Indian Journal of Fibre & Textile Research
Vol. 33, September 2008, pp. 239-245

Non-destructive determination of comfort parameters during marketing of functional garments and clothing

L Hes[a]

Department of Textile Evaluation, Faculty of Textiles, Technical University of Liberec, 46117 Liberec, Czech Republic

Selected current and new non-destructive methods and instruments for determination of thermo-physiological comfort of fabrics and garments have been described. A new way of simple evaluation of complex comfort properties of fabrics and garments by means of the so called “comfort matrix” is also proposed and discussed. An example of the use of this method in marketing of winter jackets is presented.

Keywords: Comfort parameter, Fabrics, Functional clothing, Garment, Thermal resistance

1 Introduction

Functional and protective clothings should offer higher level of protection and simultaneously higher comfort properties than common textile products. Higher added values of garments made of performance or smart fabrics result in higher price of these products in the market.[1]

Before these garments appear in the market, most of the brand name companies start massive marketing activities and publicity to attract the customers. In the past, the mentioned brand automatically indicated higher quality of the product. In case of special garments, like expensive winter jackets, the product performance has been certified by the label, e.g. confirming the water vapour permeability of the jacket.[2,3]

However, most of the medium quality products, which occupy major part of the market, do not carry any quantitative indication of their quality. From the recent research carried out at the Technical University of Liberec, it is found that not always the brand name assures the expected protection level and comfort during the wear of garment and the customer cannot discover it due to complicated way of testing the comfort properties, once the garment is confectioned.[4-6]

There are two main reasons why these garments are not tested before they appear in the shops:

(i). Although testing of comfort properties of fabrics cut into required shape is easy, the testing of garments by means of common measuring methods requires the cutting of samples in certain dimensions, which would result into destruction of the garment. Other methods like the use of thermal manikins of testing complex systems are costly. Thus, manufacturers do not have tools for economical non-destructive determination of quality of their product.

(ii). Comfort parameters of some products like sleeping bags can be characterized by means of parameter extreme temperature of the use, but more complex protective clothings, such as firemen uniforms, require very complex characterization of their quality. For certain group of garments, the system developed by Meechels[7] in Hohenstein Institute of Clothing Hygiene, offers one number (index) to characterize the thermo-physiological comfort and another number to determine the sensorial comfort, but this way, at least in author’s opinion, cannot be used for very complex garment system. That is why, researchers always try to find other measuring methods.[8-10]

In the first part of this paper, some non-destructive methods of testing of mechanical and comfort properties of fabrics/garments have been described and analyzed. In the second part, a possibility to characterise the sensorial and thermo-physilological properties of fabrics/garments in their full complexity by means of so called “comfort matrix” is outlined.[7,11]

2 Non-destructive Testing of Fabrics/Garments Comfort Properties

It was aimed to promote and, in some cases, to develop relatively cheap and user-friendly instruments, which would measure the garment comfort properties without the necessity to destroy the

---

[a] E-mail: lubos.hes@gmail.com

garments. Also, smaller dimensions of specimens reduce the testing costs. Such instruments, in future, can be used in large shopping centres and specialised shops to enable the testing of basic comfort characteristics in front of the customer. New instruments can supply selected comfort parameters, which can also be used in advanced marketing, based on quantitative garment characteristics. An example of such simple user-friendly device is the Permetest Instrument (commercialized by the Sensora Instruments, Czech Republic).

2.1 Comfort Characteristics of Fabrics / Garments

Properties of textile fabrics and garments include both purely mechanical properties and heat/moisture transfer properties. Complex effect of these properties characterise comfort properties of fabrics. The properties, which involve the effect of fabric humidity on selected mechanical parameters along with the effect of deformation properties and contact force of garments on the user's perception during the garment wearing are called sensorial properties. More simple is the fabric hand or handle, generally perceived by hands, where from transfer properties just warm-cool feeling is involved. Heat/moisture transfer properties involve steady state and transient properties, which contribute to thermal equilibrium of human thermal engine–our body. Heat transfer may be in both directions, whereas the moisture evaporation only cools the body.

There are following other parameters influencing the perception of comfort or discomfort, but some of them are less important:

—Sensorial (wearing) comfort:

- Fabric (garment) mass, bending + shearing rigidity; elasticity, fit, contact pressure
- Moisture behaviour characteristics influencing the fabric / skin friction

—Tactile (hand) characteristics of individual fabrics:

- Friction + profile
- Thickness + compressibility
- Bending + shearing stiffness (at low and large deformations)
- Elasticity, tenacity
- Warm-cool feeling (transient heat transfer)

—Thermo-physiological comfort characteristics of fabrics/garments:

- Steady-state local thermal insulation parameters (thermal resistance and conductivity)
- Steady-state total thermal resistance (including ventilation effects)
- Steady-state moisture transfer parameters (evaporation resistance)
- Transient moisture transfer (moisture absorbtivity)
- Transfer properties of fabrics and garments for UV, VIS and IR radiations

2.2 Instruments for Non-destructive Testing of Some Comfort Parameters of Garments

There are some instruments already available in the market, which allow testing of selected comfort properties of fabrics and garments (in the following text the term "garment" will be used) without any change of their shape. These instruments are given below with their short characteristics.

2.2.1 Air Permeability

Figure 1 shows the digital FX 3300 instrument which proves that any part of the garment, to be tested, can be placed between the sensing circular clamps (discs) without the garment destruction. As the fabric is fixed firmly on its circumference (to prevent the air from escaping), the garment dimensions cannot play any role. There is also enough space between the clamps and the instrument frame, which allows the measurement on large pieces.

Similarly, the Airun simple and economical tester (under development at Technical University of Liberec) enables the non-destructive air permeability evaluation.[6]

2.2.2 Water Vapour Permeability (Non-Gravimetric Methods With Electric Output)

The Permetest instrument (Fig. 2) is the so called skin model, which simulates dry and wet human skin

Fig. 1—FX 3300 air permeability tester (with permission of TEXTEST AG.)

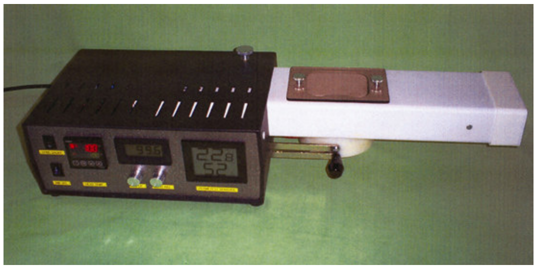

Fig. 2—Computer evaluated Permetest skin model (Sensora instruments)

in terms of its thermal feeling and serves for determination of water vapour and thermal resistance of fabrics.[5] If the instrument is used in laboratories with standard air conditions, it offers reasonable precision of measurement. Results of measurement are expressed in units defined in the ISO Standard 11092. The instrument principle is given below.

Slightly curved porous surface is moistened and exposed in a wind channel to parallel air flow of adjustable velocity. The tested sample is placed on the wetted area of diameter about 80 mm. The amount of evaporation heat taken away from the active porous surface is measured by a special integrated system. The measurement time is very short, full signal is achieved within several minutes. The instrument body can be heated above the room temperature or kept at the room temperature to maintain the isothermal working conditions.

In the beginning of the measurement, the measuring head is first covered by semi-permeable foil to keep the measured garment dry. Then, heat flow value (q_o) without a sample is registered. In the next step, the full-size garment is inserted (without being cut to special shape) between the head and the orifice in the bottom of the channel. When the signal gets steady, the level of q_s, which quantifies heat loses of wet measuring head covered by a sample, is registered. Both values then serve for automated calculation of mean value and variation coefficient of the following characteristics of the tested fabric/garment.

Relative water vapour permeability (*P*) is a non-standardized but practical parameter (*P* = 100% indicates the permeability of free measuring surface). It is given by the following relationship:

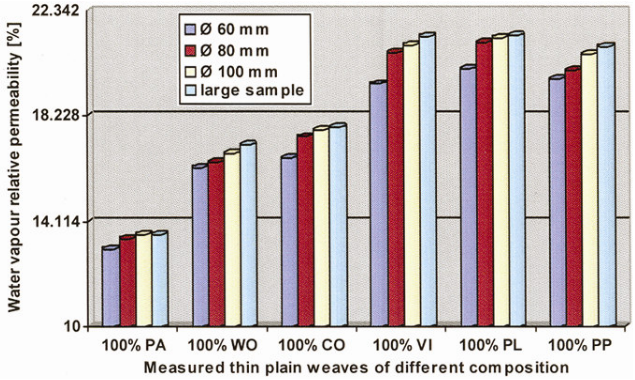

Fig. 3—Effect of sample dimension on water vapour permeability of fabrics [(PA – polyamide 66, WO –wool, CO – cotton, VI – viscose, PL –polyester and PP –polypropylene]

$$P\,(\%) = 100\,(q_s / q_o) \qquad \ldots(1)$$

Water vapour resistance R_{et} (as defined in ISO 11092) expresses the following equation:

$$R_{et}\,(\mathrm{m^2Pa/W}) = (P_m - P_a)\,(q_s^{-1} - q_o^{-1}) \qquad \ldots(2)$$

where P_m and P_a are the water vapour saturate partial pressure in Pascals, valid for ambient temperature t_a and actual partial water vapour pressure in a laboratory. The instrument also measures thermal resistance R_{ct} [$\mathrm{m^2K/W}$] of garments, similarly as described in the ISO standard 11092.

The common question of any user of this instrument may be “how the dimensions of the sample affect the measurement precision?” “Is here any effect of moisture conduction along the sample surface, which results in (incorrectly) higher water vapour permeability, than in case of the cut sample?”

Measurements of relative water vapour permeability on samples with varying dimension proved that the effect of sample dimensions (diameter) is not very strong (Fig. 3). All the results show the average values of 10 measurements for each sample. Variation coefficients in most cases do not exceed 5%, which confirms good measurement precision for this kind of measurement.[5]

Figure 3 shows that in most cases the measurement on large samples offers levels of water vapour permeability which do not differ from that determined on standard samples for more than 6%. This imperfection can be accepted at least for commercial purposes.

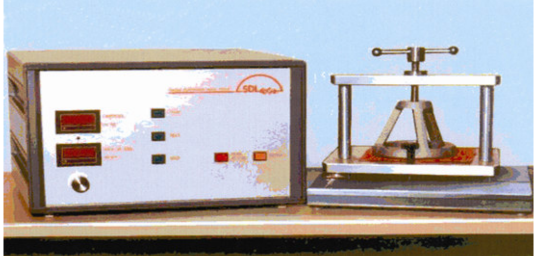

Fig. 4—M 018 hydrostatic resistance tester (SDLATLAS)

2.2.3 Resistance against Hydrostatic Pressure

As for the measurement of air permeability, the tested garment is firmly fixed on its circumference in clamps to prevent the water leakage. The M018 hydrostatic resistance tester (SDL/ATLAS) was used (Fig. 4). The garment dimensions practically do not have any limitation, as the space around the clamps is large.

2.2.4 Thermal Resistance and Conductivity

Both the instruments (Togmeter/SDL and Alambeta/Sensora) enable the insertion of the measured garment between the parallel measuring plates of the referred instruments and the geometry of the measuring space enables this procedure, if the garment is not too large.

Similarly, as in case of water vapour permeability measurement, some heat can escape by conduction along the large garment out of the measuring gap. As regards the Alambeta, the measurements reported by Hes and Kus[8] proved that for large fabrics of medium square mass, the values of thermal resistance and conductivity vary in the range of ± 6 %, if compared with the sample of dimensions identical with the dimensions of the measuring plates. This imperfection at least for commercial purposes is acceptable.

The principle of this relatively good precision results from special design of the measuring head, where the central sensing area is smaller than the total area of the measuring head. Thus, the heat flow direction in the measuring zone is perpendicular to the measuring plate and the negative edge effects are compensated.

2.2.5 Warm - cool Feeling and Moisture Absorbtivity

The procedures of the measurement of thermal absorbtivity (warm-cool feeling) and moisture absorbtivity using the Alambeta instrument (Fig. 5) were explained by Hes.[2] This instrument enables the insertion of large sample between the measuring plates (Fig. 5), but the heat might escape out of the measuring space similarly as explained above. Recording of thermal absorbtivity inside the device takes less than 2s, thus practically avoiding negative effects of heat conduction towards the edge of the measuring plate.

Fig. 5—Computer-controlled instrument Alambeta (Sensora instruments)

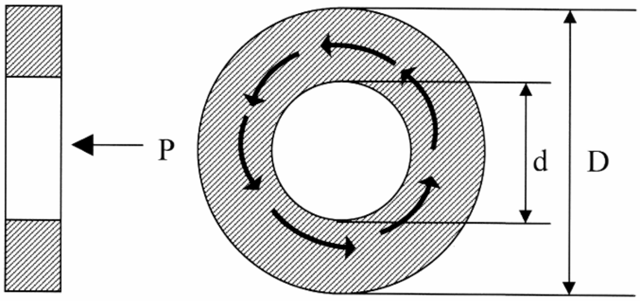

Fig. 6—Determination of fabric friction coefficient by the FRICTORQ instrument

2.2.6 Surface Friction Coefficient

Friction coefficient is one of the important parameters of textile fabrics, and its value affects both their behaviour during confectioning, and their contact comfort parameter called handle. Feeling of friction influences customer's opinion when buying new cloth for suits or skirts, and the possibility of its precise objective evaluation even in shops and markets would mean strong tool of textile marketing.

Unfortunately, common instruments for the friction assessment are too large and their operation is cumbersome. To avoid this drawback, a new simple, portable and non-destructive tester was recently developed by researchers from the Minho University in Portugal and Sensora Company in Czech Republic[4] (Fig. 6).

The instrument consists of a ring shaped body of diameters D and d, which is placed on the measured fabric, and of a sensor of torque momentum. When the ring turns around its center, it rubs against the measured fabric and generates the torque momentum. This momentum M is then proportional to the friction coefficient between the fabric and the ring surface and also to normal force P given by the ring mass. The torque momentum of this dry clutch and consequently the friction coefficient μ are given by the following equations:

$$M = 2.\mu..\pi.\int_{d/2}^{D/2} p.r^3 dr \qquad \ldots(3)$$

$$p = \frac{P}{A} = \frac{4P}{\pi.(D^3 - d^3)} \qquad \ldots(4)$$

$$\mu = \frac{3M}{P}\frac{D^2 - d^2}{D^3 - d^3} \qquad \ldots(5)$$

where r (m) is the radius; and p , the contact pressure (Pa) given by ratio of normal force P (N) and contact area A (m^2).

2.2.7 Elasticity

This instrument developed at University of Port Elisabeth[9] features two relatively narrow rectangular jaws (clamps), which are pressed together by means of pneumatic pistons fixed in a large frame. Huge dimensions of this frame enable to insert a big piece of fabric or garment between the measuring clamps, without the necessity to cut the fabric before being subjected to the unidirectional load. Special theory developed by Gardiner during her PhD study makes possible to compensate the effect of large fabric when determining the elasticity of the fabric.

3 Complex Comfort Parameters of Performance Garments

There exists several ISO or EN on the standards destined especially for work and protective clothing, either valid or under preparation, which requires the certifications of thermo-physiological parameters of this clothing. No standards are available as far as the comfort of common fabric is concerned. List of some standards is as follows:

DIN 61539—Weather protective suit
DIN 3276—Protective clothing against chemicals Type 2
DIN 61537 (E)—Protective vest against cold
DIN 30711 T2, T3—Warning clothing

Unfortunately, none of the above-mentioned standards is able to characterize complex comfort properties, involving thermo-physiological, sensorial or even hand parameters. As already mentioned, the only system used in textile praxis to characterize the complex sensorial and thermo-physiological properties of fabrics/garments is the comfort labelling system developed by Meechels[7] and his team. The recent principle proposed by Matusiak[12] also uses the weighted sum of individual parameters.

3.1 Proposal of New Comfort Evaluation System

The comfort evaluation system (CES) will consist of square matrix of various relative comfort parameters, such as thermal resistance (R_{ct}), evaporative resistance (R_{et}), moisture absorbtivity (b_w), bending rigidity (B), shear rigidity (G for weaves/elongation E for knits), wet friction coefficient (F_w), dry friction coefficient (F), compressional work (C_w), and dry thermal absorbtivity (b). The lowest (not necessarily the worst) level of each parameter will be indicated as D class and the highest (not always the best) level as A class.

The parameters R_{ct}, $R_{et,}$ and b_w represent body protection/thermo-physiological parameters; the B, G/E *and* F_w parameters express the sensorial parameters; and F, C_w and b parameters present the hand characteristics.

The R_{ct}, B, and F show the most important steady state parameters; the R_{et}, G/E and C_w are the less important steady state parameters; and the parameters b_w, F_w and b involve the transient characteristics of fabrics, as follows.

As already indicated, the number of parameters can vary from 4 for shirts or even from 2 to 9 parameters for quality suiting and leisure clothing, to 16 for protective clothing.

Why the set of all these parameters is considered as the "matrix"? In case we intend to reduce the number of characteristics describing fabric comfort, the parameters in every row can be multiplied (directly or after special transformation) by weight parameters and thus, from every group of technical parameters we receive individual indices of thermo-physiological, sensorial and hand (tactile) fabric comfort. Consequently, the final comfort characteristic of fabrics will consist just from 3 indices.

Most of the mentioned individual technical parameters are measurable by the technique available at world laboratories, mainly by means of the KESF instruments, Alambeta (R_{ct}, b and b_w), Permetest instrument and other measuring systems.

In this study, practical ranges or limits of all the mentioned parameters were proposed. In the next research, all the mentioned parameters should be verified by measurement on reference fabrics and then these fabrics/garments will be subjected to subjective evaluation and wear trials also, in order to confirm or determine the optimum levels in the proposed comfort parameters matrix. In some cases, the highest mark A need not to present the best value, like in case of bending rigidity. Therefore, the investigators should find out some other way to express the optimum values in the 4 grades scale in labels, e. g. by colour of numbers. As an example, the proposed range of thermal resistance R_{ct} [m^2K/W] levels of textile layers up to 3 mm thickness serves the following scale:

Class A: R>0.2; Class B: R(0.08-0.2); Class C: R(0.03-0.08); Class D: R <0.03

3.2 Simple Method of Evaluation of Thermo-physiological Properties of Winter Jackets

For winter and hiking jackets, the comfort matrix system can be reduced to two or three principal parameters, which sufficiently characterise their protection and wearing comfort, such as thermal resistance R_{ct} (m^2k/W), evaporative resistance or relative water vapour permeability P (%) which also expresses the wind-proof properties, and resistance against hydrostatic pressure H [m H_2O or Pa]. Here, the last parameter is less important and can be estimated by the fabric structure, hence it can be sufficient to consider just 1st and 2nd mentioned parameter when correlating the jacket performance and its (sometimes very) high price.

It is obvious that the performance of the mountain jacket improves with the levels of R and P, and higher level of one parameter cannot compensate the lack of the other one. Moreover, the jacket should exhibit some minimum levels of both parameters, otherwise the jacket would not be wearable. That is why, the proposed index of quality to characterise the complex comfort level of the jacket shows the following relationship:

$$IQ = (R_{ct} - R_{ct\,\mathrm{min}}) \times (P - P_{\mathrm{min}}) \qquad \ldots(6)$$

In our research, the index of quality has been developed for men shirts based on moisture absorbtivity, and correlated with the price of the related garments on the market.

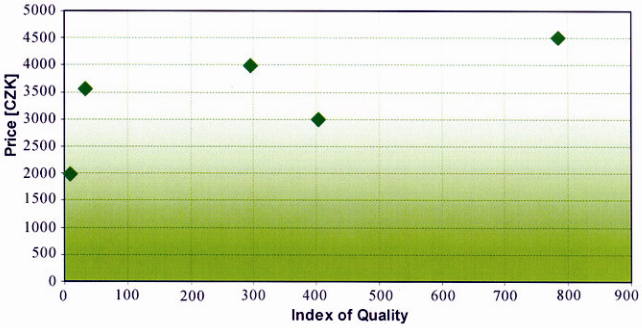

Fig. 7—Comparison of index of quality of selected jackets with their market price

3.3 Correlation between Index of Quality and Garment Price

The above relationship was applied to 5 various winter jackets, where some of them were delivered by brand name manufacturers. The individual indexes of quality were plotted against the prices (in Czech Crowns) of the jackets on Czech market.[11]

Figure 7 shows that an almost straight line can be conducted through the bottom points. All the points above this line may present an excess in the price. Nevertheless, the cheapest jacket was practically impermeable for water vapour, but it still appeared in a shop, because the jacket seller did not have the possibility to verify the water vapour permeability of the mentioned jacket without destroying it.

4 Conclusions

In this paper, the necessity of non-destructive testing of selected performance/comfort parameters of garments has been emphasised, and some instruments, which enable this way of testing, are presented and briefly characterised. The main advantage of the non-destructive testing is the possibility to reach better agreement between the price of garment and some quality index, which involve main performance/comfort parameters. The idea of the so called comfort matrix, to characterize the complex comfort parameters of functional garments, was outlined in the second part of the paper.

If the determination of these principal garments parameter is non-destructive, economic and available for customers, then these parameters, transformed into complex characterization of utility properties of garments (like index of quality), can open new approach to "objective" marketing of textile products with high added value.

References

1 Dolezal I & Hes L, *P-TEST – Computerized instrument testing of the water vapour and thermal resistance of fabrics*, paper presented at the IEEE International Symposium on Industrial Electronics, Rio de Janeiro, June 2003.

2 Hes L, Araujo M & Djulay V, Effect of mutual bonding of textile layers on thermal properties of fabric assemblies, *Text Res J*, 66 (1996) 245-250.

3 Hes L, *A new indirect method for fast evaluation of the surface moisture absorbtivity of engineered garments*, paper presented at the International Conference on Engineered Textiles, UMIST, UK, May 1998.

4 Hes L, Lima M & Martins J, *FRICTORQ-fabric friction tester based on torque evaluation,* paper presented at the Fall Fiber Society Annual Conference, Clemson, USA, 1999.

5 Hes L, *The effect of planar conduction of moisture on measured water vapour permeability of thin woven fabrics*, paper presented at the Fall Fiber Society Conference, Lake Tahoe, 2002.

6 Hes L, *Simple procedures of textile testing*, paper presented at the 1st SOTSEA Conference, Daegu, Korea, 2002.

7 Mecheels S, *Innovative and functional textiles – quality requirements and test procedures*, paper presented at the International Textile Conference AUTEX 2007.

8 Hes L & Kus Z, *Non-destructive testing of thermophysiological properties of protective clothing*, paper presented at the ECPC International Conference on Protective Clothing, Montreaux, 2003.

9 Gardiner H, *Precision of FOM instruments*, PhD thesis, CSIR Port Elisabeth, 2000.

10 Hes L, New methods of clothing comfort evaluation and their application in textile marketing, *Taiwan Text Res J*, 15 (1) (2005) 65-70.

11 Hes L, *The use of comfort parameters in marketing of textiles*, paper presented at the ITMC International Textile Conference, Casablanca, 2007.

12 Matusiak M, *Modelling the thermophysiological comfort of apparel textiles,* paper presented at the International Textile Conference AUTEX, 2007.