Coll. Antropol. **37** (2013) 1: 57–64
Original scientific paper

Evaluating Thermophysiological Comfort Using the Principles of Sensory Analysis

Ivana Salopek Čubrić and Zenun Skenderi

University of Zagreb, Faculty of Textile Technology, Department of Textile Design and Management, Zagreb, Croatia

A B S T R A C T

Thermophysiological comfort applies to the way in which clothing lets through or retains heat and moisture and helps the body retain heat balance in rest position or at various levels of activities. In this paper, the principles of sensory analysis are used to define the protocol of new method for the evaluation of thermophysiological comfort wearing different garments. Sensory analysis was chosen because as a scientific discipline that applies experiment principles using human senses is used for the evaluation of consumer goods. Test protocol using assessors described in this paper consists of the following steps: defining the interview content, finding potential assessors and making an interview, creating a survey, conducting a survey, group discussion, test and group discussion scoring, selection of assessors, assessment preparation and subjective assessment. On average the most distinctive increase in the sensation of warmth was recorded for the polyester clothing ensemble, and the lowest one for the cotton clothing ensemble. Concerning the average grades of comfort given by assesors, the most comfortable clothing ensemble is the one made of viscose. It was also found out that the method is especially suitable if a representative group of assessors is formed.

***Key words**: thermophysiological comfort, sensory analysis, evaluation method, assesors, garment*

Introduction

Thermophysiological comfort applies to the way in which clothing lets through or retains heat and moisture and helps the body retain heat balance in rest position or at various levels of activities. It is also defined as »the state of mind expressing satisfaction with environmental heat«[1,2]. This kind of state can be determined as thermally neutral since the individual does not prefer either warmer or colder environmental conditions. The most important variables affecting human thermal comfort can be categorized into the following groups[3]: clothing influence (thermal resistance, resistance to water vapor transfer,...), environmental influence (temperature, relative humidity, air speed) and the level of physical activities. Methods of testing properties essential for the characterization of thermophysiological comfort primarily apply to the measurement of heat and water vapor passage in the static and dynamic state. Generally, the mentioned test methods can be divided into three groups: methods of measuring the properties of surface materials (hot-plate instrument)[4,5], methods of measuring the properties of garments (mannequin)[6] and methods of measuring the comfort of garments using test wearing[7].

Methods of garment test wearing have a great significance in the procedure of evaluating thermophysiological comfort. Such test methods unlike objective methods of testing the properties of materials related to thermophysiological comfort can in certain cases provide even more real indications of comfort, which are in accordance with perceptions of potential garment customers. In addition, the knowledge about thermophysiological comfort given by assessors is essential for the development of new products and marketing of the product tested. Testing is done in controlled laboratory conditions maintaining the temperature and relative air humidity constant, and subjects give a rating of material comfort. During and upon completion of testing the subjects fill in evaluation questionnaires and give numerical grades to the questions about comfort level. Basic comfort scales are: Bedford scale, ASHRAE scale and MTV scale. The Bedford scale was introduced in 1936 on the basis of investigating comfort ratings of persons who performed easier jobs in the industry. Bedford classified answers in a scale of seven grades with corresponding ratings from 1 to 7, where rating 1 means »too hot«, and 7 »too cold«. Bedford con-

Received for publication February 24, 2010

cluded later that it is more practical to mark »comfortable« with zero, and sensations related to heat increase with positive values, and those related to cold increase with negative values. He also suggested that as a zero zone should be defined the zone in which more than 70% of subjects feel comfortable, and at least 86% of subjects rates the same zone between »comfortably warm« and »comfortably cool«.

ASHRAE was created in 1971 on the basis of a study in which the level of comfort was correlated with the parameters of temperature, moisture and length of exposure to an individual parameter. A scale in compliance with Bedfords considerations was created which contains seven levels in the range of marks of –3 to +3, and it is symmetrical around zero level. The conclusions of the studies helped to create ASHRAE 55 standard in 1992. According to this standard as comfort zone is defined that zone in which 80% of subjects resting or performing easier jobs find acceptable. Within the framework of this standard comfort zones are defined which correspond to the clothing with insulation values between 0.5 clo (summer clothes) and 0.9 clo (winter clothes). On the basis of the comparison of heat transfer in 30 different climatic conditions and subjective investigation conducted for 20 subjects grades for each of the climatic conditions were created and MTV (Mean Thermal Vote) was formed. Grades on the scale range from –3 (too cold) to +3 (too hot). In this scale the grades in the range from –1 to +1 are considered satisfactory for comfort evaluation.

The principles of sensory analysis to define the protocol of investigation and evaluation of clothing articles were used within the scope of this paper. Sensory analysis was chosen because as a scientific discipline that applies experiment principles using human senses is used for the evaluation of consumer goods. For the needs of the experiment described in the paper sensory analysis was modified and adapted to testing textile structures.

Material and Methods

Sensory analysis

Sensory analysis is a scientific discipline used to measure, analyze and interpret the characteristics of food and materials perceived by human senses. As such it is particularly successfully applied in the food and cosmetics industry. To evaluate product properties, one sense or more senses are used, namely: sense of sight (eyes), sense of smell (olfactory epithelium in the nose base), sense of taste (papillae in the mouth), sense of touch (mechanical receptors in the mouth, skin, mucous membrane, joints and muscles) and sense of hearing (ears). Sensory analysis answers the quality questions which can be categorized as follows: discrimination, description and preference. Specific insights of the sensory analysis consist of the understanding of physiology and psychology of sensory perception, understanding the significance of sensory properties, ability of planning and performing sensory analyses to obtain a desirable answer, result analysis and determination of correlation of sensory and instrumental methods. The basic purpose of this evaluation is to provide valid and reliable information for the purposes of product research and development, production and marketing in order for management to make correct decisions on the basis of perceived sensory product properties.

The main phases of the sensory analysis are the following: finding potential assessors (it includes defining the interview contents, finding an assessor and making an interview), selection of assessors (it includes creating and conducting a survey, doing a capability test, group discussion, test scoring and group discussion scoring, final decision on the selection of assessors), assessment preparation and assessment.

Experimental

Test protocol using assessors described in this paper consists of the following steps: defining the interview content, finding potential assessors and making an interview, creating a survey, conducting a survey, group discussion, test and group discussion scoring, selection of assessors, assessment preparation and subjective assessment. Graphical representation of assessors' participation in the mentioned test steps, depending on the outcome of each step (»positive« + or »negative« –) is shown in Fig. 1.

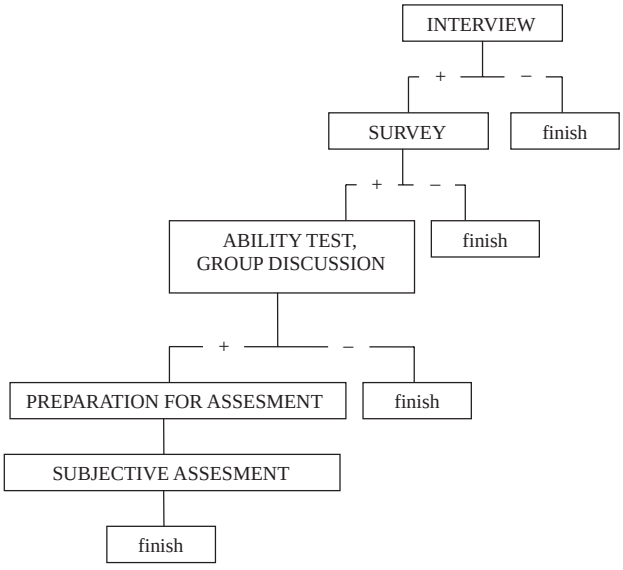

Fig. 1. Assessors' participation in the test steps.

Definition of the interview content

The interview should allow the subject to get rid of formal, content-related and psychological limitations; thus, the so-called »free interview« has been chosen which is in its form similar to »plain« talk. The interview should provide an insight into the following from potential assessors: understanding of the test concept, general interest in assessing item and test availability (concerning duration of the test).

Finding assessors and making an interview

According to the basic recommendations of sensory analysis[8] potential assessors are persons who are in no way included into research work or any similar project, and they were found by spoken means. As for the purpose of subjective assessment men's clothing ensembles in one size were made, potential assessors had to be male persons of regular figure and stature of about 175 cm. In the course of finding potential assessors 27 persons were contacted of whom 8 persons could not take part due to unavailability, and 4 persons did not show any interest in preparation for assessment. A total of 15 potential assessors were found.

Creating and conducting a survey

Following the step of finding assessors a survey was conducted for 15 potential assessors. Oral survey was used to find out an assessor's own ability for the participation in the analysis in the direct way (motivation level, availability) and the data on the state of health (general state of health, no allergy to textile fibers and chemicals used in finishing treatments). During the creation of the survey it was born in mind to avoid expert errors (use of ambiguous terms), insufficiently summarized offered answers, non-inclusion of all possible answers and suggestiveness of questions. The survey was carried out individually. The conditions for the positive assessment of an individual after the test and the survey were as follows: positive assessment of the ability test and denying health problems. Of the total number of potential assessors one potential assessor did not give adequate answers to tow defined conditions, excluding him from the subsequent selection procedure.

Conducting ability test

Ability test is used to determine whether an individual has satisfactory sensory abilities which are a prerequisite for successful testing. As a preliminary ability test the so-called triangle test. The test is based on testing the ability of observing the differences among given samples. The subject is offered three samples of which two are identical, and the third is different. The subjects are required to identify the one which is different. The triangle test was chosen because it is very suitable for the steps of selection and training. The ability test was done in two parts, and samples of knitted fabric of 100 x 100 mm were used, which were coded by a three-digit number. In the first part the subjects were asked to identify the sample different from the others using visual and tactile senses. A detailed description of the samples is given in Table 1.

The second part of the test had two sets of samples (the first set contained samples of 100% cotton, and the second set contained samples of 100% polyester) which were wetted with a different amount of water[9]. In each set two samples were wetted with the same amount of water, while the third sample for identification was wetted with a lower or higher amount of water. Samples were placed on the subject's forearm. The subjects were asked to identify a different sample in each set. The samples of the sets in both test parts were presented in three different permutations (BAA, ABA, AAB).

TABLE 1
CODED FABRICS

Set Number	Code	Description
Set I	321	100% cotton
	435	100% cotton
	514	100% polyester
Set II	213	100% viscose
	315	100% viscose
	152	100% polyester

Group discussion

A group discussion was organized for the other 14 potential assessors. The selected knitted fabric samples were coded. During the discussion dry samples and samples of knitted fabric wetted with different amounts of water were used. The candidates were required to compare the samples and to describe the perceived properties of the samples in words. The involvement of individuals in the discussion and the success of describing the properties of samples was scored with 1 to 3 points.

Test scoring and group discussion scoring

Upon completion of the group discussion the test and group discussion were scored. The subject's answers put in the ability test were scored according to the gradation scale which is defined according to the recommendations of sensory analysis (2 points for a correct answer, 0 points for an incorrect one).

Selection of assessors

To select assessors, two essential requirements were defined: acceptable answers of the survey and the total number of minimal points 65% of the highest possible number of points. By scoring the test and the discussion it was found that two candidates did not collect enough points (<65% of the maximum number of points). The results achieved by the candidates are given in Table 2. Thus, a group of 12 assessors was formed. For more complex tests, formed in a similar way, a group of 10 to 15 assessors is recommended[8]. Therefore, a group of 12 assessors was formed which is enough to do tests.

Preparation for subjective assessment

Within the preparations for subjective assessment the theoretical aspect of sensory analysis, practical significance of analysis and fundamental differentiation properties of the knitted fabric for making the garment in direct contact with the skin were explained to the subjects. Within the preparation of making a questionnaire the Bedford and ASHRAE scales were explained to the asses-

TABLE 2
THE RESULTS ACHIEVED BY THE CANDIDATES

Candidate	Survey	Score						
		Ability test		Total score Ability test	Max. possible score Ability test	Score Group discussion	Max. possible score Group discussion	Total score
		Part I	Part II					
1	+	10	6	16	24	2	3	18
2	+	8	10	18	24	3	3	21
3	+	6	6	12	24	1	3	13
4	+	12	12	24	24	3	3	27
5	+	12	6	18	24	2	3	20
6	+	8	10	18	24	1	3	19
7	+	12	10	22	24	2	3	24
8	+	10	10	20	24	2	3	22
9	+	8	8	16	24	2	3	18
10	+	12	12	24	24	3	3	27
11	+	4	4	8	24	2	3	10
12	+	10	10	20	24	2	3	22
13	+	10	8	18	24	2	3	20
14	+	8	8	16	24	2	3	18

sors. During the discussion with the assessors the ASHRAE scale was chosen because it enables them to make their assessment more easily. The assessors were given instructions how to behave on the day of subjective assessment. It was suggested to them not to eat an hour before assessing, but to drink enough water. It was also suggested not to use perfumed cosmetic products[10]. In the following phase a written survey was created to be used during subjective assessment. The survey includes questions related to the sensations of cold/warmth, dryness/moisture and comfort/discomfort as shown in Table 3.

TABLE 3
QUESTIONS AND SCALES

Type of judgement	Perception	Affective evaluation
Textual description	How do you feel in this moment?	How do you feel in this garment?
Scale	7 scale very cold – very hot very dry – very wet	5 scale very uncomfortable – very comfortable

To get answers to perceptive questions, a symmetrical seven-grade bipolar scale with the central indifferent point. The positive pole (grades –1, –2 and –3) represents the area of »cold«, and the positive pole (grades +1, +2 and +3) represents the area of »warmth«. The indifferent point (0) represents the absence of cold and warm. To make an affective assessment of comfort, a one-sided five-point bipolar scale with poles very uncomfortable – very comfortable was used.

Subjective assessment

The room for subjective assessment was prepared in accordance with the instructions for performing sensory analysis[11]. The following conditions were established in the room: 20±2ºC, 65% air relative humidity and average air flow 0,2 $m \cdot s^{-1}$. Table 4 describes anthropometric characteristics of each assessor.

TABLE 4
ANTHROPOMETRIC CHARACTERISTICS

Nr.	Age, years	Height, cm	Mass, kg	Body surface, m^2
1	22	177	68	1.84
2	21	175	67	1.81
3	23	179	73	1.92
4	22	175	68	1.83
5	19	177	66	1.81
6	20	175	66	1.80
7	21	176	67	1.83
8	21	177	69	1.85
9	22	178	69	1.86
10	21	177	64	1.79
11	22	180	73	1.92
12	22	173	66	1.79

Three garment ensembles including T-shirts and shorts (short trousers) were used in the phase of subjective assessment. The construction of the garment ensembles is the same, but the raw material composition of the fabric is different. The abovementioned is given in Table 5.

TABLE 5
FABRICS

Nr.	Designation	Raw material
1	C	100% cotton
2	V	100% viscose
3	PE	100% polyester standard

All the samples were coded so that the assessors could not know which raw material composition they assessed. Before subjective assessment the assessors received a medical questionnaire (Figure 2). By signing the medical questionnaire the assessors give their consent for taking part in testing. In the case of affirmative answers to questions 6 and 8 an additional consultation with physicians is necessary concerning the participation of the assessors in testing.

Subjective assessment was made through the following phases: acclimatization, moderate work, break, moderate work, and break. In the work phases the assessors drove an ergometer made by Monark at a speed of 60 rpm which corresponds to the work done with 120 W. The testing dynamics is presented in Table 6. In the course of acclimatization and break the subjects filled in the evaluation form.

TABLE 6
THE TESTING DYNAMICS

Phase	Acclimatization	Moderate work	Break	Moderate work	Break
min	15	10	10	15	10

Results

The grades given by each assessor during subjective assessment related to the perception of warmth, moisture and comfort in a clothing ensemble are presented in Figures 3 to 11. The testing phases are as follows: Phase 1 – before the beginning of testing, phase 2 – during testing, phase 3 – upon completion of testing. Average grades of comfort, warmth and moisture for the garment ensemble are presented in Table 7. Remarks were made in the phase of acclimatization or before the assessors' activities and in the phase of break upon completion of the activity. Comments are given in the Table 8.

TABLE 7
AVERAGE GRADES

Average grades				
Sense	Phase	Fabric		
		C	V	PE
cold/ warmth	1	–0.25	–0.25	–0.25
	2	+1.08	+1.17	+1.33
	3	+1.50	+1.67	+1.83
dryness/ moisture	1	–0.17	–0.17	–0.17
	2	+1.67	+0.33	+1.75
	3	+1.67	+0.92	+2.25
comfort/ discomfort	1	+0.18	0.00	0.00
	2	–0.50	+0.67	–0.83
	3	–0.58	+0.67	–1.25

MEDICAL QUESTIONNAIRE

Please fill in the medical questionnaire after receiving the information about the test protocol and before starting the experiment. The data required from you are confidential and will be not available to anyone but the person conducting a survey. By signing the questionnaire one gives the consent for the participation in the experiment.

Name/number _____ Year _____ Mass: _____ kg Height:_____ cm

1. Have you lost your consciousness because of physical activity? yes no
2. Are you suffering from diabetes or any similar disease connected with kidneys? yes no
3. Are you suffering form heart disease or high blood pressure? yes no
4. Are you suffering form lung diseases, for example asthma? yes no
5. Are you suffering from mental illness or depression? yes no
6. Have you got problems with skin diseases? If yes, state which ones _____
7. Have you been subjected to treatments which could lessen your sweating ability? yes no
8. Are you taking medications? If so, which ones? _____
9. Have you got back pain or generally have you got problems with motor functions? yes no

Date: _____ _____
Signature

Fig. 2. Medical questionnaire.

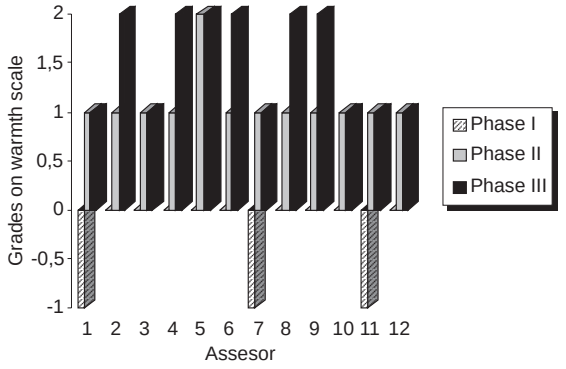

Fig. 3. Grades on warmth scale for cotton garment.

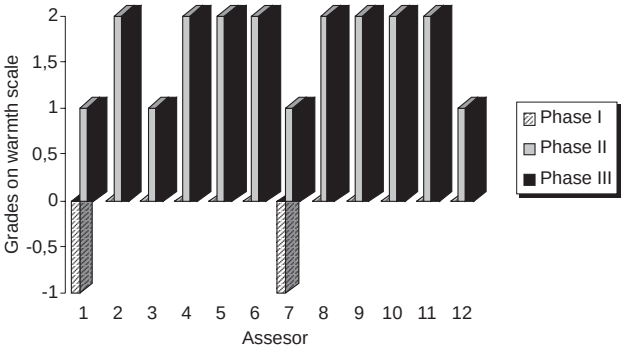

Fig. 4. Grades on moisture scale for cotton garment.

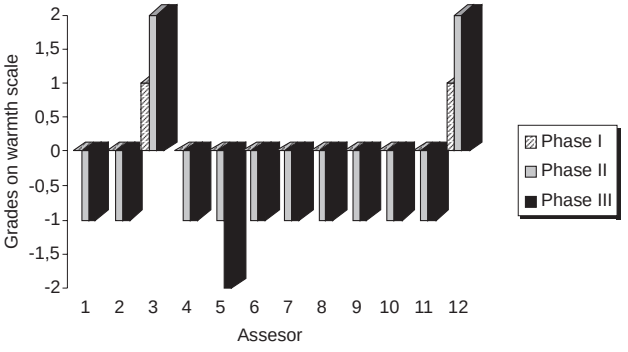

Fig. 5. Grades on comfort scale for cotton garment.

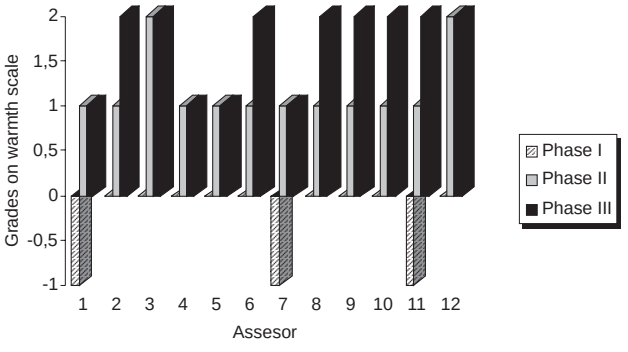

Fig. 6. Grades on warmth scale for viscose garment.

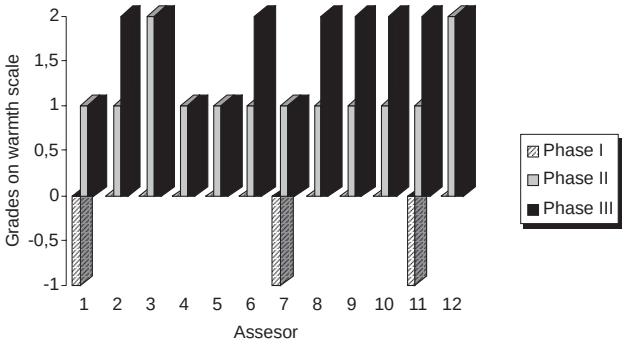

Fig. 7. Grades on moisture scale for viscose garment.

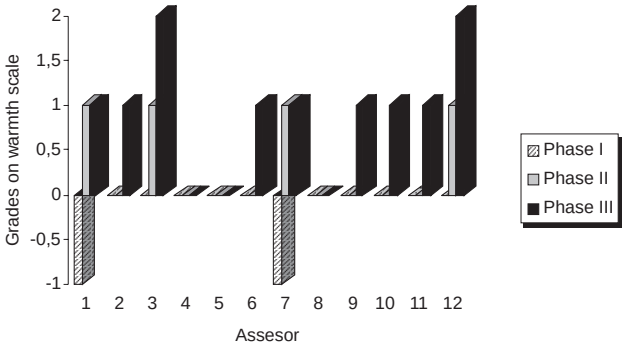

Fig. 8. Grades on comfort scale for viscose garment.

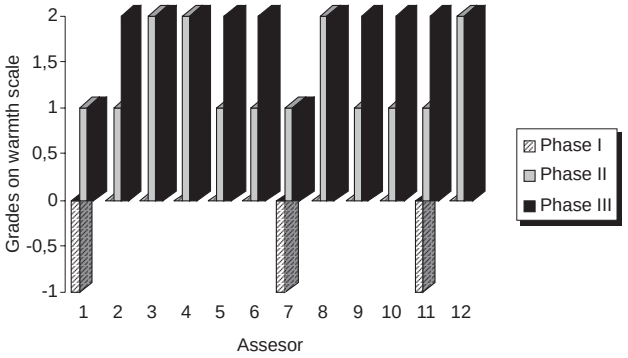

Fig. 9. Grades on warmth scale for polyester garment.

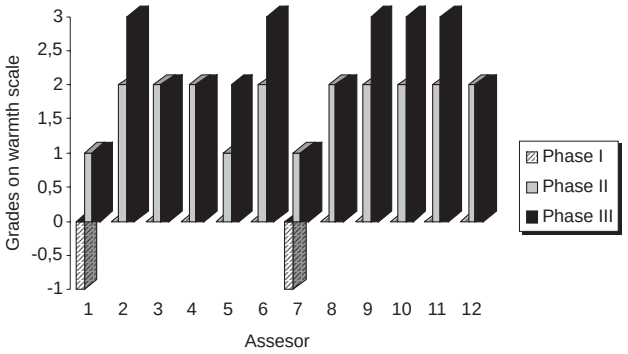

Fig. 10. Grades on moisture scale for polyester garment.

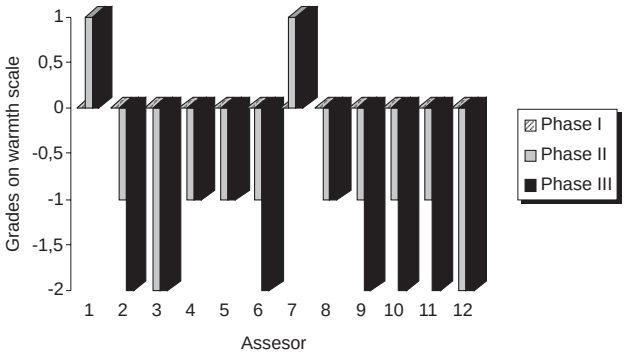

Fig. 11. Grades on comfort scale for polyester garment.

TABLE 8
COMMENTS

Sample	Phase	
	Before the start (aclimatization)	After the end (break)
C	comfotrable soft	clingy fits absorbing
V	leightweight comfortable fresh lustre extendable	comfortable
PE	flauntingly thin glancing	doesn't absorb wet moisture clammy sticky static electricity uncomfortable

Discussion and Conclusions

As it is evident in Table 7, in the initial phase there are no differences between the sensation of moisture and warmth in clothing ensembles of different raw material compositions. As a result of increasing activities the sense of warmth is intensified in all clothing ensembles. On average the most distinctive increase in the sensation of warmth was recorded for the polyester clothing ensemble, and the lowest one for the cotton clothing ensemble. The average grades do not completely correspond to the ability of the tested materials to conduct warmth. Namely, the conductivity of polyester fibers is exceptionally low (0.14 W m^{-1} K^{-1}), the conductivity of viscose fibers is slightly higher (0.28 W m^{-1} K^{-1}), and that of cotton fibers is significantly higher (0.46 W m^{-1} K^{-1}). The sensation of moisture in activity phases is the most distinctive in the polyester clothing ensemble. The said should be interpreted by the fact that polyester fiber has the lowest moisture regain or the lowest ability to retain moisture in comparison with viscose and cotton (moisture regain of polyester is to 0.5, of cotton 8.5 and viscose 12–14). Viscose has the highest moisture regain, and just this clothing ensemble was given the lowest grades of moisture. Thus, it can be concluded that the grades are in accordance with expectations, regarding the sensation of moisture too. The above described sensations of warmth and moisture affect the determination of the overall sensation of comfort. Concerning the average grades of comfort, the most comfortable clothing ensemble according to the assessment of the assessors who participated in the experiment is the ensemble made of viscose fibers. The mentioned ensemble was given positive grades in the phases of break during testing and upon completion of testing, and the average grade is 0.67. The grades of comfort for the ensembles made of cotton and polyester were negative. If the grades of comfort during phases 2 and 3 are compared with the grades of moisture, the same trend is observed according to which comfort decreases by increasing the sensation of moisture. Thus, the polyester clothing ensemble, which was given the highest grades of moisture (±1.75 in phase 2 and +2.25 in phase 3), is the least comfortable according to the assessors' grades (grade –0.83 in phase 2 and –1.25 in phase 3). The recorded assessors' remarks (Table 8) in the phase of break after testing are in line with the given grades of comfort. The clothing ensemble made of polyester fibers was given the worst grade. Its characteristics were described as follows: does not absorb, sensation of moisture, moist, wet, sticky, accumulates electricity, uncomfortable. Very warm/very cold as grades of the scale increase with increasing the assessor's work intensity, but for these lightweight garments they do not affect the grade of comfort more substantially. The graphics of individual grades given by each of 12 assessors show the uniformity of the grades given by the assessors. Assessors 1 and 7 stand out because they gave negative grades for warmth and moisture for all tested ensembles, and only they gave positive grades of comfort for the polyester clothing ensemble. Taking account of the results for subjective assessment and uniformity of the grades among the assessors, it can be concluded that the new developed method, where the principles of sensory analysis were used to define the protocol of the investigation of garment wearing comfort, is a good instrument for evaluating garment comfort. The mentioned method is especially suitable if a representative group of assessors is formed. The developed method and the performed investigations form the basis for further investigations which can be done with target groups of assessors such as athletes, persons of different heights, persons with distinctive dermatologic problems etc. It is to expect that the above investigations could indicate an increased tendency of some materials to the development of skin diseases. Although the clothing made of cotton fibers has been preferred for decades, recently there have been reports on an increased sensitivity of persons to underwear made of natural fibers. In addition, athletes and climbers wear clothes made of man-made fibers to a greater ex-

tent. In Europe it is very common that mature age women, who used to wear underwear made of man-made fibers in their youth, prefer to wear underwear made of natural fibers. Thus, it would be very interesting to explore cultural and other aspects influencing the selection of a preferred raw material.

Aknowledgements

The authors are sincerely grateful to the spinning mills Predilnica Litija from Litija, Slovenia and Predionica Klanjec (within the group Linz-Textil) from Klanjec, Croatia, for their contribution in the production of yarns.

REFERENCES

1. ISO 7730:1994 Moderate thermal environments – Determination of the PMV and PPD indices and specification of the conditions for thermal comfort — 2. ASHRAE Standard 55–66 (American Society of Heating, Refrigerating and Air-Conditioning) Engineers: Thermal Comfort conditions, New York, 1996. — 3. SALOPEK ČUBRIĆ I, Thermophysiological comfort of knitted structures, Doctoral thesis, (2009) — 4. SKENDERI Z, SALOPEK ČUBRIĆ I, SRDJAK M, Fibres Text East Eur, 17 (2009) 72. — 5. SALOPEK ČUBRIĆ I, SKENDERI Z, Mell Int, 15 (2009) 144. — 6. HOLMER I, Eur J Appl Physiol, 92 (2004) 614. DOI: 10.1007/s00421-004-1135-0. — 7. MIJOVIĆ B, SKENDERI Z, SALOPEK I. Coll Antropol, 33 (2009) 315. — 8. ISO 8586-1:1993, Sensory analysis — General guidance for the selection, training and monitoring of assessors – Part 1: Selected assessors — 9. SADIKOGLU T G, Fibres Text East Eur, 13 (2005) 54. — 10. ISO 6658: 2005 Sensory analysis – Methodology – General guidance — 11. ISO 8589 Sensory analysis – General guidance for the design of test rooms.

I. Salopek Čubrić

University of Zagreb, Faculty of Textile Technology, Department of Textile Design and Management, Baruna Filipovića Street 28a, 10000 Zagreb, Croatia
e-mail: ivana.salopek@ttf.hr

EVALUACIJA TERMOFIZIOLOŠKE UDOBNOSTI PRIMJENOM PRINCIPA SENZORSKE ANALIZE

SAŽETAK

Termofiziološka udobnost odnosi se na način na koji odjeća propušta ili zadržava toplinu i vlagu te pomaže tijelu da zadrži toplinsku ravnotežu u stanju mirovanja ili različitim razinama aktivnosti. U ovom su radu principi senzorske analize korišteni za definiranje protokola nove metode ocjene termofiziološke udobnosti nošenjem različitih odjevnih predmeta. Senzorska analiza je odabrana jer se ista koristi za ocjenu različitih artikala koristeći ljudska osjetila. Protokol ispitivanja uz sudjelovanje ocjenjivača uključuje sljedeće faze: definiranje sadržaja intervjua, pronalazak potencijalnih ocjenjivača i provođenje intervjua, izrada ankete, provođenje ankete, grupna diskusija, bodovanje testa i grupne diskusije, odabir ocjenjivača, priprema za ocjenjivanje i subjektivno ocjenjivanje. Prosječno je najizrazitiji porast osjećaja topline zabilježen za poliesterski komplet, a najmanji za pamučni komplet. S obzirom na srednje ocjene udobnosti, za ocjenjivače koji su sudjelovali u eksperimentu, najudobniji je komplet izrađen iz viskoznih vlakana. Pokazalo se da je nova metoda osobito prikladna za evaluaciju uspije li se formirati reprezentativna skupina ocjenjivača.