An overview of measuring methods and international standards in the field of thermal environment, thermal characteristics of the clothing ensembles and the human subjects assessment of the thermal comfort

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Review

A continuous development of the terminology, materials, measuring instruments and methods, requires the implementation of the unified specifications and definition of the standards, so that clear quality management system could be established, for both the production systems and testing methods. In the field of the measurements of thermal characteristics of the environment and the clothing garments or ensembles, as well as in the field of thermophysiology of the human body, the most significant international standards are published by the international organizations for standardization such as ASTM International, ISO and ASHRAE. Those international standards define the insulation characteristics of different materials, the clothing garments and the ensembles, the thermal and the water-vapour resistance, the measuring systems and the measuring protocol, the testing requirements, the PMV and PPD indexes, the environments and the interpretation of the measured results. The standards in the field of the ergonomics of the thermal environments define both the parameters and the measuring methods, which affect the human thermoregulation in some specific environment, while other standards describe the prediction of the thermal protection based on those parameters, or respectively how to predict either thermal comfort or discomfort and the health risks which could affect human subjects in particular thermal environments.

Key words: *international organizations for standardization, standards, measuring methods, thermal characteristics of the environment and the clothing garments or ensembles, subjects thermal comfort*

1. Introduction

The development of the standards and the unification of the testing methods is of crucial significance to the market globalization because it provides a unique application throughout the world and a networking among different producers. The information, the requirements and the quality control, which are described in the international standards, provide the application for the specific market segments and the insurance that the consumers' needs will be fulfilled worldwide. The standards provide the establishment of the unique generally accepted guidelines, the methods and the regulations which define the requirements for the production processes, the quality control and the products itself.

The international organizations for standardization are ASTM International, ISO and ASHRAE. The ASTM (acronym for *American Society for Testing and Materials*) is the internationally recognized organization. Together with the ISO international organization (acronym for *International standard organization*), this association is nowadays one of the most significant generator of the contemporary analysing standards, although none of the international associations mentioned does the product testing itself. The ASHRAE's prior mission (acronym for *The American Society of Heating, Refrigerating and Air-Conditioning*) is the enhancement in the field of an energy efficiency, the air quality in the interiors, industrial and building systems' sustainability. Thanks to the work performed by those organizations, nowadays there is around 12000 ASTM standards, 19500 ISO standards and few regular ASHARE publications in usage [1].

The era of the Industrial revolution brings the development of the new materials and the need for implementation of the clear specifications and also the establishment of the standards. This is a time of an emersion and invention of the new materials and their application in a technological advancement. Simultaneously with an introduction of the new materials and an invention of the new techniques, need for the explicit quality system management has been indicated by the producers, to prevent eventual application of the unsuitable raw materials. During this period, the first detailed documents with the material and resources' specifications appeared on American soil, along with equipment for quality determination, despite the resistance which was demonstrated by the American public.

C. B. Dudley initiated the material testing for American railroad construction and standardize specification issuing. He published his first major report in 1878. under title *Chemical Composition and Physical Properties of Steel Rails* in which he analysed the durability of different types of steel. With his work, he continued to implement the idea on the collaboration between steel producers and manufacturers which has resulted in the creation of the unitary quality control system and also an establishment of the ASTM organization in 1898. This places ASTM as the first the international organizations for standardization.

2. International organizations for standardization

20th century has been marked by accelerated evolution and application of the new materials, their testing methods and the technological advancement. Simultaneously the idea about the need for the clear quality management system implementation for raw materials and testing procedures has been developed. This resulted in development of the first detailed publications and reports on the material and resources' specifications. The above mentioned international organizations are described in this article. They are generators of the contemporary standards which define clear guidance in measuring methods' and raw material characteristics' development. The standards in the field of the ergonomics of the thermal environments define both the parameters and the measuring methods, which affect the human thermoregulation and the prediction of the level of the thermal protection and minimum requirements for product quality which serve as protection under extreme temperatures and environmental conditions. The clear quality management system is main requirement which aims for consumer protection and gives precise guidance to producers while designing new products and testing procedures.

2.1. ASTM International organization

The main mission of this organization was the creation of the uniform standards for the quality control of both raw materials and final products. Because of his negative experiences in attempting to establish the uniform system for the quality control and standardization, C. B. Dudley suggested an implementation of the technical committees' system. These committees would be formed by the representatives of the main parties, and the forums would be organized to display and discuss every aspect of specifications and testing procedures in quality control for a given material. The goal was to reach a consensus that was acceptable to both producers and to the customer, as well to the American rails. This negotiating principle became the basis for the formation of the International Association for Testing Materials (IATM) and nowadays ASTM International organization.

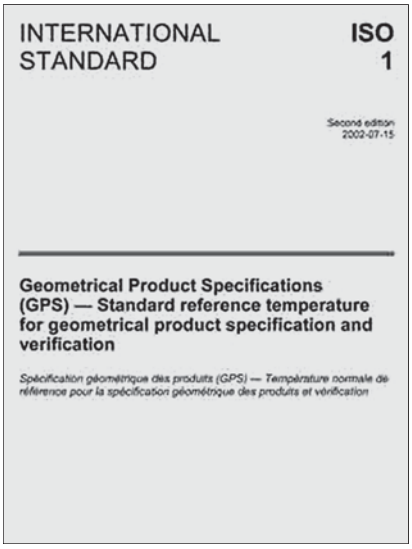
The technical committee of the American department of the IATM approved the first standard specifications in 1901. for steel used in buildings construction under title *Structural Steel for Bridges*. This standard was afterwards classified as ASTM's standard specification A7. Finally, in 1902 IATM was renamed to ASTM. Parallel with the work of this organization, the federal government of USA tried to established the NBS or the National Bureau of Standards in 1901. However, the founding of NBS was met by the great resistance from both the manufacturers and engineers, which disapproved the government plan to duplicate European practices and establishment of the authority body which will force laws and regulations upon industry. This decision proved to be crucial in the creation of the democratic American style of the development of standards and quality control. As the years passed, the global market climate in USA changed. After the turn of the century, several new committees were formed quickened by the emersion of the new raw materials such as Cement, Clay, etc. In 1910 ASTM introduced a yearbook which later became Annual Book of ASTM Standards. This publication became the foundational publication in the field of standard development and issuing. Each volume presented the complete work in the field of the standardization for the specific area, including the overview of all, at the time existing and revised standard specifications.

The World War I introduced further changes and many companies reassigned their business to military processing industry. In those early 1920's, ASTM's main activities still focused on the traditional materials such as steel and cement. Over 100 technical committees was founded and assigned to work on supervision and development of the standards in other areas. In the coming decade the American economic development began contributing to the rise of the mass production in many industrial areas. One of the most propulsive area was automobile industry ahead with **H. Ford**.

In 1981 ASTM opens the first European standards distribution centre in London to broaden his activities on growing markets such as Japan, western Europe and so-called "tiger economies" on the Pacific. Simultaneously, fast development of new communication technologies was set and international cooperation was improved. ASTM International broadens his participation in international waters forging close ties with DIN (Deutsches Institut für Normung), AFNOR (Association Francaise de Normalisation), JSA (Japanese Standards Association) and BSI (British Standards Institution). In 2001 ASTM changes name to ASTM International to reflect global participation in the creation of standards for the worldwide usage [2]. Today ASTM International operates in more than 140 countries and publishes around 12575 standards.

2.2. ISO organisation

The second large organization for standardization is ISO organization. The acronym ISO is derived from the Greek *isos*, meaning equal and an arrangement was made to accept this acronym as official abbreviation of the organization. Since establishment in 1947 with initial 67 technical committees to todays 3368 institutional bodies, this international organization for standardization successfully operates, with headquarters in Geneva, in the field of publication of the standards from different areas (agriculture, building construction, engineering, medical equipment, etc.). It was formed by merging the two organizations, International Federation of the National Standardizing Associations (ISA) and United Nations Standards Coordinating Committee (UNSCC). The first ISO standard was published in 1951 and is now *ISO 1:2002 Geometrical Product Specifications (GPS) - Standard reference temperature for geometrical product specification*, Fig.1.


INTERNATIONAL STANDARD

ISO 1

Second edition 2002-07-15

Geometrical Product Specifications (GPS) — Standard reference temperature for geometrical product specification and verification

Spécification géométrique des produits (GPS) — Température normale de référence pour la spécification géométrique des produits et vérification

Fig.1 The cover sheet of the first ISO standard published in 1951; SOURCE: www.iso.org

The international ISO organisation for standardisation operates as world association composed of members from the national standards bodies. The lead standard development is performed by the ISO the technical committees. Soon as a draft has been developed and accepted by the technical committee, it is shared with ISO's member bodies who vote on it. The publication which shall become the international standard should be approved by 75 % of the voting membership bodies.

The ISO Journal

The official ISO Journal started with publication in 1952 and in 1960 ISO published the standard in correspondence to international system of units (SI) called *ISO 31: on quantities and units*, which has later been replaced by ISO 80 000. Up until today, ISO has published over 19500 international standards. In 1987, ISO published one of the most important worldwide quality management standard, the ISO 9000. In their work ISO cooperates with national institutions for standardization from 162 countries. It is also important to mention that from 1979, the work of ISO organization is completely coordinated with requests set by The Technical Barriers to Trade (TBT) Agreement with WTO (*World trade organisation*). Today ISO organization publishes a large number of standards from a number of technical areas [3]. Every country is presented by only one national referent body, Fig.2. Croatian Standard Institute is Croatian ISO national membership orga-

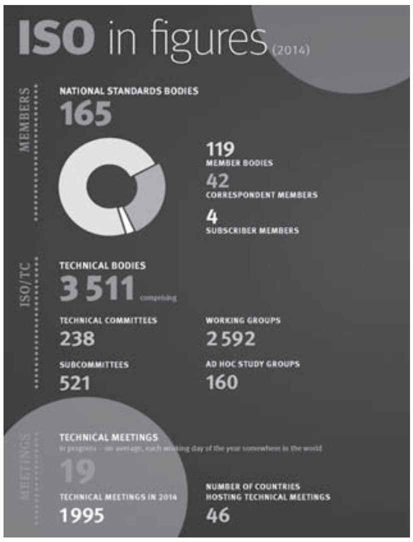


Fig.2 The overview of the referent national bodies and ISO membership institutions; SOURCE: www.iso.org

nization. The standards which describe the terms, the measuring methods, the thermal environments and other parameters connected to the transfer and the effects of the heat belong to category of ISO standards in the field of the ergonomics of the thermal environments [4].

2.3. ASHRAE organisation

The American Society of Heating, Refrigerating and Air-Conditioning Engineers was founded in 1959. and formed from the union of two organizations, *American Society of Heating and Air-Conditioning Engineers* and *The American Society of Refrigerating Engineers*. Today this organization counts over 50 000 members all over the world [5].

In first decade of the 20th century this two associations had somewhat different spheres of operation. In 1920s, with the advancement of new technologies, an air conditioning became the field of interest to both associations. The heating systems were slowly replacing steam and hot water heating by forced warm air systems, combing the heating and air conditioning and in 1954. American Society of Heating and Air-Conditioning Engineers changed its name to the *American Society of Heating and Air – Conditioning Engineers*. By the 1950s a significant overlap was noted in the research programs of both societies so negotiations resulted in merging of those association in unified organization.

Extremely important edition published by the ASHRAE is the *Handbook of Fundamentals*. The origin of this publication goes way back to distant 1922 when the American Society of Heating and Ventilating Engineers published its *Heating and Ventilating Guide*. The guide was published until 1961, following the merging with the American Society of Refrigerating Engineers', and both societies started publication of the combined ASHRAE *Guide and Data Book*. Separate volumes were issued for *Fundamentals and Equipment, and Applications* and *Guide and Data Book* was renamed into *Handbook of Fundamentals*, with separate *Systems, Applications, and Equipment* volumes. In 1973, the Guide and Data Book was renamed into the *ASHRAE Handbook*. Separate I-P and SI unit volumes were issued in 1985. Although volume groupings have shifted over the years, the compiled volumes have continued to become important literature in the field of heating, refrigerating and air - conditioning.

3. Overview of the most significant standards in the field of thermal environment measurements, measurements of thermal characteristics of fabrics and clothing and thermal comfort of human subjects

The numbering of the ASTM international standards is somewhat different comparing to the numbering and nomenclature of the ISO international standards. While individual ISO standards belong to one separate domain, as for example the domain of *Ergonomics of the thermal environments*, ASTM standards belong to the specific section and afterwards to the specific volume. The section 7 covers all the standards intended to be used for defining and testing of fabrics (around 330 of them) and is divided in two volumes, one of which is 7.01 (fabrics, clothing, textile care, fibres, yarns, non-woven textiles, flammability, accessories such as zippers, etc.) and 7.02 (the body measurements, stiches and seams, UV finishing in textile products, etc.). Section 11 covers the technology of the water purification and environmental technology and is composed of 8 sub-volumes, with sub-volume 11.03 which is significant to experts in the field of thermal measurements of clothing ensembles. This sub-section covers the topics in the field of Occupational Health and Safety and Protective Clothing. Every ASTM standard can be found in above mentioned Annual Book of ASTM Standards, which is published by ASTM International organization. ASHRAE Handbook of Fundamentals on the other hand contains fundamental data, explanation of the physical quantities and their measuring units. This guide is published in the series containing four volumes and each year one volume is revised to ensure the in time publishing of all relevant information and actual scientific knowledge. All the corrections can be checked on-line.

3.1. Overview of the most significant ASTM standards in the field of thermal environment measurements, measurements of thermal characteristics of fabrics and clothing and thermal comfort of human subjects

The impact of the overall thermal transmission coefficient of textile materials (or thermal transmittance) is determined by ASTM standard D 1518 – 85 under title *Standard Test Method for Thermal Transmittance of Textile Materials*, Tab.1. The procedures described in this standard are used to identify the impact of the overall thermal transmission coefficient, which is the outcome of the combined action of conduction, convection, and radiation for dry specimens of textile fabrics, battings, and other materials. The overall thermal transmission coefficient is used to measure the time rate of heat transfer from a warm, dry, constant-temperature, horizontal flat-plate up through a layer of the test material to a relatively calm, cool atmosphere [6].

When establishing the applicability of the certain personal protective clothing ensemble for specific occupation, it is important to quantify the thermal resistance and evaporative resistance of textile fabrics, battings, and other materials used for production of those ensembles. The ASTM F1868-14 method entitled *Standard*

Tab.1 Overview of ASTM standards in the field of thermal environment measurements, measurements of thermal characteristics of fabrics and clothing and thermal comfort of human subjects

Designation	Title
ASTM D1518-85	Standard Test Method for Thermal Transmittance of Textile Materials
ASTM F1868-14	Standard Test Method for Thermal and Evaporative Resistance of Clothing Materials Using a Sweating Hot Plate
ASTM F1939-15	Standard Test Method for Radiant Heat Resistance of Flame Resistant Clothing Materials with Continuous Heating
ASTM D7024-04	Standard Test Method for Steady State and Dynamic Thermal Performance of Textile Materials
ASTM F1291-15	Standard Test Method for Measuring the Thermal Insulation of Clothing Using a Heated Manikin
ASTM F2370-05	Standard Test Method for Measuring the Evaporative Resistance of Clothing Using a Sweating Manikin
ASTM F2371-05	Standard Test Method for Measuring the Heat Removal Rate of Personal Cooling Systems Using a Sweating Heated Manikin
ASTM F2700-08	Standard Test Method for Unsteady-State Heat Transfer Evaluation of Flame Resistant Materials for Clothing with Continuous Heating

Test Method for Thermal and Evaporative Resistance of Clothing Materials Using a Sweating Hot Plate covers the measurement of the thermal resistance and the evaporative resistance, under steady-state conditions, of fabrics, films, coatings, foams, and leathers, including multi-layer assemblies, for use in clothing systems. The range of this measurement technique for thermal resistance is from 0.002 to 0.2 K m^2/W and for evaporative resistance is from 0.01 to 1.0 kPa m^2/W [7].

The evaluation of the heat transfer properties of the flame resistant clothing materials subjected to a continuous and standardized radiant heat source are assessed by standard ASTM F1939-15 *Standard Test Method for Radiant Heat Resistance of Flame Resistant Clothing Materials with Continuous Heating*. The specimen in placed in a static, vertical position and can be tested by two standard sets of exposure conditions: 21 kW/m^2 and 84 kW/m^2. This test method rates the non-steady state thermal resistance or insulating characteristics of flame resistant clothing materials subjected to a continuous, standardized radiant heat exposure [8].

The determination of the overall thermal transmission coefficient (thermal transmittance) due to conduction for dry specimens of textile fabrics, battings, and other materials and the determination of the temperature regulating factor (TRF) [9] is evaluated according to standard ASTM D7024-04 *Standard Test Method for Steady State and Dynamic Thermal Performance of Textile Materials*. This method is applicable for quality and cost control during manufacturing and can be used to establish criteria for establishing thermal and comfort parameters for textiles used in the clothing industry.

The test method ASTM F1291-15 *Standard Test Method for Measuring the Thermal Insulation of Clothing Using a Heated Manikin* covers the determination of the insulation value of a different garments or a clothing ensembles. It is applicable for the determination of the insulation properties of clothing to dry heat transfer in static conditions, dependent on the fabric layers, the coverage of the body or to be exact the amount of body surface area covered by clothing and the impact of the ease allowance added to specific clothing ensemble (looseness or tightness of fit). The ensembles' insulation values can be used for the models that predict the different physiological responses of people in different environmental conditions. This test method is used to determine the insulation values of clothing ensembles but it also describes dry heat transfer from a heated manikin to a relatively calm and cool environment (ambient temperature set to t_a = 21 ± 1.0°C or at least 10°C below the manikin's mean skin temperature which is set to t_s = 32 – 35 ± 0.3°C, air velocity set to v_a = 0.1±0.05 m/s and relative humidity set to RH = 30 – 70 ± 5%). The testing is performed only for particular clothing ensembles in static conditions with thermal manikin standing. The consequences with respect to air movement, are not addressed in this test method [10].

The determination of the evaporative resistance of clothing ensembles is covered in accordance with standard ASTM F2370-05 *Standard Test Method for Measuring the Evaporative Resistance of Clothing Using a Sweating Manikin*. The measurement of the resistance to evaporative heat transfer of clothing ensembles is measured by the static standing heated sweating thermal manikin. The standard can be used in model formation that predicts the different physiological responses of people under different environmental conditions. This test method covers the determination of the evaporative resistance of clothing ensembles. It describes the measurement of the resistance to evaporative heat transfer from the heated sweating thermal manikin to a relatively calm environment. It also specifies the sweating thermal manikin configuration, testing protocol and testing conditions [11].

The evaluation and comparison of *PCS's-Personal Cooling Systems*, which are dressed in combination with classic clothing or other specified clothing ensembles, is performed according to ASTM standard ASTM F2371-05 *Standard Test Method for Measuring the Heat Removal Rate of*

Personal Cooling Systems Using a Sweating Heated Manikin. The method covers the objective property evaluation for different Personal Cooling Systems' constructions because both the resistance to dry heat transfer by means of conduction, convection, and radiation is taken into consideration. It requires the usage of the sweating heated thermal manikin. It is particularly crucial to take into account sweating capability as the potentially large fraction of heat dissipation is associated with evaporative cooling. It describes the evaporative heat removal rate and the duration of cooling provided by the Personal Cooling System, in order to assess the effectiveness. The resistance to evaporative heat loss of PCS's is measured with static sweating thermal manikins constructed to maintain a certain constant uniform temperature over the body surface [12].

ASTM F2700-08 standard describes the procedures to measure the unsteady-state heat transfer through different materials used in flame resistant clothing exposed to combined convective and radiant thermal hazards. The title is *Standard Test Method for Unsteady-State Heat Transfer Evaluation of Flame Resistant Materials for Clothing with Continuous Heating*. It describes the response of materials, products, or assemblies to heat under controlled conditions, but they don't necessarily incorporate all factors required for fire hazard or fire risk assessment of the materials, products, or assemblies under actual fire conditions [13].

3.2. The overview of the most significant ISO standards in the field of thermal environment measurements, measurements of thermal characteristics of fabrics and clothing and thermal comfort of human subjects

The ISO 7726:2001 *Ergonomics of the thermal environment - Instruments for measuring physical quantities* specifies the minimum characteristics of instruments and measuring methods for measuring physical quantities characterizing different environments, Table 2. This norm doesn't define an overall index of comfort or thermal stress, but it standardizes the process of recording information leading to the determination of such indices subsequently. The basic physical quantities defined by the standard are: air temperature, mean radiant temperature, absolute humidity of the air, air velocity and surface temperature [14]. The measuring methods defined by this standard are classified in two categories depending on the thermal environment for which they are set to. The C category specifies conditions and methods that relate to measurements carried out in moderate environments approaching comfort conditions and the C category specifies conditions and methods that relate to measurements carried out in environments subjected to a greater thermal stress or even to the environments of extreme thermal stress. An environment may be considered to be "homogeneous" from the bio-climatic point of view if, at a given moment, air temperature, radiation, air velocity and humidity can be considered to be practically uniform around the subject. When the environment is too heterogeneous, the physical quantities should be measured at several locations around the subject and the mean values should be assessed. The derived physical quantities characterize a group of environmental factors, weighted according to the characteristics of the sensors used. They are

Tab.2 Overview of ISO standards in the field of thermal measurements, defining thermal environment of fabrics and thermal request set upon textiles and clothing

Designation	Title
ISO 7726:2001	Ergonomics of the thermal environment-Instruments for measuring physical quantities
ISO 7730:2005	Ergonomics of the thermal environment-Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria
ISO 7933:2004	Ergonomics of the thermal environment-Analytical determination and interpretation of heat stress using calculation of predicted heat strain
ISO 8996:2004	Ergonomics of the thermal environment - Determination of metabolic rate
ISO 9886:2004	Ergonomics-Evaluation of thermal strain by physiological measurements
ISO 9920:2009	Ergonomics of the thermal environment-Estimation of thermal insulation and water vapour resistance of a clothing ensemble
ISO 10551:2001	Ergonomics of the thermal environment-Assessment of the influence of the thermal environment using subjective judgement scales
ISO 11079:2007	Ergonomics of the thermal environment-Determination and interpretation of cold stress when using required clothing insulation (IREQ) and local cooling effects
ISO 11092:1993 (BS EN 31092:1993)	Textile - Physiological effects–Measurement of thermal and water–vapour resistance under steady–state conditions (Sweating guarded–hotplate test
ISO 14058:2004	Protective clothing-Garment for protection against cool environments
ISO 342:2004	Protective clothing-Ensembles and garment for protection against cold
ISO 15831:2004	Clothing-Physiological effects- Measurement of thermal insulation by means of a thermal manikin

often used to define an empirical index of comfort or thermal stress without having recourse to a rational method based on estimates of the various forms of heat exchanges between the human body and the thermal environments, and of the resulting thermal balance and physiological strain.

The methods predicting the general thermal sensation and degree of discomfort (thermal dissatisfaction) of people exposed to moderate thermal environments, are described in standard ISO 7730:2005 *Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria*. This method enables the analytical determination and interpretation of thermal comfort using calculation of PMV (predicted mean vote) and PPD (predicted percentage of dissatisfied) and local thermal comfort criteria [15].

It implies that the environmental conditions are considered acceptable for general thermal comfort as well as those representing local discomfort, caused by thermal environment. It is applicable to healthy men and women exposed to (un)comfortable indoor environments, depending weather one wants to conduct assessment for improvement of the existing conditions or to design new ones. It is intended to be used with reference to ISO/TS 14415:2005 [16] when considering persons with special requirements, such as those with physical disabilities. Comfort limits can be expressed by the PMV and PPD indices and by calculating local discomfort factors such as draught, vertical air temperature difference, cold or warm floors and radiant temperature asymmetry. It describes environmental conditions that are considered acceptable for general thermal comfort as well as for the non–steady–state thermal environments.

Standards in the field of Ergonomics of the thermal environment are ISO 7726 [14] (measuring physical quantities) and ISO 8996 [17] (determination of metabolic rate). These standards are used to describe and quantify the parameters influencing human thermoregulation in some specific environment, but standards such as ISO 9886 [18] (evaluation of thermal strain by physiological measurements) and ISO 9920 [19] (estimation of thermal insulation and water vapour resistance of a clothing ensemble) are describing how to predict the degree of thermal protection based on those parameters, apropos thermal comfort or discomfort and health risks possibly sustained by the subjects in certain environment.

The methods for evaluating health risks, while exposing to hot environments, on the basis of variation from the heat balance conditions between the human body and the environment [20], are covered by standard ISO 7933:2004 *Ergonomics of the thermal environment-Analytical determination and interpretation of heat stress using calculation of predicted heat strain*. This method is acceptable in the cases where classical clothing is worn (personal protective and functional clothing is not addressed by this standard) and it describes the method for predicting the sweat rate and internal core temperature that the human body will develop in response to the hot environmental conditions. This is the mean to evaluate the thermal stress felt by the subject and physiological strain. It is also suitable for prediction of the maximum allowable exposure times in hot environments.

The standard ISO 8996:2004 *Ergonomics of the thermal environment - Determination of metabolic rate*) [17] is used to determine the metabolic rate, as a conversion of chemical into mechanical and thermal energy. It describes the measurements of the energetic cost of muscular load and gives a numerical index of activity. The metabolic rate is the crucial factor while determining the comfort or the strain resulting from exposure to a thermal environment. In hot environments the thermal strain rises due to the high levels of metabolic heat production associated with muscular work. As large amounts of heat need to be dissipated from the body into the environment, mostly by sweating. The data included in this standard concern an average male 1.75 m high, weighting 70 kg with the body surface area of 1.8 m^2 and average female 1.70 m high, weighting 60 kg with the body surface area of 1.6 m^2. This standard implies that the total energy consumption while working is assumed equal to the heat production. The mechanical efficiency of muscular work, so-called the useful work W, is negligible.

Four approaches for determining the metabolic rate are given by the standard. The choice can be made between the two methods: Method 1A is a classification according to occupation while method 1B is a classification according to the kind of activity. Method 2A is the method of determining the metabolic rate by adding the metabolic rate for body posture, the metabolic rate for the type of work and the metabolic rate for body motion related to work speed to the baseline metabolic rate. Method 2B is the method of determining the metabolic rate by means of the tabulated values for various activities. The metabolic rate could be determined from heart rate recordings over a representative period of time (level 3 analysis). This method for the indirect determination of metabolic rate is based on the relationship between oxygen uptake and heart rate under defined conditions. The expertise is mean of metabolic rate assessment on the basis of three possible methods performed by trained experts. Method 4A covers the oxygen consumption measured over short periods (10 min to 20 min). The 4B method is the so-called doubly labelled water method aiming to characterize the average metabolic rate over much longer periods of 1 to 2 weeks and 4C is a direct calorimetry method.

The second standard ISO 9886:2004 *Ergonomics-Evaluation of thermal* *strain by physiological measurements* describes measurements and interpretation of the physiological parameters of the human body, which are basis for estimating the strain possibly sustained by a subject during exposure in specific environment or while performing certain activities [21]. The standard describes methods for measuring and interpreting the following physiological parameters such as the body core temperature, the skin temperatures, the heart rate and the body-mass loss. The body core temperature could be approximated on the basis of oesophageal temperature, rectal temperature, intra-abdominal temperature, oral temperature, tympanic temperature, auditory canal temperature and urine temperature. Depending on the technique used, the temperature measured can reflect the mean temperature of the body mass, or the temperature of the blood irrigating the brain and therefore influencing the thermoregulation centres in the hypothalamus.

The measurements of the mean skin temperature are performed at different location on the body, cause skin temperatures aren't homogeneous at different parts of the body, using a temperature transducer with a precision of ±0,1°C in the range from 25 °C to 40 °C. This skin's heterogeneity is primary the consequence of ambient conditions. One can measure the local skin temperature (t_{sk}) measured at a specific point of the body surface, and the mean skin temperature on the entire surface of the body. The skin temperature is influenced by the thermal exchanges by conduction, convection, radiation and evaporation at the surface of the skin, and the variations of skin blood flow and the temperature of the arterial blood reaching the particular part of the body. Assessment of thermal strain on the basis of heart rate is based on measuring the beats per minute over a time interval in minutes. The increase in heart rate is usually related to the increase in the core temperature and thermal stress due to environmental conditions. The increase in heart rate for an increase of 1°C in the body core temperature is called thermal cardiac reactivity and is expressed in heartbeats per minute and per degree Celsius [bmp/min·°C].

Assessment of physiological strain on the basis of body-mass loss due to sweating is determined on the basis of measuring the gross body-mass loss of a person during a given time interval. When assessing the physiological strain on the basis of body-mass loss due to sweating, one will determine the sweat loss and the net water balance of the body. In warm and hot environments, the sweat loss can be considered as an index of the physiological strain, including not only the sweat that evaporates at the surface of the skin but also the fraction dripping from the body surface or accumulating in the clothing. The net water balance is important when considering the risk of dehydration. Regular intake of small volumes of water is able to balance for about 75 % of the water loss. The MSR 12 is an example of measuring equipment for measuring physiological parameters of human body in accordance with standard ISO 9886:2004, Fig.3 [22].

Fig.3 Modular measuring system MSR 12 for measuring physiological parameters of human body in accordance with standard ISO 9886:2004 [22]

The assessment methods for prediction of the thermal characteristics of the clothing, the thermal insulation and the water vapour resistance under reference conditions, including the effects of body movements and air velocity on the clothing thermal insulation values and the water vapour resistance [19] are determined according to ISO 9920:2009 *Ergonomics of the thermal environment-Estimation of thermal insulation and water vapour resistance of a clothing ensemble*.

The standard describes the effects of clothing, such as adsorption of water, buffering or tactile comfort. It also takes into account the influence of rain and snow on the thermal characteristics, role of the special protective clothing, or deals with the separate insulation on different parts of the body and discomfort due to the asymmetry of a clothing ensemble.

The standard ISO 10551:2001 *Ergonomics of the thermal environment-Assessment of the influence of the thermal environment using subjective judgement scales* [23] proposes a set of specifications on direct expert assessment of thermal comfort/discomfort expressed by subjects. The persons are subjected to various degrees of thermal stress during periods spent in various climatic conditions at their workplace. The data provided by this assessment will be used to supplement physical and physiological methods of assessing thermal loads. This standard covers the application of judgement scales intended for providing reliable and comparative data on the subjective aspects of thermal comfort felt in working environments.

Other standards form this series (such as ISO 7726 and 7730) provide the experts to objectively evaluate the thermal environments. These standards provide the methods for analytical determination of the indices, which are used to predict the average climatic conditions needed to obtain thermal comfort or the degree of thermal stress, felt by the persons in their working places. Most of the working areas show spatial heterogeneities with local climatic differences and temporal fluctuations. Furthermore, subjective preferences of each subject differ. So it is important to take subjective judgements into consideration while designing work place and suggesting the most optimal working conditions. This standard implies this kind of specific analytical approach. At the begging of each survey, one must construct and choose the appropriate judgement scales. It is important to mention that the thermal environments which lend themselves to the application of subjective judgement scales relate to conditions which differ to a moderate degree from thermal neutrality. Under all testing procedures one must take into account the appropriate deviation from moderate working climate, so no health risks are set upon subjects. The data obtained by this standard are combined with other standards from this series of the Ergonomics of the thermal environment (ISO 7243, 7726, 7730, 7933, 8996, 9886, 9920, 11079). There are a number of subjective judgement scales for thermal environments, which differ in whether emphasis is placed on the specific time frame (present or past), the duration of testing, as to the object of judgement is subjective judgement of the environment or the consequences felt by the person while working in some environment, whether this is perceptual or affective judgement scale, whether the global or localized consequences of the organism are tested, whether the testing is instantaneous or extended over a period of time, etc. They also differ the whole or its component parts (the temperature, humidity, air movement; thermal state of the body, skin wetness, respiration), permanent or temporary situation, temperate or extreme conditions. This International Standard is limited to the five scales of subjective judgement. By repeatedly applying the same scales, the evolution with time of the thermal comfort or strain experienced in constant conditions may be assessed and an integrated judgement obtained over the whole time of exposure by appropriate computation of the data (e.g. overall mean). In the case of steady climatic conditions, with sedentary working people, the testing is applied after acclimatization of 30 min. Persons submitted to repeated application of the same judgement scales should be informed beforehand. After responses to given questions in questionnaires are collected, statistical analysis is performed.

The low ambient temperatures are the primary parameter which affects human body, endangering the human health. However, the standard ISO 11079:2007 *Ergonomics of the thermal environment-Determination and interpretation of cold stress when using required clothing insulation (IREQ) and local cooling effects* [24] describes the impact of the cold felt under windy conditions usually in cold climatic conditions called the *wind chill index-WCI*.

The humans have the ability of both unconscious and conscious adaptation to climatic conditions. The thermoregulatory control mechanisms could be unconscious and conscious. Unconscious mechanisms are described through negative feedback, hypothalamus and hormones, while conscious thermoregulatory control mechanisms include behavioural changes such as moving closer to the heat source when it is cold or dressing in extra layers of thicker clothing or removing extra layers of clothing when it's hot. The clothing is main conscious factor in maintaining the thermal neutrality and acquiring the state of thermal comfort in dynamic climatic conditions and reactions inside the human body. Therefor it is important to know the insulation values of clothing garments and ensembles and requirements then imposed upon. The heat exchange in human organism has its origin above all in heat balance equation. Thus it is very important to include heat exchange at the surface of the skin and the effect of clothing as main barrier on the way of heat release from human body to the environment. This standard is compatible to other standards (ISO 7726, 8996, 9237, 9920, 13731, 13732-3, 15831 and 511), which set requirements while measuring human reactions in warm environments, parameters assessment and while describing thermal environments, fabric type and clothing ensembles for protection against cold.

The physical properties of textile materials which contribute to physiological comfort involve a complex combination of heat and mass transfer [25]. Each may occur separately or simultaneously. They are time-dependent, and may be considered in steady-state or transient conditions. The measuring methods of textile materials are described through standard ISO 11092:1993 (BS EN 31092:1993) *Physiological effects–Measurement of thermal and water–vapour resistance under steady–state conditions (Sweating guarded–hotplate test*). Thermal resistance is the complex result of the combination of radiant, conductive and convective heat transfer, and its value depends on the contribution of each component to the total heat transfer. Although it is an intrinsic property of the textile material, its measured value may change with the conditions of testing due to the interaction of parameters such as radiant heat transfer with the surroundings. There are several methods which may be used to measure the heat and the moisture properties of textiles, each of them being associated to a certain property and relying on certain assumptions for its interpretation. The sweating guarded-hotplate, which is often called the skin model, is described in this standard and is intended to simulate the heat and mass transfer processes which occur next to human skin, Fig.4.

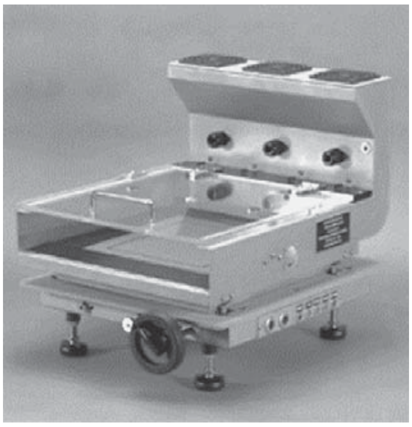


Fig.4 The example of the sweating guarded-hotplate apparatus by Thermometrics in accordance with ASTM F1868 and ISO 11092 [26]

Measurements involving one or both processes may be carried out either separately or simultaneously using a variety of environmental conditions. This conditions involve combinations of temperature, relative humidity, air speed, either in the liquid or gaseous phase. Hence transport properties measured with this apparatus can be made to simulate different wear and environment conditions in both transient and steady states. This standard covers only steady-state conditions, while the application area is defined through specifying the thermal and water-vapour resistance under steady-state conditions, of e.g. fabrics, films, coatings, foams and leather, including multilayer assemblies, for use in clothing, quilts, sleeping bags, upholstery and similar textile or textile-like products. The application of this measurement technique is restricted to a maximum thermal resistance and water-vapour resistance which depend on the dimensions and construction of the apparatus used (e.g. 2 m^2 K/W and 700 m^2 Pa/W respectively, for the minimum specifications of the equipment). The test conditions are not intended to represent specific comfort situations, and performance specifications in relation to physiological comfort are not stated. Protective clothing ensembles for protection of human body against cold are described by standard ISO 342:2004 [27].

Single clothing garments for protection from the effects of cool environments are described by another standard ISO 14058:2004 [28]. In the standard ISO 14058:2004 *Protective clothing - Garment for protection against cool environments*, requirements on single clothing garments, which should be achieved, are stated to protect against local body cooling. Thermal stress sustained due to cold is observed from the point of entire body cooling, called *general cooling* and partial body cooling of certain area of the body, called *local cooling*. In the standard ISO 14058:2004 the focus is on describing the consequences from local body cooling and their impact on obtaining the feeling of thermal comfort. With local body cooling, susceptible parts of the body are extremities such as hands, feet and face. Single body garments which cover a part of the body are described, such as undershirt with long sleeves, long underpants, up to knee socks, one layered jacket, one layered trousers, vest and coat. This garments need to give certain degree of thermal protection. Both requirements set upon those garments and testing methods are described in the standard. The specific requirements set for the thermal protection of the extremities (e.g. hands, feet, face) are not covered by this standard. The specific requirements for glows are described by standard ISO 511:2006 [29], while the specific requirements for footwear are described by ISO 20344:2004 *Personal protective equipment - Test methods for footwear* [30]. The specific requirements for thermal protection of head are described in above mentioned standard ISO 342:2004 *Protective clothing - Ensembles and garments for protection against cold* [31]. However, this standard describes only one type of protective garments for head protection against cold and this is *balaclava*. The level of thermal protection, which should be achieved by those garments, is depend primary on the application of these garments. If their usage is mainly for protection while working under low temperatures and under long exposures, the level of thermal protection of specific clothing garments should be precisely assessed. Those garments could be used for work both in indoor and outdoor environments. In these cases, the standard is referred to moderate low temperatures, which don't deviate much from optimum working temperatures, but could affect the working capabilities during prolonged exposures (e. g. while working indoor where lower temperatures are required like for cold storage in food processing industry).

Another above mentioned standard, called ISO 342:2004 *Protective clothing-Ensembles and garment for protection against cold* [31], defines the requirements and testing methods for protective clothing, especially clothing ensembles and afterwards singles clothing garments for protection against cold. The thermal insulation is one of the most important properties which is tested by thermal manikin apparatus The convective heat losses. are increased by the effect of wind. Therefore, the water vapour permeability, apropos the water vapour permeability of the outer layer of the clothing ensemble and thermal insulation of clothing are important factors to be taken into account in relation to the protection of the wearer against cold. Except the thermal insulation and the water vapour permeability, protective clothing should also have a defined ability for moisture absorption. Sweating is unavoidable physiological process but is also extremely dangerous during the cold exposures. The moisture absorption will progressively reduce garment's thermal insulation and the degree of thermal protection. Thereby for protective clothing, whose main purpose is thermal protection during the cold conditions, it is important to select flexible, adjustable garments who adapt to body contours rather than to select the maximal insulation level. When designing such protective garments one should take into account ventilation openings, so that excessive heat and moisture management and spontaneous cooling of the body could be ensured. The passive diffusion of excessive moisture is not that efficient as active ventilation through for that purpose foreseen, ventilation openings. When the environment temperatures are below 10, the water vapour release into the environment is weakened due to condensation and freezing, which takes place inside the structure of the material.

The test procedure used to measure the thermal insulation of a clothing ensemble by means of thermal manikin is described through standard ISO 15831:2004 *Clothing-Physiological effects- Measurement of thermal insulation by means of a thermal manikin* [32]. The testing is performed to determine the efficiency of the thermal insulation of clothing, which the wearer will use in the relatively calm environments. This thermal insulation of clothing can be used to determine the physiological effect of clothing on the wearer in specific climate and activity scenarios. There are number of thermal manikin constructions. The measurement could be performed with the manikin stationary or with the extremities moving simulating the human walk. On University of Zagreb, Faculty of textile technology in Department of clothing technology, the hardware components and software for thermal manikin have been developed [33, 34]. A segmented metal mould, anatomically constructed to simulate human body, so called thermal manikin, consists of 24 human body segments with installed electrical heaters, temperature sensors, 14 microcontroller interfaces and pneumatic system for arms and legs movements, Fig.5.

This standard specifies following terms:

- *Clothing ensemble* is a group of garments worn together on the body at the same time.
- *Thermal insulation of clothing* is a temperature difference between the wearer's skin surface and ambient atmosphere divided by the resulting dry heat flow per unit area in the direction of the temperature gradient where the dry heat flow consists of conductive, convective and radiant components. Depending on the end use of the clothing, different thermal insulation values can apply.
- *Total thermal insulation of clothing,* I_t is total thermal insulation from skin to ambient atmosphere,

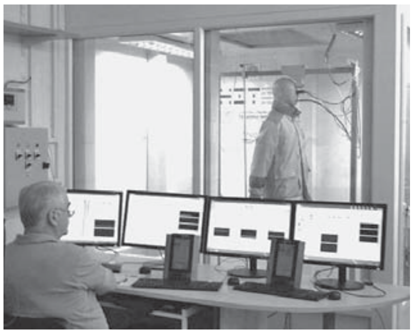


Fig.5 Thermal manikin developed at Department of clothing technology at Faculty of textile technology [34]

Tab.3 Overview of other significant ISO standards in the field of thermal measurements, defining thermal environment of fabrics and thermal request set upon textiles and clothing

Designation	Title
ISO 7243:1989	Hot environments - Estimation of the heat stress on working man, based on the WBGT-index (wet bulb globe temperature
ISO 11399:1995	Ergonomics of the thermal environment - Principles and application of relevant International Standards
ISO 12894:2001	Ergonomics of the thermal environment - Medical supervision of individuals exposed to extreme hot or cold environments
ISO 13731:2001	Ergonomics of the thermal environment - Vocabulary and symbols
ISO 13732-1:2006	Ergonomics of the thermal environment - Methods for the assessment of human responses to contact with surfaces - Part 1: Hot surfaces
ISO/TS 13732-2:2001	Ergonomics of the thermal environment - Methods for the assessment of human responses to contact with surfaces - Part 2: Human contact with surfaces at moderate temperature
ISO 13732-3:2005	Ergonomics of the thermal environment - Methods for the assessment of human responses to contact with surfaces - Part 3: Cold surfaces
ISO/TS 14505-1:2007	Ergonomics of the thermal environment - Evaluation of thermal environments in vehicles - Part 1: Principles and methods for assessment of thermal stress
ISO 14505-2:2006	Ergonomics of the thermal environment - Evaluation of thermal environments in vehicles - Part 2: Determination of equivalent temperature
ISO 14505-3:2006	Ergonomics of the thermal environment - Evaluation of thermal environments in vehicles - Part 3: Evaluation of thermal comfort using human subjects
ISO/TS 14415:2005	Ergonomics of the thermal environment - Application of International Standards to people with special requirements
ISO 15265:2004	Ergonomics of the thermal environment - Risk assessment strategy for the prevention of stress or discomfort in thermal working conditions
ISO 15743:2008	Ergonomics of the thermal environment-Cold workplaces-Risk assessment and management

including clothing and boundary air layer, under defined conditions measured with a stationary manikin.

- *Resultant total thermal insulation of clothing, I_{tr}* is total thermal insulation from skin to ambient atmosphere, including clothing and boundary air layer, under defined conditions measured with a manikin moving its legs and arms.

3.3. ASHRAE Handbook of fundamentals

ASHRAE organization has issued *Handbook of fundamentals* in 2005.

Fig.6 Portrait of the Handbook of Fundamentals cover published by ASHRAE

whose 8. chapter defines the thermal comfort. Fig.6 shows the cover of the mentioned publication released in 2013.

Thermal comfort is defined as *that condition of mind that expresses satisfaction with the thermal environment* [35], by the standard *ASHRAE Standard 55-2010* [36]. The thermoregulatory control mechanisms could be unconscious and conscious, and humans consciously deduce conclusions on thermal comfort or discomfort based on direct stimulus from skin and core of the body. In general, comfort occurs when body temperatures are held within narrow ranges, when the skin moisture is low, and when situation doesn't requires substantial physialogical efforts of the organism for the environmental adaptation. As a consequence of adaptation human body is capable to initiated a number of conscious behavioural actions to reduce discomfort. Some of the possible behavioural actions to reduce discomfort are altering clothing variety, altering intensity and type of activity, changing posture or location, opening or closing a window, etc. Surprisingly, although regional climate conditions, living conditions, and cultures differ widely throughout the world, the temperature that people choose for comfort under like conditions of clothing, activity, humidity, and air movement has been found to be very similar.

The 8th chapter summarizes the fundamentals on human thermoregulation and comfort in terms useful to the engineer for operating systems and designing for the comfort and health of building occupants [35].

4. Conclusion

The most significant international organizations for standardization are ASTM (acronym American Society for Testing and Materials), ISO (International standard organization) and ASHRAE (The American Society of Heating, Refrigerating and Air-Conditioning). All of the three organizations conduct systematic publication of the internationally recognized standards whose application allows the unification of testing procedures and quality control of both raw materials need for production as well as the final products. The development of the international standards in the field of the thermal environment, thermal characteristics of the clothing ensembles and the human subjects' assessment of the thermal comfort, allows systematic control of both measuring methods, as well as the control of the services and final products which are distributed on global market. Besides, the results obtained by measurements from every laboratory could be reviewed and checked across accredited laboratories equipped with standardized and specified measuring equipment. Information, requirements and quality control described in above mentioned international standards ensure that the needs of the consumers on global market are met. The development of new products and manufacturing processes also imposes continuous development of standards so they are systematically improved. In the field of the thermal environment, thermal characteristics of the clothing ensembles and the human subjects' assessment of the thermal comfort, these standardized international standards describe, depending on the area of activity, the measuring method for testing of thermal characteristics of the textile materials, final clothing garments and combined clothing ensembles. Besides products testing, some of the standards define testing conditions and requirements for measuring equipment. Only chapter 8 from Handbook of fundamentals by ASHRAE describes all of the relevant terms without direct description of the measuring methods which define environments, human body and clothing as boundary protective layer during an interaction and heat exchange.

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