of heat retention ability α, according to the formula:

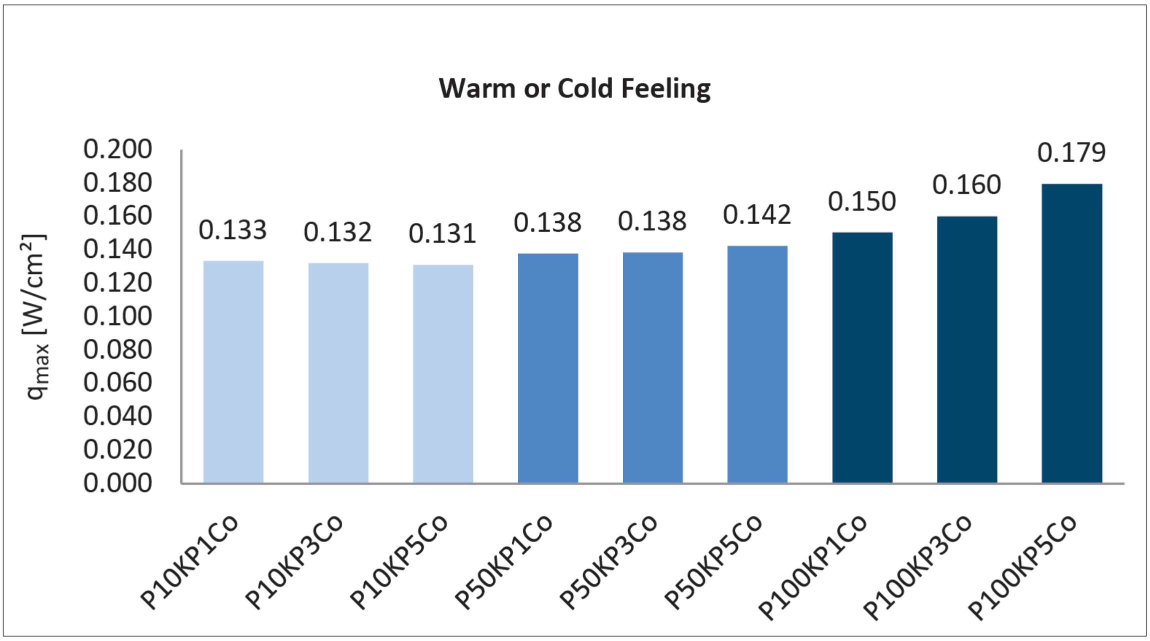
$$\alpha=((Wo-W)/Wo) \times 100\ [\%] \quad (1)$$

where:
W- value of loss of heat flow with the sample at standard temperature (20 ^{O}C) and relative humidity (65 %) [W],
Wo- value of loss of heat flow without the sample at standard temperature (20 ^{O}C) and relative humidity (65 %) [W].

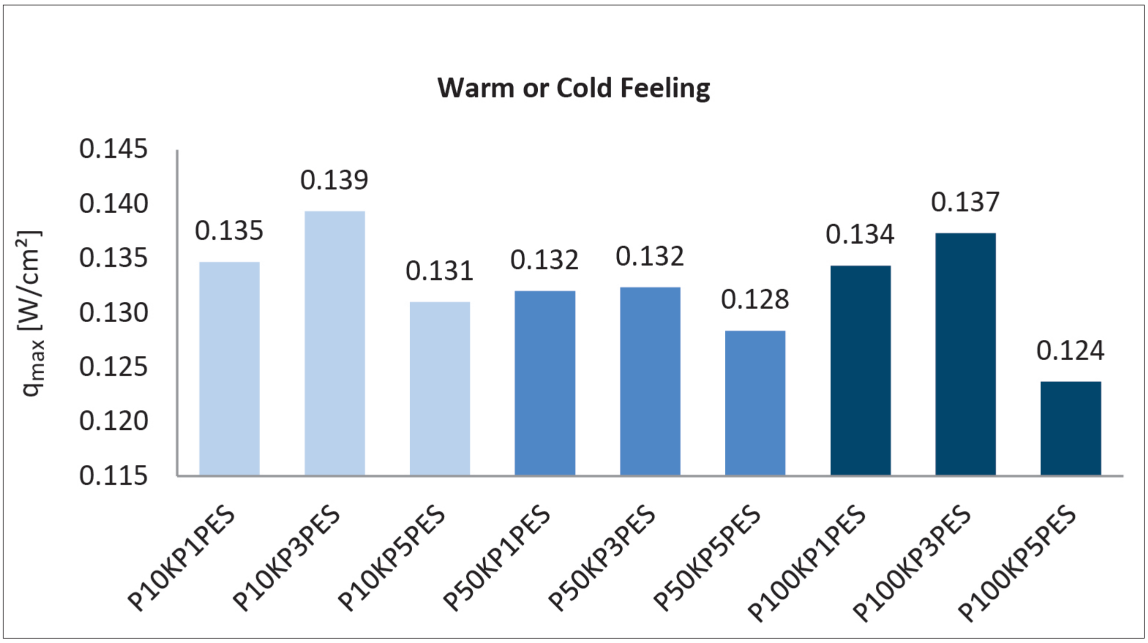
Results and discussion

Warm or cold feeling analysis

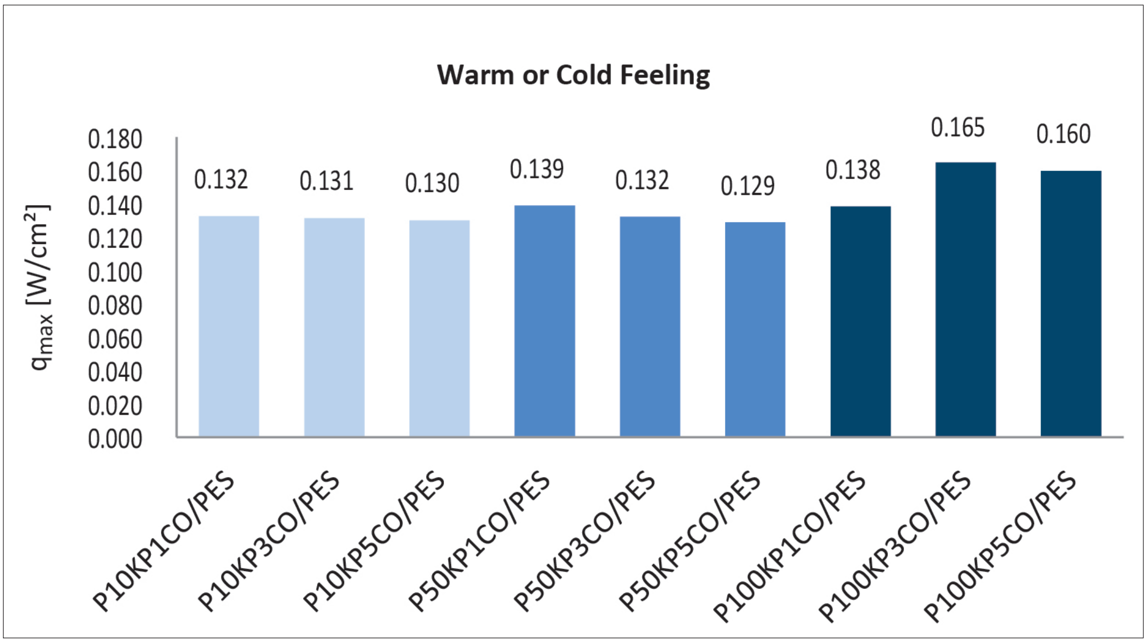
Test results of warm or cold feeling of selected printed cotton knitwear are shown in Figure 2. Using KES-F7 Thermo Labo II measuring device, it was obtained warm or cold feeling result of tested, unprinted cotton knitwear and it was 0.144 [W/cm^2]. Comparing that value with the values of printed samples (Fig. 2) it can be noticed that on the samples printed with 10% and 50% of tonal values the value of warm or cold feeling decline in relation to unprinted samples, ie. these samples give a warmer feeling compared to unprinted samples. For samples printed with 100% tonal value of black are noticed the higher results of warm or cold feeling in relation to unprinted samples, ie. these samples give a colder feeling compared to unprinted samples. Also, it is revealed that the increase of tone value leads to higher values of warm or cold feeling. Observing the values of the samples printed with 10% tonal value notes that were recorded almost identical values in printing with a different number of passes. For samples printed with 50% tonal value obtained are identical values of the samples printed in one pass and samples printed in three passes. Slightly higher value is recorded on samples printed in five passes. The highest values were noted on samples with a tone value of 100%. Thereby, with increase of number



» **Figure 2:** *Warm or cold feeling of cotton knitwear subjected to the printing process (Note: P mark indicates knitwear, 10, 50 and 100 denote a print with 10%, 50% and 100% of tonal values, K is a black ink mark, P1, P3 and P5 are the marks of the print with 1, 3 and 5 passes, CO stands for cotton)*



» **Figure 3:** *Warm or cold feeling of polyester knitwear subjected to the printing process (Note: P mark indicates knitwear, 10, 50 and 100 denote a print with 10%, 50% and 100% of tonal values, K is a black ink mark, P1, P3 and P5 are the marks of the print with 1, 3 and 5 passes, PES stands for forpolyester)*



» **Figure 4:** *Warm or cold feeling of CO/PES knitwear subjected to the printing process (Note: P mark indicates knitwear, 10, 50 and 100 denote a print with 10%, 50% and 100% of tonal values, K is a black ink mark, P1, P3 and P5 are the marks of the print with 1, 3 and 5 passes, CO/PES stands for mixture of cotton and polyester)*

of passes were obtained higher values of warm or cold feeling. Test results of warm or cold feeling of selected printed polyester knitwear are shown in Figure 3. The measured value of the warm or cold feeling of unprinted polyester knitwear is 0.140 [W/cm^2]. From Figure 3 can be noticed that the printed samples, in the print of all tonal values and the number of passes, give lower values of warm or cold feeling in relation to unprinted sample.

This shows that the clothes made of printed polyester knitwear give warmer feeling compared to knitwear without printing. By analyzing the samples printed with a 10% tonal values can be noticed that the highest value was achieved with print in three passes. Slightly lower values were achieved with print in a single pass, while the lowest values were recorded during the print with five passes. The values of the samples printed with 50% tonal values were almost identical in print with a different number of passes. In print with a 100% tonal values the highest values were recorded during the print with three passes, slightly lower in print with a single pass, and significantly lower in print with five passes. Next, observing the samples with the number of passes can be noticed that the highest results were achieved in print with three passes, then in print with a single pass and the lowest values were achieved during the print with five passes.

The measured value of the warm or cold feeling of unprinted CO/PES knitwear is 0.142 [W/cm^2]. Comparing this value with the values of printed samples (Fig. 4) can be noticed that the values of printed samples are lower, except for samples printed with 100% tonal values with three and five passes. Analyzing the results, it’s noticed that the values of the samples printed with 10% tonal values were almost identical in the print with a different number of passes. For samples printed with 50% tonal values the highest values were achieved with a single pass print, slightly lower with three passes print and the lowest with five passes print. For samples printed with 100% tonal values the highest values were achieved with the three passes print, slightly less with five passes print and significantly lower with single pass print. Furthermore, the observation of the measured values on samples printed in a single pass showed that the value of the printed samples with 50% and 100% tonal values were almost equal, while the values of the samples printed with 10% tonal values were lower. In print with three passes warm or cold feeling values of the samples printed with 10% and 50% tone values are almost equal, and samples printed with a 100% tonal value show considerably higher results. The five passes print had the same trend of warm or cold feeling values as well as the three passes print, only with the slightly lower values.

Heat retention ability analysis

The measured values of the stationary heat flow and calculated results of heat retention ability of selected printed cotton knitwear are shown in Table 2. Analysis of calculated values of heat retention ability shows that with the samples printed with 10% tone value with increase of the number of passes comes to increase of ability to retain heat. Samples printed with 50% tonal values in single pass and three passes have equal value of heat retention, while the samples printed with five passes have a slightly higher ability to retain heat.

Table 2
Heat retention ability of cotton knitwear subjected to printing process

Sample	Stationary heat flow φ [W]	Heat retention ability α [%]
P10KP1CO	1.95	27.18
P10KP3CO	1.91	28.43
P10KP5CO	1.91	28.55
P50KP1CO	1.99	25.56
P50KP3CO	1.99	25.56
P50KP5CO	1.97	26.31
P100KP1CO	2.05	23.32
P100KP3CO	1.95	27.06
P100KP5CO	1.98	25.94
PCO	1.85	30.92

Samples printed with 100% tonal value have the highest ability to retain heat with the three passes print, slightly lower at the print with five passes and the lowest in the single pass print. Also, it can be seen that in a single pass print with increasing of tonal value comes to reducing the ability to retain heat. With three passes print highest values were achieved with the tonal values of 10%. The increasing of tonal values to 50% reduces the value of heat retention. Further increasing of tonal values to 100% leads to new increase of heat retention ability. However, the obtained values are still lower than the value of the samples printed with the 10% tone value. At the five passes print with increase of tonal values, the heat retention ability declines.

In Table 3. are shown the measured values of the stationary heat flow and heat retention ability of selected printed polyester knitwear.

Table 3
Heat retention ability of polyester knitwear subjected to printing process

Sample	Stationary heat flow φ [W]	Heat retention ability α [%]
P10KP1PES	2.13	20.20
P10KP3PES	2.10	21.32
P10KP5PES	2.11	21.07
P50KP1PES	2.07	22.57
P50KP3PES	2.11	21.20
P50KP5PES	2.13	20.45
P100KP1PES	2.07	22.57
P100KP3PES	2.00	25.31
P100KP5PES	2.11	21.07
PPES	2.07	22.45

Considering the values of the ability to retain the heat from Table 3. it was noted that the single pass print value was nearly equal to the tonal value of 10% and 50%, while the tonal value of 100% is slightly higher. At the print with three passes results of heat retention ability behave in the same way, with values higher than the values obtained on samples that were printed with a single pass. At the five passes print heat retention ability is equal to the field of 10% and 100% of tonal values, while 50% field of tonal values has lower ability to retain heat. It also notes that in the printing with the three passes were samples with the highest heat retention ability. At the same time results of samples printed with five passes show that they had the lowest heat retention ability.

In Table 4. are shown the measured values of the stationary heat flow and heat retention ability of selected printed CO/PES knitwear.

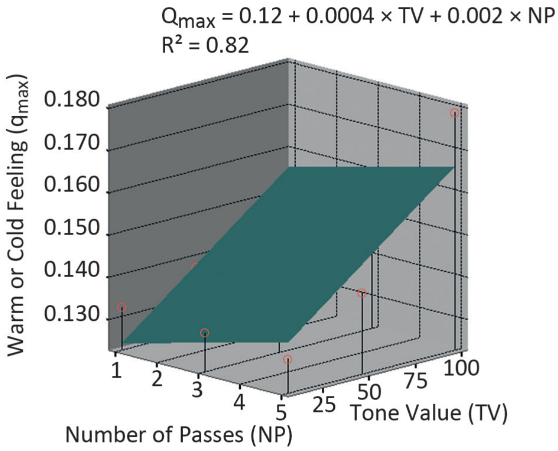
Table 4
Heat retention ability of CO/PES knitwear subjected to printing process

Sample	Stationary heat flow φ [W]	Heat retention ability α [%]
P10KP1CO/PES	1.88	29.55
P10KP3CO/PES	1.94	27.31
P10KP5CO/PES	1.97	26.19
P50KP1CO/PES	1.95	27.18
P50KP3CO/PES	1.98	25.81
P50KP5CO/PES	1.96	26.68
P100KP1CO/PES	1.98	25.81
P100KP3CO/PES	1.99	25.44
P100KP5CO/PES	1.97	26.43
PCO/PES	1.87	30.05

The results from Table 4. show that with one and three passes print increasing the tonal values decrease the ability to retain heat. Thereby, lower values were noted with three passes print. With five passes print ability to retain heat is approximately equal in all tonal values. In print with 10% tonal values parameter of thermal properties α has lower values than the values obtained in the print with a single and three passes. Value of parameter α on fields with 50% and 100% tone value were slightly higher than the same field printed with one and three passes.

Statistical analysis of results

To determine the dependence of the number of passes and tonal value on warm or cold feeling and heat retention ability were used simple and multiple regression analysis. Simple linear regression analysis showed a statistically reliable dependence of warm or cold feeling of tonal values for cotton knitwears ($q_{max} = 0.1261 + 0.0003 \cdot TV$) with a linear regression coefficient $R^2 = 0.74$, while the coefficient of simple regression for PES and CO/PES knitwear were significantly lower. Processing of results of cotton knitwear using multiple linear regression analysis also show statistically reliable dependence of warm or cold feeling of tonal values and the number of passes, Fig. 5, the multiple regression coefficient was R^2=0.82.



» **Figure 5:** *Graphic representation of warm or cold feeling dependence from tonal value and number of passes*

The coefficient of multiple linear regressions for PES and CO/PES knitwear had significantly lower values and therefore statistical dependence of q_{max} of tonal values and the number of passes is not significant. Obtained statistical dependencies of heat retention ability of tonal values and the number of passes are significant because the multiple regression coefficients were ranged from 0.42 for PES knitwear to 0.64 for cotton knitwear.

Conclusion

Textile materials are increasingly being subjected to the process of printing. This paper examines the effect of the parameters of digital printing on thermo-physiological characteristics of printed textile materials. For this purpose, the influence of the tonal value and different numbers of passes in print on the warm or cold feeling and the heat retention ability.

In the analysis of cotton and CO/PES knitwear it was noted that increase of the tonal values well as increase of number of passes leads to increase of the warm or cold feeling. In printing the polyester knitwear initial increase of tonal value results in reduction of warm or cold feeling, while further increasing of tonal value leads to a growth of the value of warm or cold feeling. This confirms that the change in the tonal value or the number of passes, as the parameters of digital printing, can affect change in warm or cold feeling. Depending on whether the textile material is intended for making summer or winter clothing the parameters of the print should be adjusted, in order to obtain lower or higher values of warm or cold feeling. Analysis of the heat retention ability indicates that this parameter may be affected by the parameters of the print. The study noted that increasing the tonal values of cotton knitwear decrease heat retention ability. At the same time with increase of number of passes comes to increase of value of this parameter. The increase of tonal value of polyester knitwear leads to the growth of heat retention ability. Increasing the tonal values in CO/PES knitwear will lead to a drop in ability to retain heat, as well as increasing the number of passes. Also, in cotton and CO/PES knitwear was noticed a greater ability to retain heat compared to PES knitwear. Test results of multiple linear regression analysis showed a statistically reliable dependence of warm or cold feeling- q_{max} from the number of passes (NP) and tonal values (TV) of cotton knitwear, with a coefficient of multiple regression R^2 = 0.82.

Summarizing the results it can be concluded that the print parameters have an important effect on warm or cold feeling and the heat retention ability, as one of the important parameters of the thermal comfort of textile materials. It is significant to note that on the parameters of thermal characteristics of materials, such as warm or cold feeling and the heat retention ability, tonal values have higher influence then number of passes. In order to further knowledge it is planned to test how other process colours affect the studied parameters. Also, research is needed to expand to other physiological parameters of thermal comfort, such as thermal conductivity, thermal resistance, resistance to the flow of water vapour and others. In addition to the knitwear tests listed research is needed to carry out on fabrics too.

Acknowledgements

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