

# Occupational Health Impacts of Climate Change: Current and Future ISO Standards for the Assessment of Heat Stress

Ken PARSONS<sup>1</sup>

<sup>1</sup>Loughborough Design School, Loughborough University, United Kingdom

*Received September 26, 2012 and accepted November 16, 2012*

**Abstract:** The current system of International Standards (ISO) is assessed to consider whether standards are fit for purpose for the future in the context of climate change. ISO 7243, ISO 7933 and ISO 9886 provide the current ISO system for the assessment of heat stress. These involve a simple monitoring index, an analytical approach and physiological monitoring, respectively. The system relies on accurate measurement of the thermal conditions experienced by the worker (ISO 7726); and estimations of metabolic heat production due to work (ISO 8996) and the thermal properties of clothing (ISO 9920). As well as standards for heat stress assessment, the full range of ISO standards and the physical environment is listed as well as current work and proposed standards. A particular ‘gap’ in anticipating requirements for ISO standards in the future is the link between meteorological data and ISO standards. This is important for predicting the global consequences of a changing climate and anticipating potential impacts on occupational health across countries and cultures.

**Key words:** International standards, Ergonomics, Health, Heat stress, climate change

## Introduction

In the future, people across the world will be exposed to different thermal environments during work than they have been used to in the past. This is because of changes in industrial processes and stages of national and regional development for both indoor and outdoor work, as well as effects due to climate change where more varied and extreme climates can be expected, often atypical of a particular region. For example people will be exposed to heat or cold when they are not used to it and this may have a significant impact on occupational health.

International standards are produced by groups of national and international experts in a subject and they are accepted by a system of rules and international voting

on drafts of a standard leading to a final accepted version<sup>1, 2</sup>). There are currently twenty accepted international standards in the area of the ergonomics of the thermal environment covering indoor and outdoor conditions and including heat stress, cold stress and thermal comfort. The standards are intended to represent the best available and agreed information and methods that can be used internationally to assess the impact of thermal conditions on health and comfort. It is useful to have an international standard not only to allow the best methods to be used internationally but to ensure reliability in methods and systems as well as an ability to compare results and learn from outcomes across the world. It is also worth noting that, as well as supporting the health and safety of workers, they support the establishment of quality control and fair trading in international markets as well as stimulating national and international debate that leads to research and to the development of the subject and its practical applica-

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E-mail: K.C.Parsons@lboro.ac.uk

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tion.

For international standards in the area of thermal environments a number of principles have become established. Underpinning all of the assessment methods is that there are six important factors, all of which have to be taken into consideration when assessing human response to thermal conditions and using the standards. These are the environmental factors: air temperature; radiant temperature; air velocity; and humidity and the personal factors: clothing and activity. It is the interaction of all six factors that determine human response and not a subset or one alone. This can be demonstrated from heat transfer analysis between the human body and the environment<sup>3)</sup>. Another principle is that a person responds to the local conditions to which they are exposed, so the above six factors have to be quantified in terms of the exposure of the person. The interaction of the four environmental factors can be considered to be the thermal exposure and of the six factors, the thermal stress. Thermal strain is the response of the body. A thermal index is a single number that represents the integrated thermal stress and can be used to predict thermal strain. Thermal strain can be physiological strain, measured by heart rate, body temperature, sweating etc. and psychological strain including subjective response, such as ratings of discomfort or intolerance, or behavioural response such as changing clothing or moving away from the stress. The principle is that a strain is a 'movement away' from an optimal condition such as thermal comfort where there are preferred subjective responses as well as comfortable internal body temperatures and mean skin temperatures (e.g. usually around 37°C and 33°C respectively for sedentary people). In the context of hot conditions, the terms heat exposure, heat stress and heat strain are used.

The principles described above are fundamental and generally accepted internationally. They are relevant to provide assessment guidance when new methods and standards are proposed. To propose a thermal index, where not all six factors are influential or that does not represent the thermal stress experienced by people, inherently will be deficient. An example will be attempting to predict heat stress and health from meteorological data where some of the important factors have traditionally not been measured. This is a challenge for the future.

For International Standards to provide the best available methods for the future they are continually reviewed in terms of new knowledge and future requirements. Climate change will provide challenges and threats to industrial health. It is important that ISO standards are available to

meet that challenge which will be a global phenomenon. A description of current ISO standards is provided below with a consideration of future requirements and strategy. It is emphasized that when applying standards the reader should use the original standard and not the summary descriptions provided in this paper. Countries that have been involved in the production of ISO standards and the physical environment are listed in Appendix 1. The twenty current international standards for the assessment of thermal environments as well as a description of additional standards, proposed standards and current work is provided in Appendices 2 and 3.

### **Current ISO Standards for the Assessment of occupational Heat Stress**

*ISO 7243 (1989) Hot environments – Estimation of heat stress on working man, based upon the WBGT – index (wet bulb globe temperature)<sup>4)</sup>*

#### **Principle**

This international standard provides a simple measurement method for monitoring thermal conditions to which workers are exposed and allows interpretation of the measurement to determine whether it is safe to work or if further action is required. Although the WBGT instrument used to make the assessment does not measure the air temperature, mean radiant temperature, air velocity and humidity directly (i.e. the factors that influence human response), it is influenced by all of those physical parameters and therefore has validity. When considered with the additional factors of activity and clothing, the index value is used to assess heat stress, predict possible thermal strain and indicate whether a hot environment is safe for work.

#### **Scope**

“This international standard gives a method, which can easily be used in an industrial environment, for evaluating the heat stress to which an individual is subjected in a hot environment and which allows a fast diagnosis. It applies to the evaluation of the mean effect of heat on man during a period representative of his activity but it does not apply to the evaluation of heat stress suffered during very short periods, nor to the evaluation of heat stresses close to the zones of comfort.”<sup>4)</sup>

#### **Contents**

Method; Introduction; Scope; Principle and general definition; Measurement of parameters characteristic of the environment; Measurement or estimation of metabolic

energy; Measurement specifications; Period and duration of measurements; Reference values; Evaluation report; Table of reference values of the WBGT heat stress index; Curves showing reference values of WBGT and method of acclimatization to heat; Example of an evaluation report; Bibliography.

#### Description of the standard

This standard provides a simple convenient method, and uses the wet bulb globe temperature (WBGT) heat stress index to assess hot environments.

Inside buildings and outside buildings without solar load

$$WBGT = 0.7t_{nw} + 0.3t_g \quad (1)$$

While outside buildings with solar load

$$WBGT = 0.7t_{nw} + 0.2t_g + 0.1t_a \quad (2)$$

where:

$t_{nw}$  is the natural wet bulb temperature

$t_g$  is the temperature of a 150 mm diameter black globe

$t_a$  is the air temperature

Equipment used must be within specification. For example if the globe size is incorrect or the air temperature is not shielded from radiation, this may have significant consequences for the outcome of the assessment. The following summarizes the specification for the sensors.

The natural wet bulb sensor is cylindrical in shape ( $6 \pm 1$  mm diameter and  $30 \pm 5$  mm long), with a measuring range of 5–40°C and accuracy of  $\pm 0.5^\circ\text{C}$ . The support of the sensor is 6 mm in diameter and a clean white wick of highly water absorbent material (e.g. cotton) covers (as a sleeve fitted with precision) the whole of the sensor and 20 mm of the support.

The globe temperature is the temperature at the centre of a thin, matt black globe (mean emission coefficient of 0.95) with a measuring range of 20–120°C with an accuracy of  $\pm 0.5^\circ\text{C}$  to 50°C and  $\pm 1^\circ\text{C}$  to 120°C. It is important that the globe is of 0.15 m in diameter.

The air temperature sensor should be shielded from the effects of radiation by a device that does not restrict air circulation. It should measure over the range of 10 to 60°C with an accuracy of  $\pm 1^\circ\text{C}$ .

The WBGT value used in the standard is a weighted average, over time and space, and is measured over a period of maximum heat stress. The weighting for spatial variation is given by:

**Table 1. WBGT reference values (ISO 7243<sup>4</sup>)**

Metabolic rate ( $Wm^{-2}$ )	WBGT reference value	
	Acclimatized ( $^\circ\text{C}$ )	Not acclimatized ( $^\circ\text{C}$ )
Resting $M < 65$	33	32
$65 < M < 130$	30	29
$130 < M < 200$	28	26
$200 < M < 260$	25 (26)*	22 (23)*
$M > 260$	23 (25)*	18 (20)*

The values given have been established allowing for a maximum rectal temperature of 38 °C for the persons concerned.

\*Figures in brackets refer to sensible air movement; figures without brackets refer to no sensible air movement.

From ISO 7243 (1989).

$$WBGT = \frac{WBGT \text{ head} + 2 \times WBGT \text{ abdomen} + WBGT \text{ ankles}}{4} \quad (3)$$

For time variations (e.g. in metabolic rate, WBGT, globe temperature) a time-weighted average is taken over a period of work/resting of one hour. This is calculated from the beginning of a period of work.

The WBGT value of the hot environment is compared with a WBGT reference value, allowing for a maximum rectal temperature of 38°C (Table 1).

#### Future requirements and ISO 7243<sup>4</sup>

The WBGT index is the most widely used heat stress index across the world. It is incorporated into ISO 7243<sup>4</sup> as well as the influential American Conference of Governmental Industrial Hygienists 'exposure limits' for heat stress<sup>5</sup>. It is also used by many national standards bodies and professional organisations in standards and procedures. Recently the working group responsible for developing the standard (ISO TC 159 SC5 WG1) has undertaken a review and revision of the standard to ensure that it is fit for purpose for the future. Although only at the discussion stage, so changes can be expected, it has been confirmed that the standard will be required in the future; the specification of the instrument for measuring WBGT will not change (i.e. globe size will remain 150 mm diameter); a more detailed mechanism for taking account of the properties of clothing is needed; a method for predicting WBGT from basic parameters of air temperature; radiant temperature; air velocity and humidity is required and a method of predicting globe temperatures of different diameter globes is required.

It is often found that in hot countries, particularly in hot weather spells which will increase with climate change,

the WBGT values are close to, or exceed, reference values so the standard would restrict all work and is difficult to apply. It is generally found that the reference values provided are ‘safe’ limits’. That is, if applied, there will be few health problems among the work force, however there will be workers who can work safely at WBGT levels above the reference values. It can be noted that ISO 7243<sup>4)</sup> reference values are in an informative annex and hence not a formal part of the standard. It would be possible therefore to apply the standard with reference values related to context. However, evidence suggests that as WBGT levels increase above the reference values provided in the Annex to the standard, heat casualties increase. This is a challenge for the future and work design must play a role (appropriate work/rest schedules, providing cool areas or shaded areas from the sun etc). ISO 7243 and the WBGT index will play a major role in monitoring occupational heat stress in the future and with climate change this will be an important first line of defence in the avoidance of heat casualties.

*ISO 7933 (2004) Ergonomics of the thermal environment – Analytical determination and interpretation of heat stress using calculation of the predicted heat strain<sup>6)</sup>*

#### Principle

This standard uses a calculation of the heat transfer between the person and the environment to predict likely heat strain. The heat transfer is calculated from individual measurements of air temperature; radiant temperature; air velocity and humidity along with estimates of metabolic heat production and clothing insulation. The consequent heat storage is interpreted in terms of the predicted physiological response of the body. This in turn is interpreted in terms of acceptable conditions and if they are predicted to become unacceptable, allowable exposure times. An important part of the calculation is to obtain the sweat rate that is required in order to maintain heat balance (no heat storage). Whether this can be achieved by the person or not and for how long it can be sustained, along with other physiological indicators, provides the basis for the interpretation.

#### Scope

“This international standard specifies a method for the analytical evaluation and interpretation of the thermal stress experienced by a subject in a hot environment. It describes a method for predicting the sweat rate and the internal core temperature that the human body will develop in response to the working conditions.

The various terms used in this prediction model, and in particular in the heat balance, show the influence of the different physical parameters of the environment on the thermal stress experienced by the subject. In this way, this international standard makes it possible to determine which parameter or group of parameters should be modified, and to what extent, in order to reduce the risk of physiological strains.

The main objectives of this international standard are the following:

- a) The evaluation of the thermal stress in conditions likely to lead to excessive core temperature increase or water loss for the standard subject;
- b) The determination of exposure times with which the physiological strain is acceptable (no physical damage is to be expected). In the context of this prediction mode, these exposure times are called “maximum allowable exposure times”.

This International Standards does not predict the physiological response of individual subjects, but only considers standard subjects in good health and fit for the work they perform. It is therefore intended to be used by ergonomists industrial hygienists, etc., to evaluate working conditions<sup>6)</sup>.

#### Contents

Scope; Normative References; Symbols; Principles of the method of evaluation; Main steps of the calculation; Interpretation of the required sweat rate; Data necessary for the computation of thermal balance; Criteria for estimating acceptable exposure time in a hot work environment; Metabolic rate; Clothing thermal characteristics; Computer programme for the computation of the Predicted Heat Strain.

#### Description of the standard

This standard provides a method of assessment based upon the analysis of the heat transfer between the worker and the thermal environment as defined by the six basic parameters: air temperature, radiant temperature, air velocity, humidity, clothing properties and metabolic heat production produced by activity. A previous standard (ISO 7933,1989 – withdrawn)<sup>7)</sup> calculated from the heat transfer equation, the sweat rate required to be produced by a person in order to ensure that any heat gain by the body is within acceptable limits. For example to ensure that internal body temperature does not increase to levels that would endanger health. The current standard is a development of that analysis. From the analysis, predic-

tions of likely heat strain can be made and exposure times to preserve health can be calculated. An analytical method provides a causal model in terms of identifying relative causes (heat transfer mechanisms and component factors) of the heat strain. This can lead to redesign of the work and environment to provide mechanisms for ensuring that conditions and exposures are not a threat to health. This analytical method is carried out using a computer programme which is given in hard copy in the standard. It is also available electronically. For a description refer to the original standard and Parsons<sup>3</sup>. For a description of the Predicted Heat Strain method see Malchaire *et al*<sup>8</sup>.

The predicted heat strain is calculated from equations of heat transfer between the worker and the environment. Inputs to the method are the six basic parameters described above. The required evaporation is calculated from:

$$E_{req} = M - W - C_{res} - E_{res} - C - R - dS_{eq} \quad (4)$$

Where

$M$  is metabolic rate ( $Wm^{-2}$ ) and is derived from ISO 8996.

$W$  is mechanical work ( $Wm^{-2}$ ) and can often be neglected.

$E_{req}$  is required evaporative heat flow  $Wm^{-2}$

$C_{res}$  is respiratory convective heat flow  $Wm^{-2}$

$E_{res}$  is respiratory evaporative heat flow  $Wm^{-2}$

$C$  is convective heat flow  $Wm^{-2}$

$R$  is radiative heat flow  $Wm^{-2}$

$dS_{eq}$  is body heat storage rate for increase in core temperature associated with the metabolic rate  $Wm^{-2}$

$dS_{eq}$  is derived from the core temperature increase, the proportion of the body that is at core temperature and the specific heat of the body.

The terms in equation (4) can be calculated from the following equations.

$$C_{res} = 0.00152M(28.56 - 0.885 t_a + 0.641 P_a)$$

$$E_{res} = 0.00127M(59.34 + 0.53 t_a - 11.63 P_a)$$

$$C = h_{cdyn} \times f_{cl} \times (t_{cl} - t_a)$$

$$R = h_r \times f_{cl} \times (t_{cl} - t_r)$$

$$E = w(P_{sk,s} - P_a)/R_{tdyn}$$

$$dS_{eq} = C_{sp} \times (t_{cr,eqi} - t_{cr,eqi-1}) \times (I - \alpha)$$

Where

$t_a$  is air temperature $^{\circ}C$

$t_r$  is mean radiant temperature $^{\circ}C$

$t_{cl}$  is clothing surface temperature $^{\circ}C$

$P_a$  is water vapour partial pressure kPa

$P_{sk,s}$  is saturated water vapour pressure at skin temperature kPa

$h_{cdyn}$  is dynamic convective heat transfer coefficient  $W m^{-2} K$

$h_r$  is radiative heat transfer coefficient  $W m^{-2} K$

$w$  is skin wettedness dimensionless

$f_{cl}$  clothing area factor dimensionless

$R_{tdyn}$  dynamic total evaporative resistance of clothing and boundary air layer  $m^2 kPa W^{-1}$

Note: the formula for  $C_{res}$  above is from the standard. In the computer programme listing included in the annex of the standard however  $C_{res}$  includes  $0.115t_a$ , not  $0.885t_a$ .  $0.115t_a$  is probably more correct.

Required sweat rate ( $SW_{req}$ ) and required skin wettedness ( $w_{req}$ ) are given by

$$SW_{req} = \frac{E_{req}}{r_{req}} \quad (5)$$

and

$$w_{req} = \frac{E_{eq}}{E_{max}} \quad (6)$$

Where  $r_{req}$  is the required evaporative efficiency of sweating. The maximum evaporative heat flow at the skin surface ( $E_{max}$ ) is given by

$$E_{max} = \frac{(P_{sk,s} - P_a)}{R_{tdyn}} \quad (7)$$

Interpretation of analysis for the Predicted Heat Strain model

Two criteria of thermal stress (maximum skin wettedness ( $w_{max}$ ) and maximum sweat rate ( $SW_{max}$ )) and two criteria for thermal strain (maximum acceptable rectal temperature ( $t_{re,max}$ ) and maximum allowable dehydration and water loss ( $D_{max}$ )) are used to interpret the analysis. Suggested limit values are provided in Table 2.

In Table 2 it is assumed that maximum sweat rate in acclimatised subjects is, on average, 25% greater than for non-acclimatised subjects. Dehydration limits ( $D_{max}$ ) are based upon a maximum dehydration rate of 3% (for industry, not the Army or sportsmen). Even when water is available, workers tend not to drink as much as they lose in sweat. For an exposure lasting 4 to 8 h, a rehydration rate of 60% is observed on average (in 50% of workers) regardless of the total amount of sweat produced, and is greater than 40% in 95% of cases. Hence based upon the rehydration rate  $D_{max50}$  and  $D_{max95}$  are set (i.e. 60% replacement of 7.5% loss = 4.5% so 7.5% - 4.5% = 3% dehydration. 40% replacement of 5% loss = 2%, so 5% - 2% = 3% dehydration).

Rectal temperature is derived from heat storage  $S$  where:

**Table 2. Suggested limit values used in the Predicted Heat Strain Method (ISO 7933<sup>6)</sup>)**

	Non-acclimatized	Acclimatized
Maximum wettedness		
$W_{\max}$	0.85	1
Maximum sweat rate		
$SW_{\max} W_m^{-2}$	$(M - 32) \times A_D$	$1.25 \times (M - 32) \times A_D$
Maximum dehydration and water loss		
$D_{\max 50}$	$7.5\% \times \text{body mass}$	$7.5\% \times \text{body mass}$
$D_{\max 95}$	$5\% \times \text{body mass}$	$5\% \times \text{body mass}$
Rectal temperature limit		
$T_{re\max}$	38 °C	38 °C

$$S = E_{req} - E_p + S_{eq}$$

S is body heat storage rate

$E_p$  is predicted evaporative heat flow

$S_{eq}$  is body heat storage for increase of core temperature associated with metabolic rate

Heat storage leads to an increase in core temperature taking into account the increase in skin temperature.

A flow chart is provided in the standard for the calculation of predicted sweat rate ( $SW_p$ ), predicted wettedness ( $w_p$ ) and predicted evaporation rate ( $E_p$ ).

In general when values that are required are achievable by the workers then they are the predicted values. When they are not achievable, the maximum values are the predicted values. This is a generalisation and the detail is provided in the standard.

Determination of the allowable exposure duration (DLE)

The maximum allowable exposure duration,  $D_{lim}$ , is reached when either the rectal temperature or the accumulated water loss reaches the corresponding limits. If  $E_{\max}$  is negative (i.e. condensation) or estimated allowable exposure time is less than 30 min, then the method is not applicable.

To allow calculation using the PHS method, an electronic copy of a computer programme can be downloaded from the worldwide web.

### Future requirements and ISO 7933<sup>6)</sup>

In a future of climate change and extreme heat an analytical approach to the assessment of heat stress will be required to evaluate work and determine working practices. Currently the Predicted Heat Strain method is the most developed method for predicting potential health problems due to work in the heat. In the future models of human thermoregulation may play a part as well as the use of me-

teorological data but neither are sufficiently developed at present. ISO 7933<sup>6)</sup> is particularly suited to the assessment of work. Developments are still required however. These include a more valid method for the assessment of changing environments as well as more consideration of thermal radiation particularly for outdoor work. The question of usability of the standard is also often raised. Assuming a 'black box' approach where the user carries out an assessment with a computer programme but without a profound knowledge of the method may be appropriate. However, this may lead to misunderstanding of the results and is not transparent. Currently the method is complex and it is not clear how much use has been made of the standard or how accessible the computer programme has been found to be. Greater profile and use of the standard will stimulate development tools. The assessment of rapidly changing environments and short exposures as well as hot environments where specialist protective clothing is worn are outside of the scope of the standard at present and whether the standard can be extended to include these in the future is not clear. For those situations, ISO 9886<sup>9)</sup> and personal physiological monitoring may remain the method of assessment.

*ISO 9886 (2004) Ergonomics – Evaluation of thermal strain by physiological measurements<sup>9)</sup>*

Principle

ISO 7243<sup>4)</sup> provides a simple monitoring method for assessing heat stress and ISO 7933<sup>6)</sup> provides an analytical approach. These standards are applicable to many environments however they are not valid for all hot conditions at work, for example where protective clothing and equipment are worn or where exposures are short or rapidly changing. They also are not valid for predicting the responses of individuals. Where an individual response

is required then it is necessary to make physiological measurements. ISO 9886<sup>9)</sup> provides measurement techniques for the four main physiological indicators of thermal strain. These are body core temperature, mean skin temperature, heart rate and body-mass loss. A range of methods for measuring the indicators is provided together with the principle of the measurement, measurement techniques, precautions and potential errors and method of interpretation. Where there is a risk of damage to health then physiological measurement will provide an indication of the thermal state of the body and allow a rapid response to remove the person from the heat stress. This standard will complement the development of personal monitoring systems for use in practical application.

### Scope

“This International Standard describes methods for measuring and interpreting the following physiological parameters:

body core temperature;  
skin temperatures;  
heart rate;  
body-mass loss.

The choice of variables to be measured and techniques to be used is at the discretion of those responsible for the health of the employees. These persons will have to take into account not only the nature of the thermal conditions, but also the degree of acceptance of these techniques by the employees concerned.

It should be emphasised that direct measurements on the individual can only be carried out on two conditions.

- a) If the person has been fully informed about the discomfort and the potential risks associated with the measurement technique and gives free consent to such measurements.
- b) If the measurements present no risk for the person which is unacceptable in view of general or specific codes of ethics.

In order to simplify this choice, Annex A presents a comparison of the different methods concerning their field of application, their technical complexity, the discomfort and the risks that they might involve.

This standard defines the conditions which are to be met in order to ensure the accuracy of the data gathered from the different methods. The measurement methods are described in Annex B. Limit values are proposed in Annex C (informative).

This standard is not concerned with experimental conditions for which investigators may develop alternative

methods intended to improve knowledge in this area. It is however recommended, when conducting such studies in the laboratory, to use the methods described below as references, so that results may be compared.

Before using the evaluations methods described in this International Standard, the user is required to follow the ethics and legal rules in force in his country or institution. Accordingly, ethical committees will be consulted and rules concerning free written consent, freedom of participation, confidentiality, etc. will be strictly followed<sup>9)</sup>.

### Contents

Scope; Normative references; Symbols and abbreviated terms; Measurement of body core temperature; Measurement of body skin temperature; Assessment of thermal strain on the basis of heart rate; Assessment of physiological strain on the basis of body mass loss due to sweating; Comparison between the physiological methods of evaluation of thermal strain; Measuring techniques; Limit values of the physiological parameters of thermal strain; Bibliography.

### Description of the standard

In extreme environments, or for other reasons such as research, it may be necessary to measure the physiological strain on humans exposed to thermal environments. This Standard describes methods for measuring and interpreting body core temperature, skin temperatures, heart rate and body mass loss.

Annex A of the Standard presents a comparison of the different methods concerning their field of application, their technical complexity, their discomfort, and the risks that measurement might involve. Measurement methods are described in Annex B and limit values are proposed in Annex C of the Standard (Table 3).

The principle of the Standard is to present information to allow the informed selection and correct application and interpretation of physiological measures.

### Future requirements of ISO 9886<sup>9)</sup>

When ISO 9886<sup>9)</sup> was first developed physiological measurement was the domain of the physiologist and medical practitioner. This was the expected target user group for the standard. More recently developments in technology and availability of equipment ‘over the counter’ as well as developments in computer analysis systems has led to a much wider potential user group and has raised the importance of the standard to ensure that measurements are made correctly and interpreted with understanding.

**Table 3. Physiological measures considered by ISO 9886 (2004)<sup>9)</sup>**

Physiological response	Measure considered
Body core temperature	Oesophageal temperature
	Rectal temperature
	Gastro-intestinal temperature
	Oral (mouth) temperature
	Tympanic temperature
	Auditory canal temperature
	Urine temperature
Skin temperature	Local skin temperature
	Mean skin temperature
	ISO 4-point method
	ISO 8-point method
	ISO 14-point method
Heart rate	The partial method is used to identify the component due to thermal stress
Body mass loss	Due to respiration and sweating
Take account of body inputs (food and drink) and body outputs (urine and stools)	

The availability of measuring systems and their utility in occupational health assessment presents a need for the standard to be updated and reviewed. This is a continuing process and additions such as infra-red tympanic temperature measurement systems as well as the gastro-intestinal radio pill have been made in revisions of the standard. If extremes of climate do become more prevalent then the standard will have increased use. Developments in technology are on-going and new indicators may be identified. Physiological monitoring of whole groups of workers, (also military personnel, space or aircraft crews or sports teams for example) is now possible on-line with potential rapid response, and the methods for processing and presenting such data, and systems of response have yet to be fully explored. The physiological principles will be important and there will be a need for a continual update of this standard to meet future requirements.

*ISO 7726 (1998) Ergonomics of the thermal environment – Instruments for measuring physical quantities<sup>10)</sup>*

**Principle**

This international standard provides the specification of instrumentation for measuring the physical environment. It does not specify particular instruments. Any instrument that meets the specification is acceptable for use in quantifying the thermal environment such that values can be used in other international standards. These include those for assessing heat stress, cold stress and thermal comfort.

Physical parameters to be measured include air temperature, radiant temperature, air velocity and humidity. Any developments in technology or new instruments that are developed will be acceptable for use if they meet the specification provided (i.e. measurement range; accuracy; response time).

**Scope**

“This international standard specifies the minimum characteristics of instruments for measuring physical quantities characterizing an environment as well as the methods for measuring the physical quantities of this environment.

It does not aim to define an overall index of comfort or thermal stress but simply to standardize the process of recording information leading to the determination of such indices. Other International Standards give details of the methods making use of the information obtained in accordance with this standard.

This international standard is used as a reference when establishing

- a) Specifications for manufacturers and users of instruments for measuring the physical quantities of the environment;
- b) a written contract between two parties for the measurement of these quantities.

It applies to the influence of hot, moderate, comfortable or cold environments on people<sup>10)</sup>

**Contents**

Scope; Normative references; General; Measuring instruments; specifications relating to measuring methods; Measurement of air temperature; Measurement of the mean radiant temperature; Measurement of plane radiant temperature; Measurement of the absolute humidity of the air; Measurement of air velocity; Measurement of surface temperature; Measurement of operative temperature; Bibliography.

**Future requirements for ISO 7726<sup>10)</sup>**

Principles of measuring the thermal environment rely on the physics of heat transfer and remain relevant as do properties of instruments such as accuracy, reliability, response time and range of application. The specification of instruments in ISO 7726<sup>10)</sup> will therefore sustain. However, technological developments allow new ways of achieving specifications and new opportunities for presenting measurements such as the use of data logging and local processing as well as the development of computer sys-



tems (including 'Apps'). Future requirements will therefore be to ensure that the standard embraces developments and takes account of opportunities to improve and enhance specifications. Climate change will provide a need for valid measurements of the hot environments to allow valid predictions of occupational exposure and consequences for health. The use of meteorological instrumentation and parameters should be included as such data will be used in the future for assessing heat and occupational health across the world. This will need to be coordinated with experts who specify meteorological measuring equipment to ensure a unified approach and an understanding of what is required to predict human responses to thermal conditions.

*ISO 8996 (2004) Ergonomics of the thermal environment – Determination of metabolic rate<sup>11)</sup>*

Principle

The primary purpose of this standard is to present ways of determining the metabolic heat production in the body when it is conducting activities. Four categories of estimation are provided from simple screening and estimation from a general description of work to expertise involving measurement. The metabolic heat production is a fundamental factor in heat stress assessment and is very influential in determining thermal response. An indication of accuracy of methods is provided and any inaccuracy can lead to significant changes in prediction and interpretation of human response. This standard is therefore important to support the application of other standards such as ISO 7933<sup>6)</sup>. Another purpose of the standard is to provide an estimate of metabolic rate for use in energy calculations for the body such as those used in nutritional analysis.

The estimated value of metabolic rate is provided for a standard person and is given in  $\text{Wm}^{-2}$ . That is Joules per second per square meter of the body surface area. The division by the surface area of the body allows individuals of different sizes to be compared. For example 1 Met is regarded as the metabolic rate of a resting person and is  $58 \text{ Wm}^{-2}$ . Light manual work can be estimated as  $100 \text{ Wm}^{-2}$ . For a larger person the heat production rate in the body will be larger but so will the surface area so individuals can be compared in a meaningful way. If the surface area of a person is known then an adjustment can be made to provide a more appropriate value in Watts. This will become important where populations have different body surface areas than those assumed in the standard.

Scope

“The metabolic rate, as a conversion of chemical into

mechanical and thermal energy, measures the energetic cost of muscular load and gives a numerical index of activity. Metabolic rate is an important determinant of the comfort or the strain resulting from exposure to a thermal environment. In particular, in hot climates, the high levels of metabolic heat production associated with muscular work aggravate heat stress, as large amounts of heat need to be dissipated, mostly by sweat evaporation.

This International Standard specifies different methods for the determination of metabolic rate in the context of ergonomics of the climatic working environment. It can also be used for other applications – for example, the assessment of working practices, the energetic cost of specific jobs or sport activities, the total cost of an activity etc.

The estimations, tables and other data included in this international standard concern an ‘average’ individual:

- a man 30 years old weighing 70 kg and 1.75 m tall (body surface area  $1.8 \text{ m}^2$ );
- a woman 30 years old weighing 60 kg and 1.7 m tall (body surface area  $1.6 \text{ m}^2$ )

Users should make appropriate corrections when they are dealing with special populations including children, aged persons, people with physical disabilities etc.”<sup>11)</sup>

Contents

Scope; Normative references; Principle and accuracy; Level 1, screening; Level 2, observation, Level 3, analysis; Level 4, expertise; Evaluation of metabolic rate at level 1, screening; Evaluation of metabolic rate at level 2, observation; Evaluation of metabolic rate at level 3, analysis; Evaluation of metabolic rate at level 4, expertise.

**Future requirements of ISO 8996<sup>11)</sup>**

It is important to give the best available estimate of metabolic heat production to provide an accurate assessment using ISO 7243<sup>4)</sup> and ISO 7933<sup>6)</sup>. Technology has improved so that techniques are more easily used, however the simple principles remain valid and inaccuracies, especially when predicting the metabolic rate of individuals, prevail. Future requirements include consideration of the metabolic rate of types of indoor and outdoor work across the world and for different cultures and populations. The difference between paced work, where the worker has to maintain a level of activity, and non-paced work, where the worker can vary the activity level to control heat stress, is of importance and should be considered in the application of the standard. The influence of clothing on metabolic rate, in both resistance to movement and weight, requires further research and guidance should be

included in the standard. Research into individual differences in metabolic rate for the same activity requires further investigation as does the role of nutrition. These are important requirements as the estimation of metabolic heat production could be regarded as one of the limiters in improvements in validity to standards for the assessment of heat stress, cold stress and thermal comfort.

*ISO 9920 (2007) Ergonomics of the thermal environment – Estimation of thermal insulation and water vapour resistance of a clothing ensemble<sup>12)</sup>*

#### Principle

ISO 9920<sup>12)</sup> provides methods for estimating and quantifying the thermal properties of clothing. The values can be used in ISO 7243<sup>4)</sup> and ISO 7933<sup>6)</sup> as an integral part of the assessment of heat stress. The standards can also be used in other areas where the thermal properties of clothing are relevant, for example as part of the specification of clothing, clothing selection and clothing design. Thermal insulation values can be determined using a human shaped heated thermal manikin. The standard provides such values for a wide range of clothing garments and ensembles that have been determined in climatic laboratories mainly for military and civilian western clothing. The primary properties of clothing ensembles and garments are the thermal insulation which is a resistance of the clothing to the transfer of ‘dry’ heat from the body surface to the environment and the evaporative resistance, a resistance to water vapour transfer for example due to evaporated sweat. Thermal insulation is assumed to be a resistance to heat conduction and has the units of  $\text{m}^2 \text{ }^\circ\text{C W}^{-1}$ . One Clo is the thermal insulation of a typical business suit and has a value of around  $0.155 \text{ m}^2 \text{ }^\circ\text{C W}^{-1}$ . Zero Clo is no resistance and is a nude subject although a factor is the resistance of the air around the body which must also be taken into account. Evaporative resistance is in units of  $\text{m}^2 \text{ kPa W}^{-1}$ . Other factors considered in the standard include the effects of movement and wind on thermal properties as well as measurement methods on manikins and human subjects.

#### Scope

“This international standard specifies methods for estimating the thermal characteristics (resistance to dry heat loss and evaporative heat loss) in steady-state conditions for a clothing ensemble based on values for known garments, ensembles and textiles. It examines the influence of body movement and air penetration on the thermal insulation and water vapour resistance.

This International Standard does not

- deal with other effects of clothing such as adsorption of water, buffering, tactile comfort;
- take into account the influence of rain and snow on the thermal characteristics;
- consider special protective clothing (water cooled suits, ventilated suits, heated clothing);
- deal with the separate insulation on different parts of the body and discomfort due to the asymmetry of a clothing ensemble<sup>12)</sup>.

It should be noted that after the standard was published in 2007, a correction was added in 2008. The most recent version of the standard may therefore be published in 2008 or in some national versions in 2009<sup>13)</sup>.

#### Contents

Scope; Principles and general definitions; Estimation of the thermal insulation of a clothing ensemble based on tables with values measured on standing thermal manikin; Estimation of the clothing area factor; Influence of body movements and wind on the thermal insulation of a clothing ensemble; Estimation of the evaporative resistance; Thermal insulation values for clothing ensembles; Thermal insulation values for individual garments; Measurement of the thermal insulation of clothing on a thermal manikin; Measurement of the thermal insulation and evaporative resistance of a clothing ensemble on human subjects; Different expressions for the thermal insulation of clothing; Evaporative resistance of a clothing ensemble.

#### Future requirements for ISO 9920<sup>12)</sup>

There is a requirement to include clothing from different parts of the world. Clothing is often a dynamic system to provide appropriate insulation depending upon conditions. In addition different styles and materials for clothing are used. Currently the standard is not comprehensive on these issues although some information is given. The estimation of clothing properties is greatly influential in estimating heat stress and predicting thermal strain and accurate information is essential for a valid assessment. The limitations outlined in the scope of the standard (water adsorption, rain, snow, special protective and active clothing, distribution of clothing) are all important and limit the application of the standard. Developments in technology such as smart clothing and the dynamics of activity and clothing are requirements for future versions of the standard.

## Discussion

### *The ISO system*

ISO standards for the assessment of heat stress have been produced and used for over 30 yr and provide a comprehensive system of assessment. There are still many challenges that remain for standards to meet current requirements and improvements to the standards are ongoing. Future occupational environments will provide additional requirements that will need to be identified and met. Consequences of not anticipating future requirements, for example due to climate change, will lead to increased heat casualties including deaths in extreme conditions. This paper has concentrated on heat stress and occupational health. However future requirements for standards will also be to consider sustainable use of resources including for example comfort temperatures or general work design that encourage energy efficiency. Future requirements for individual standards have been discussed in this paper but it is also of interest to discuss whether the ISO system itself will be fit for purpose.

The current system of standards involves the use of the WBGT index<sup>4)</sup> as a simple monitoring index. There are other simple measuring instruments that could be used, however the WBGT index has validity and most importantly it is now widely used. It has become part of the global assessment culture. If a simple index is to be part of the system of assessment then the WBGT index seems as good as any. The analytical assessment method using the heat balance equation<sup>6)</sup> provides a complex and sophisticated assessment but can be easily used with a computer program. Physiological monitoring<sup>9)</sup> completes the rationale for the ISO assessment system where there is a need for the assessment of individuals. All three standards can be improved as described in this paper but overall the system seems robust and could be developed to meet future requirements. The three stage system is not the only system that could be used however and the need for a simple index has been disputed. The use of models of heat exchange and human thermoregulation have also been proposed which could potentially replace the heat balance approach<sup>3)</sup>. Physiological monitoring would seem to have a role in the future although it has been suggested that for work in the heat, personal monitoring will be so available, inexpensive, convenient and sophisticated that other methods that attempt to predict 'average' responses will not be required.

### *Practical application*

Current international standards are 'human centred' and it is assumed that principles apply over a wide range of applications. ISO 14505 parts 1 to 3 considers vehicle environments and ISO 13732 parts 1 to 3 considers safe surface temperatures in terms of skin contact (Appendix 2). However, there are a number of other environments where specific consideration may be required (people in crowds, small cabins on cranes, space or underwater vehicles and 'buildings', work on construction sites, outdoor work in fields etc) and future standards on working practices for hot environments should consider these as well as the usability of the standards in these areas. It is also important for standards to identify intended users of standards and ensure that they 'fit' with organisational structures. Safety officers, ergonomists, building services engineers, occupational hygiene specialists, occupational health personnel, health and safety managers, managers of small firms and maybe individual workers are all stakeholders that may use the standards. This will require training and the inclusion of ISO standards in the curriculum will be important.

ISO 15265<sup>14)</sup> provides a risk assessment strategy which outlines stages of assessment. This has yet to be fully reconciled with the current ISO system of standards and should be considered in the future. It may be particularly relevant in providing a practical strategy for future heat stress assessment caused by climate change. This is because it provides stages of assessment where the early stages are not resource intensive and are easy to apply. Three stages of risk assessment are presented. These are Observation, analysis and expertise. Observation is carried out by workers or management from the organisation who have knowledge of the working conditions. They need have only average knowledge of ergonomics and the cost is low and it takes around two hours to complete. The method allows the detection of a problem using qualitative observations. The analysis method is carried out by the same people as for the observation method but with the addition of specialists in the assessment of thermal environments. It takes around one day to complete and involves some measurements. The expertise method involves all of the people from the first two methods but with experts involved. It is of higher cost, will typically take a few days to complete and is used when cases are complex involving specialist measurements and evaluation. The observation method is the first stage method and will be useful globally as a low cost risk assessment tool. It involves collecting information on the thermal environment and the work using scoring scales and identifies mechanisms for

improvement involving control and reduction of the risk. This may be sufficient in many cases. A future proposed standard will be concerned with working practices for hot environments and that will give an opportunity for the risk assessment procedures to be integrated into the overall standards system for the assessment of heat stress.

#### *Diverse populations*

Climate change will lead to workers being exposed to more varied and extreme climates. Improvements in health and safety systems across the world will lead to greater protection of workers from hazards. This often involves protective clothing and equipment which in turn leads to greatly increased heat stress. Globalisation will involve a diversity of contexts, climates, cultures and populations. The principles of human response to heat will be similar across the world but specific populations will have specific requirements for the application of standards. Two additional standards that have not been discussed so far will provide additional support. These are ISO 12894<sup>15)</sup> which provides methods for screening people to ensure only those fit for the work are exposed, and ISO 28803<sup>16)</sup> which provides guidance on the application of standards for people with special requirements (defined as being outside of the scope of existing standards – not fit, young, male and healthy, for example). This is important as there are millions of so called vulnerable people in the world, including some people with disabilities, and these are the people who are mainly at risk in heat waves. Disability discrimination legislation correctly identifies that where reasonably practicable, working environments should be accessible to diverse populations. This is a challenge for future standards.

#### *Future models*

Models of human thermoregulation are now routinely used in computer aided design and analysis. There is a new project (ISO/NP 16418)<sup>17)</sup> to produce an ISO standard in this area. Whether this will be an ISO model or guidance on the development of models is still under debate. It was not the intention of the new standard to replace existing standards as they have been developed specifically for purpose (e.g. heat stress assessment, cold, thermal comfort etc.). A new development however has proposed a Universal Thermal Climate Index (UTCI) which is based upon a model of human thermoregulation<sup>18, 19)</sup>. This is a first step in the link between meteorological data and predicting the impact of climate on health. There is still some way to go however. The UTCI uses an approximation to a model of

human thermoregulation rather than the model itself and the method for determining an equivalent temperature (ET) is not straight forward. A calculator for the UTCI is available on the internet and is extremely simple to use but it is a simplified version and does not use the full power of the model of human thermoregulation upon which it is based. Deficiencies in available data (e.g. radiation) will lead to deficiencies in predictive power of the UTCI system for predicting responses to outside work and particularly inside work where local climates may be very different from those used in the calculation. There is a need for a standard to make full use of available meteorological data and this should be pursued in the future. Current meteorological data are inadequate (e.g. in terms of radiation) and are measured in the ‘wrong’ place (i.e. not at the workplace). However, they are extensive, global and often all that is available to provide a population level assessment of health impact.

#### *Accessibility of standards*

A final word is relevant on the accessibility of ISO standards as this will greatly affect their use and hence effectiveness in the avoidance of heat casualties. This is not a scientific point but is relevant to application. The structure of the ISO standards organisation ensures that there are many countries throughout the world that adopt the standards and they are available through national standards bodies and distributed to and by contributing industries and organisations. There is some cost involved which may become prohibitive to some work organisations where there is potential for heat casualties. Mechanisms for ensuring accessibility of standards at an affordable price need to be determined to ensure that standards are used in the future.

Although human response to heat does not vary and much is known, people still die because of heat. Developments in technology, new techniques and indicators of thermal strain, new types of work, climate change, globalisation and diverse populations all provide significant challenges and will require continual review of existing standards and new strategies and standards for the future.

## **Acknowledgements**

All of the views expressed in this paper are those of the author. I would like to acknowledge the contribution of members of ISO TC 159 SC5 and its working groups for their significant work in the production of the standards.

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## Appendix 1: Countries involved in the production of ISO standards for heat stress and the Ergonomics of the physical environment

### Participating Countries:

United Kingdom (BSI – secretariat); Belgium (NBN); Brazil (ABNT); Canada (SCC); China (SAC); Czech Republic (UNMZ); Finland (SFS); France (AFNOR); Germany (DIN); Israel (SII); Italy (UNI); Japan (JISC); Republic of Korea (KATS); Malaysia (DSM); Netherlands (NEN); Poland (PKN); Sweden (SIS); Thailand (TISI); USA (ANSI)

### Observing Countries:

Australia (SA); Austria (ASI); Bulgaria (BDS); Cyprus (CYS); Denmark (DS); Ireland (NSAI); Kenya (KEBS); Malta (MCCAA); Romania (ASRO); Russian Federation (GOST R); Slovakia (SUTN); Spain (AENOR)

## Appendix 2: Published ISO standards and the Ergonomics of the Physical Environment (ISO TC 159 SC5)

### ISO TC 159 SC5 WG1: Ergonomics of the thermal environment

ISO 7243 (1989) (ED 2) Hot environments–Estimation of the heat stress on working man, based on the WBGT-index (wet bulb globe temperature)

ISO 7726 (1998) (ED 2) Ergonomics of the thermal environment–Instruments for measuring physical quantities

ISO 7730 (2005) (ED 3) 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) (ED 2) Ergonomics of the thermal environment–Analytical determination and interpretation of heat stress using calculation of the predicted heat strain

ISO 8996 (2004) (ED 2) Ergonomics of the thermal environment–Determination of metabolic rate

ISO 9886 (2004) (ED 2) Evaluation of thermal strain by physiological measurements

ISO 9920 (2007) (ED 2) Estimation of thermal insulation and water vapour resistance of a clothing ensemble

ISO 10551 (1995) (ED 1) Ergonomics of the thermal environment–Assessment of the influence of the thermal environment using subjective judgement scales

ISO 11079 (2007) (ED 1) Ergonomics of the thermal environment–Determination and interpretation of cold stress when using required clothing insulation (IREQ) and local cooling effects

ISO 11399 (1995) (ED 1) Ergonomics of the thermal environment–Principles and application of relevant International Standards

ISO 12894 (2001) (ED 1) Ergonomics of the thermal environment–Medical supervision of individuals exposed to extreme hot or cold environments

ISO 13731 (2001) (ED 1) Ergonomics of the thermal environment–Vocabulary and symbols

ISO 13732–1 (2001) (ED 1) 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) (ED 1) 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) (ED1) 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) (ED 1) Ergonomics of the thermal environment – Evaluation of the thermal environment in vehicles – Part 1: principles and methods for assessment of thermal stress.

ISO 14505–2 (2006) (ED 1) Ergonomics of the thermal environment – Evaluation of the thermal environment in vehicles – Part 2: Determination of Equivalent Temperature (see also ISO 14505–2 (2006)/Cor 1:2007: (ED 1) Technical Corrigendum 1.)

ISO 14505–3 (2006) (ED 1) Ergonomics of the thermal environment – Evaluation of the thermal environment in vehicles – Part 3: Evaluation of thermal comfort using human subjects

ISO 15265 (2004) (ED 1) Ergonomics of the thermal environment – Risk assessment strategy for the prevention

of stress or discomfort in thermal working conditions.

ISO 15743 (2008) (ED 1) Ergonomics of the thermal environment – Cold work places – Risk assessment and management

**ISO TC 159 SC5 WG2: Lighting (Disbanded)**

ISO 8995 (1989) (ED1) Principles of visual ergonomics – The lighting of indoor work systems (Work transferred to CIE).

**ISO TC 159 SC5 WG3: Signals and communication in noisy environments (Disbanded)**

ISO 7731 (2003) Ergonomics–Danger signals for public and work areas–Auditory danger signals

ISO 9921 (2003) Ergonomics–Assessment of speech communication

ISO 11428 (1996) Ergonomics–Visual danger signals–General requirements, design and testing

ISO 11429 (1996) Ergonomics–System of auditory and visual danger and information signals

ISO/TR 19358 (2002) Ergonomics–Construction and application of tests for speech technology

**ISO TC 159 SC5 WG4: Integrated environments**

ISO 28802 (2012) Ergonomics of the physical environment–Assessment of environments by means of an environmental survey involving physical measurements of the environment and subjective responses of people

**ISO TC 159 SC5 WG5: Environments for people with special requirements**

ISO 28803 (2012) Ergonomics of the physical environment–Application of International Standards to people with special requirements

ISO 24500 (2010) Ergonomics–Accessible design–Auditory signals for consumer products

ISO 24501 (2010) Ergonomics–Accessible design–Sound pressure levels of auditory signals for consumer products

ISO 24502 (2010) Ergonomics–Accessible design–Specification of age-related luminance contrast for coloured light

**ISO TC 159 SC5 WG6: Perceived air quality**

No completed standards to date

### Appendix 3: ISO Standards proposed and under development in the area of Ergonomics of the Physical Environment

**ISO TC 159 SC5 WG1: Ergonomics of the thermal environment**

ISO/PWI 7243 Hot environments–Estimation of the heat stress on working man, based on the WBGT-index (wet bulb globe temperature)

ISO/PWI 7933 Ergonomics of the thermal environment–Analytical determination and interpretation of heat stress using calculation of the predicted heat strain

ISO/PWI 10551 Ergonomics of the thermal environment–Assessment of the influence of the thermal environment using subjective judgement scales

ISO/PWI 11399 Ergonomics of the thermal environment–Principles and application of relevant International Standards

ISO/PWI 13731 Ergonomics of the thermal environment–Vocabulary and symbols

ISO/NP 16418 Ergonomics of the thermal environment–Mathematical model for predicting and evaluating the dynamic human physiological responses to the thermal environments

ISO/AWI TR 16594 Guide for working practices for mod-

erate thermal environments

ISO/PWI 16596 Personalized environment

**ISO TC 159 SC5 WG4: Integrated Environments**

ISO/PWI 16597 Determination of the combined effects of the environmental components on people

**ISO TC 159 SC5 WG5: Environments for people with special requirements**

ISO NP 17630 Ergonomics–Accessible design–Colour combination for younger and older people

ISO CD 24504 Ergonomics–Accessible design–Sound pressure levels of spoken announcements for products and public address systems

ISO/NP TR 17535 Accessible outdoor warnings and markings on and at walkways and walking surfaces

**ISO TC 159 SC5 WG6: Perceived air quality**

ISO/NP Ergonomics of the physical environment – A method for assessing perceived indoor air quality using human subject panels (project withdrawn as duplication of work with another ISO committee). Future work items under consideration.