International Journal of Advanced Engineering and Management Research
Vol. 1 Issue 5, 2016

www.ijaemr.com ISSN: 2456-3676

TESTING METHODS OF THE HEAT AND HUMIDITY TRANSFER AS PARAMETERS OF CLOTHING COMFORT

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ABSTRACT

The aim of this study is to explain the developed and mostly used test methods for determining the heat and humidity transfer as a parameters of clothing comfort. There was shown importance off these methods and their distance to results taken from measurement done by people. Finally was given suggestions about what can be done in future studies in this area for doing them more realistic.

Key Words: thermal and moisture comfort, measurement methods, clothing

I. Clothing Comfort

For felling comfortable in the clothes expectations from clothing can be listed as follows:

- The clothing should be able to protect human body from high loss of temperature

-The clothing should be able to protect human body from negative weather and environmental conditions.

-Should be able to improve physical appearance in terms of fashion-related desires

-The clothing should make the person feel morally comfortable in his or her social environment in terms of the customs, traditions and ethics

- The clothing should have the characteristics to mitigate the illnesses a person has, rather than triggering them.

- For being accessible to the buyer in the market, the price of the clothing should not be over the value the customer considers for it

- During use, it should allow for optimum performance of the wearing person's body movements

- The clothing should positively influence the spirit of the wearing person

The above-listed expectations may vary from one person to another, or according to the sections of the society, and even according to the regimes of different countries (Yılmaz and Erdoğan ,2012).

Physiological comfort is determined by physiological properties of garments, which determine the balance of heat preservation, and so the temperature and moisture transport between the human body and the environment (Wrzawinski at al, 2011) . The physiological behaviour of comfort is observed when the heat balance described by the function (1) is equal to zero.

$$f\left[\frac{Q}{A_{Du}}, \Delta_{cl}, t_w, t_{mr}, p_w, v, t_s, \frac{Q_w}{A_{Du}}\right] = 0 \qquad (1)$$

In function (1) the mean of symbols are : Q/A_{Du} – amount of internal heat exuded by organism in relation to surface area of body without any clothes (A_{Du}= DuBois surface), A_{cl} – heat transfer resistance, t_w – air temperature, t_{mr} – mean radiation temperature, p_w – pressure of moisture in air, v –relative air rate, t_s – skin temperature, Q_w/A_{Du} – amount of heat used for evaporation of moisture in relation to surface area of body without any clothes (Fanger,1974).

The importance of testing methods for heat and moisture transport, which was wery well explained by Umbach, is shown in figure1. Many of the test methods to measure thermophysiological comfort try to mimic the heat and mass transfer from the human skin to the environment through the textile layers. The Hohenstein institute in Germany developed a 5-level system for the physiological evaluation of clothing (Umbach 1983). Levels 1 and 2 assess physical properties of the fabric layers and the clothing whereas levels 3 to 5 also consider the physiological impact of the clothing on the human body. The intrinsic thermophysiological properties of the fabrics like the thermal resistance or the water vapour resistance are determined in level 1. As the wear comfort of clothing is also very much dependent on the air layers trapped between the fabric and the body, the garments must be assessed with human- shaped, life-sized manikins (level 2). The validation of these results is made with human subject tests, under well-controlled conditions in the laboratory (level 3). Levels 4 and 5 are usually restricted to a very small number of newly developed, optimized clothing systems (Rossi,2005).

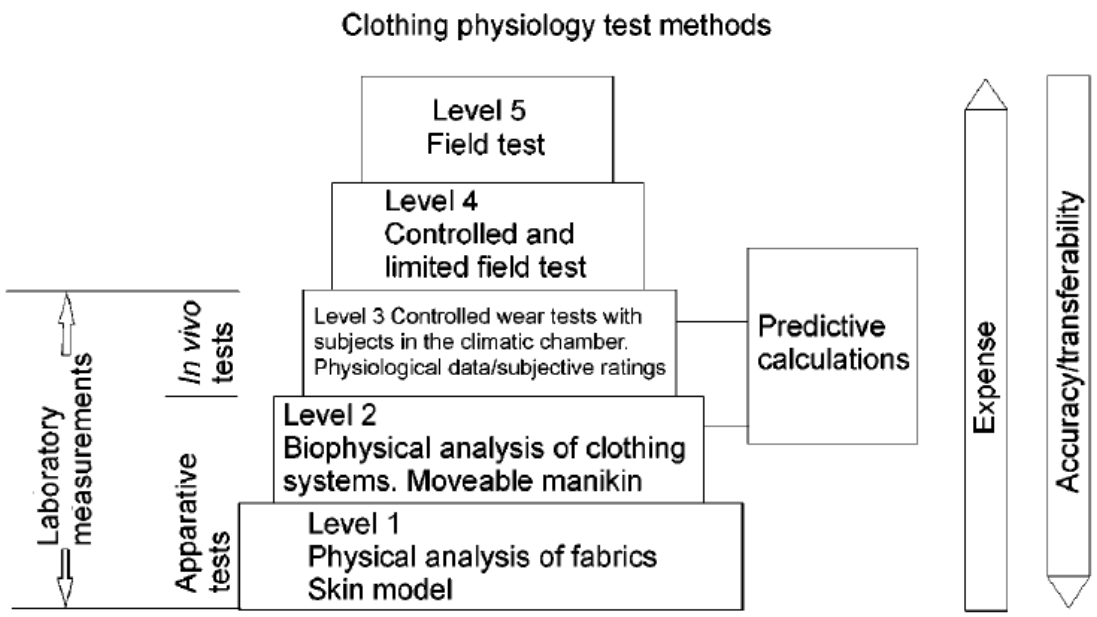

Figure 1. Five level system of phisiological evoluation of clothing (Umbach, 1983; Rossi, 2005)

II.The relationship between comfort of clothing and the transference of heat and humidity

Clothing has an important role in the relationship of human body and environment in heat transference. According to Harter and his companions thermal sensibility has 3 functions:
-The calibration of the body heat
-The prevention of the harm on the regional part of the skin because of hot and cold
-The determination of the heat of the item that is touched

The psychophisical mechanism of sensations related to warmth and humidity

A human body tries to stabilize its internal heat at 37° C and its skin surface heat at 33.4 ° C and when a change happens above 4.5 ° C , there occurs a comfort problem.
One of the parameters that effects clothing comfort is clothing properties. Identifying the thermal comfort of clothing is an independent subject in itself. Thus, in this study, generally, evaluation methods intended to thermal transfer which effects clothing comfort are emphasized. The body should have a specific thermal balance. If it does not have heat gain and loss in a balance, any sudden change in the body heat may lead to vital danger.
The physical mechanisms of the perception of warmth and damp, is highly effectable on the comfort that is felt because it is variable due to the level of personal activity and to environment factors as warmth/frigidity, wetness and stickness .The sensation of the feelings and the transference of them to the brain is done by termoreceptors.

- Termoreceptors

Termoreceptors, are divided into two as warm and cold receptors due to the dinamic responses.

-The parameters related to perceptions of warmth and wetness

Frigidity and wetness are primary sensations which are results of metabolic process in our body and effect the thermal comfort negatively. These sensations are effected by the process of the warmth and damp transference of the fiber and the fabric and the relations between the skin and the fabric determines the amount of the physical stimulation.
The forearm test is one of the subjective evaluation methods which is performed in comfort studies and it is made to determine the frigidity and wetness sensations resulted by the contact between the skin and the fabric. It uses also to determine the properties of the cloth that are related to these feelings (Kaplan ,2009).

Subjective Comfort Evaluations

In comfort researches, subjective clothing trials is a common method by which some physical changes on the body are recorded due to garment on person body, with certain activity program that is applied in controlled environmental conditions; the sensory perceptions which are exposed are wanted to be determined by defined adjectives. The parameters which should be under control or which should be chosen due to the plan that is determined in subjective clothing trials are listed below:

-Environmental Conditions

According to ASHRAE (American society of heating, Refrigerating and Air Conditioning Engineers) standarts the environmental parameters which are effective on thermal comfort are; air temperature, average radiant temperature , relative humidity and air velocity.

- The participants of the trial

In order to have reliable results, the repeat number should be high, because these tests are done onto limited order of participants.

Taking of the ethical permissions for the clothing trials, application of volunteerism, take care for the medical problem which can be faced at any time to the persons, are necessary.

The factors which are effective on the subjective evaluations are divided into two as physical and phsichological by Meilgaard.

-Physiological Measurements

All through the experiment, in determined terms, the parameters which are connected to body physiology as the participants' skin temperatures, the changes in the relative humidity (due to the evaporation of the sweat) in the air layer between the skin and the cloth, the rate of sweating, pulse, receiving oxygen , consuming energy are measured.

-Examined Perceptions and Current Scales

The aim of this subjective experiments is to provide evaluation of the physiological perceptions which are related to the person's cloths, environmental conditions and the applied activity program via scales. The qualifications that are evaluated or the given numbers to the subject are used to state the level of that qualification. And these numbers cannot be real numbers.

III. The Parameters Which Effect The Thermal Comfort

Thermal comfort is a kind of thermoregulation system which is made up of the signals received from the skin's surface and from the thermoreceptor from the bottom layers.
According to ASHRAE(The American Society of Heating, Refrigerating and Air Conditioning Engineers) standards ; thermal conditions. A person's thermal comfort changes according to the cloth which is worn, environmental factors and activity level.

Thermal comfort is related to the how much the cloth transfer the heat and how much it evaporates the sweat from the skin to the environment. Ten percent of the heat which comes up from the body's metabolic activities are given to the external environment by breathing and 90 % is given thorough the skin. When the difference between the internal body heat and external environment increases the amount of the heat given to outside from human body increases too.

IV. The Identification Methods Of The Heat Transference For Clothing Comfort.

The methods of measuring thermal comfort of clothing are determined as three main methods as fallow .

Subjective Thermal Comfort Measurement Methods

Fanger revealing the ISO 7730 international standards related to thermal comfort has examined it's bases. The standard grounds on determination of thermal conditions which are acceptable from some part of the society as comfortable. The discomfort caused of the heat and cold is expressed by the PMV and PPD indexes. PMV index is named as "predicted mean evaluation" and is used to predict the thermal situation of body by using the scale up to seven which depends from cold to heat. PPD index is named as the rate of estimated unsatisfaction. In the standard, there are suggestions about a value range between these two indexes. In the later times, the designated PMV index has been modified while taking relative humidity of the environment or water evaporation pressure and water permeability of the cloth into consideration by Gagge and his colleagues.

Objective Thermal Comfort Measurement Methods

For determining thermal comfort of human body there are used thermal manikins. Some thermal manikins have been developed to decrease the difficulties in subjective clothing experiments and to reveal some more results depending on more general acceptations. By the help of the models which have been developed in the shape of men and women, it is being studied to reach the human heat transference mechanism.

Thermal manikins are the systems which have been designed to simulate the human body. With a more detailed explanation; thermal manikins are systems made up of metal or plastic, which can move anatomically and has body which consist of 15 to 20 segments as head, chest, stomach, back, arms, hands and feet with average of 1.70 m height, with surface areas of 1.7 m^2 and 33-34 ° C of external surface heat , and is used for measuring the parameters as heat loss, heat insulation and thermal resistivity (Pamuk ,2006). The manikins are designed in forms of woman

and man body. For example the Newton thermal manikin, which is designed and built by Measurement Technology Northwest is man model and consist from 34 independently controlled thermal zones and can be used sweating or dry.

Most manikins are divided into body segments with independent temperature control and measurement (even though they are intended to be used to quantify the heat transfer characteristics of total body systems). The segments can all be controlled at the same temperature (i.e., 34°C), or a skin temperature distribution where the extremities have lower temperatures than the head and trunk. These manikins can indicate the relative amounts of heat loss from different parts of the body under specific environmental conditions and/or measure the insulation value or evaporative resistance value of each segment (Coullogh,2005). The picture 1 and 2 shows the thermal manikins designed from different company or universities.

A study for heat transfer off liquid cooling garment was done with a copper manikin, typical of which was its soft simulated skin – a newly thermoplastic elastomer material (Yang et al ,2008).

Picture 1. The thermal manikin at Kansas State University is dressed for the evaluation

Picture 2. Newton thermal manikin (Measurement Technology Northwest, 2010)

of sports apparel. (Coullogh,E.2005)

Based on this novel thermal manikin, the heat transfer analysis of an extravehicular liquid cooling garment was performed. To satisfy the practical engineering application and simplify analysis, the hypotheses were proposed, and then the heat transfer model was established by heat transfer theory, in which the heat exchange equation of the liquid cooling garment with the thermal manikin and with the air layer, and the garment's total heat dissipating capacity were derived. This research shows that it is an effective method to control the heat-dissipating capacity of a liquid cooling garment by changing the inlet temperature to some degree, but not by changing the liquid velocity.

Extravehicular spacesuit is composed of many layers, such as outside cover, vacuum insulation layer, air retaining layer, ventilation structure, liquid cooling garment, and underwear (Skoog et al. 2002).

Thermal Comfort Modeling Methods

There are commonly two thermal comfort models. These are the instantly energy balance model with two segments and constant regime energy balance model. In these two models, it is assumed that such heat and the transference of heat from the skin surface is in balance and it is assumed that the body is in one piece. (Atmaca, 2006)

- Instantly energy balance model with two segments

This model which was developed for temporary regime and which is known as Gagge model is accepted as two telescopic cylinders of human body. The internal cylinder symbolizes the inside of the body (skeleton, muscles, innards) and the external cylinder symbolizes the body skin . In Gagge model, there is a mass transference and also there is a sensible and hidden heat transference (Gagge, A.P., J.A.J. Stolwijk, Y. Nishi. 1971).

When instantly energy balance happens the heat energy collected per unit time is equal to difference between the taken heat and lost heat. If the First Law of Thermodinamic is written for the two body cylinders it will be formulated as follows (Anonimous 1993, Atmaca, 2006) :

$$S_{cr} = M - W - (C_{res} + E_{res}) - Q_{cr,sk} \quad (2)$$

$$S_{sk} = Q_{cr,sk} - (C + R + E_{sk}) \quad (3)$$

In these formulas parameters are defined as follows,

S_{cr} = the heat energy collected per unit time in the internal cylinder, W/m^2

S_{sk} = the heat energy collected per unit time in the body, W/m^2

M = heat energy produced in metabolic processes, W/m^2

W = done mechanical work, W/m^2

C_{res} = moving lost heat by breathing, W/m^2

E_{res} = vaporize lost heat by breathing, W/m^2

$Q_{cr,sk}$ = total heat transfer from the internal cylinder to the skin which is moved from body tissue by conduction and blood flow, W/m^2

C+R = sensible heat loss from skin, W/m^2

E_{sk} = total vaporize lost heat from skin , W/m^2

The heat energy collected per unit time in the body is equal to increase of internal energy.

- Constant energy balance regime

The constant energy balance regime model which has been developed by Fanger, based on the hypothesis that, human body is in thermal balance and energy storage can be neglected. In this model, it is taken in hand that body is limited by the skin which has control mass with only one heat.

Since the body is considered as only one piece, tremble and blood flow are not taken into consideration and heat is accepted as constant due to the time. If there is no heat storage, in constant regime, the heat produced by the body should be equal to heat loss.

$$M - W = Q_{sk} + Q_{res} = (C + R + E_{sk}) + (C_{res} + E_{res})$$

In this equation

Q_{sk} = total heat loss from the surface of body leather, W/m^2

Q_{res} = total heat loss by breathing, W/m^2.

- Simulation model

There has been a lot of studies of modeling on identification of humans responses to the thermal environment, which are being done in the recent years. Many of these studies depend on

Stolwijk model. Modeling studies of Huizenga et al., Yi et al. and Tanabe et al. can be given as examples (Atmaca , 2006).
In these studies, Stolwijk model is developed mostly as an enlargement of the numbers of body parts in which models are practiced or are developed taking into consideration the amount of sweat on the skin surface . These studies are based on Stolwijk model in which the body has 4 segments as skin, fat, muscle and ember and these are very detailed models.

V. Suggestions.

The given methods has some deficiency because every of them accept negligence of some unknown or impossible to simulate parameters of human thermoregulation mechanism. In some researches is stated that by subjective methods is possible to determine the thermal comfort parameters of humans body by 40 % approach. That's why it is need to be done much more studies on humans thermal clothing comfort and to develop standard methods which can give information nearest to the humans sensations. For it it is necessary to work with people and do subjective tests, and the statistical examples of people must be of hundreds to can represent people population living in large geographic areas with similar climates. There are necessity of doing international projects with big budget to determine thermal comfort of humans with taking measurements on heat insulation and water vapor permeability in different ensemble of clothes .

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Note : Note: This paper was been publicated in MAGAZINE TEXTILE AND CLOTHING 1/2015, ISSN 1310-912X

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