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Ergonomics of the thermal environment — Principles and application of relevant International Standards

Ergonomie des ambiances thermiques — Principes et application des Normes internationales pertinentes

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Contents

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 11399 was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 5, *Ergonomics of the physical environment*.

Annexes A, B and C of this International Standard are for information only.

Introduction

This International Standard is one of a series of standards which specify methods of measuring and evaluating hot, moderate or cold thermal environments. It provides the underlying principles behind the assessment of human response to thermal environments in general and, in particular, those used in the development of each International Standard. It also demonstrates the relationships between the standards and how they can be used in a complementary way to evaluate the whole range of thermal environments.

Ergonomics of the thermal environment — Principles and application of relevant International Standards

1 Scope

The purpose of this International Standard is to specify information which will allow the correct, effective and practical use of International Standards concerned with the ergonomics of the thermal environment.

This includes:

a) a description of each relevant International Standard and the complementary way in which these standards can be used in the ergonomic assessment of thermal environments;

b) a description of the underlying principles used in each relevant International Standard;

c) a description of the underlying principles concerning the ergonomics of the thermal environment.

This International Standard applies to the application of those International Standards listed in clause 2. These standards cover thermal environments over the whole range of ergonomics investigation.

The information provided in this International Standard is not sufficient for the assessment of thermal environments. For that purpose, the appropriate International Standard should be used (see clause 2).

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 7243:1989, *Hot environments — Estimation of the heat stress on working man, based on the WBGT-index (wet bulb globe temperature).*

ISO 7726:1985, *Thermal environments — Instruments and methods for measuring physical quantities.*

ISO 7730:1994, *Moderate thermal environments — Determination of the PMV and PPD indices and specification of the conditions for thermal comfort.*

ISO 7933:1989, *Hot environments — Analytical determination and interpretation of thermal stress using calculation of required sweat rate.*

ISO 8996:1990, *Ergonomics — Determination of metabolic heat production.*

ISO 9886:1992, *Evaluation of thermal strain by physiological measurements.*

ISO 9920:1995, *Ergonomics of the thermal environment — Estimation of the thermal insulation and evaporative resistance of a clothing ensemble.*

ISO 10551:1995, *Ergonomics of the thermal environment — Assessment of the influence of the thermal environment using subjective judgement scales.*

ISO/TR 11079:1993, *Evaluation of cold environments — Determination of requisite clothing insulation (IREC).*

3 Ergonomics of the thermal environment — Principles

Ergonomic investigations of thermal environments involve an understanding of a number of underlying concepts and principles concerning human response to thermal environments and measurement methods. Of fundamental importance are the basic parameters which describe human thermal environments. These are air temperature, mean radiant temperature, humidity, air velocity, clothing insulation and metabolic heat production. Other important concepts and terms include human thermoregulation, heat transfer, the heat balance equation, direct, empirical and rational thermal indices, acclimatization, body core and shell temperatures, surface temperature, thermal sensation and thermal comfort, skin wettedness, derived parameters, required sweat rate, required clothing insulation and others. Many of the above terms are used and some are explained in the relevant International Standards.

NOTE 1 A description of the principles underlying the ergonomics of the thermal environment and the use of the above concepts is provided in annex A.

4 The use of relevant International Standards to assess thermal environments

4.1 General

International Standards dealing with the ergonomics of the thermal environment can be used in an integrated way to allow assessment of human exposure to hot, moderate and cold environments. Guidelines are given in tables 1 and 2 and also described below.

4.2 Hot environments

For the assessment of hot environments, ISO 7243 provides a simple, rapid method of assessment based on the wet bulb globe temperature (WBGT) index. If the WBGT reference values are exceeded or more detailed analysis is required, ISO 7933 provides an analytical method for assessing the environment. If the response of individuals is required, then physiological measurements should be made according to ISO 9886.

The International Standards described in clause 9 will complement the use of standards for assessing hot environments.

4.3 Moderate environments

ISO 7730 allows the calculation of the PMV and PPD and hence the assessment of moderate environments. Average thermal sensation and individual variation in response can be related to thermal comfort and degree of thermal dissatisfaction. Conditions which would produce (average) thermal comfort can also be determined. Individual responses can also be obtained using subjective measurement according to ISO 10551. Where possible, both International Standards should be used in a complementary way to assess moderate environments.

The International Standards described in clause 9 will support and complement the use of standards for assessing moderate environments.

4.4 Cold environments

ISO/TR 11079 (Technical Report) can be used to assess cold environments using $IREQ_{neutral}$, $IREQ_{min}$, WCI and t_{ch}. If IREQ is used to select appropriate clothing for a cold environment, then ISO 9920 can be applied. For the assessment of individuals and specific populations, ISO 9886 will provide guidance on physiological response and ISO 10551 will provide guidance on subjective measurement.

The International Standards described in clause 9 will support and complement the standards for assessing cold environments.

4.5 Contact with solid surfaces

When assessing hot, moderate and cold environments, persons may come into contact with solid surfaces. Future International Standards will be available to assess the thermal sensation and degree of damage which may be caused by contact between bare or covered skin and solid surfaces. For individuals and for non-extreme environments, ISO 10551 will provide guidance for subjective assessment.

Table 1 — Assessment of thermal environments using International Standards

Parameter evaluated	Type of thermal environment		
	Hot	Moderate	Cold
	Means of evaluation		
Comfort and stress	Wet-bulb globe temperature index (WBGT) Required sweat rate (SW_{req})	Predicted mean vote (PMV) and predicted percentage dissatisfied (PPD) indices	Windchill index (WCI) Required clothing insulation (IREQ)
Physiological strain	"Core" and skin temperature, heart rate, mass loss by sweating and respiration		
Psychological strain	Subjective assessment methods		

Table 2 — Ergonomics of the thermal environment — Applicable International Standards

Purpose		Title	Number
General presentation of the set of standards in terms of principles and application		Ergonomics of the thermal environment: principles and application of relevant International Standards	ISO 11399
Standardization of quantities, symbols and units used in the standards		Ergonomics of the thermal environment — Vocabulary	ISO/CD 13731[1)]
Thermal stress evaluation in hot environments	Analytical method	Hot environments — Analytical determination and interpretation of thermal stress using calculation of required sweat rate	ISO 7933
	Diagnostic method	Hot environments — Estimation of the heat stress on working man, based on the WBGT-index (wet bulb globe temperature)	ISO 7243
Comfort evaluation		Moderate thermal environments — Determination of the PMV and PPD indices and specification of the conditions for thermal comfort	ISO 7730
Thermal stress evaluation in cold environments		Evaluation of cold environments — Determination of required clothing insulation (IREQ)	ISO/TR 11079 Technical Report
Data collection standards	Metabolic rate	Ergonomics — Determination of metabolic heat production	ISO 8996
	Requirements for measuring instruments	Thermal environments — Instruments and methods for measuring physical quantities	ISO 7726
	Clothing insulation	Ergonomics of the thermal environment — Estimation of the thermal insulation and evaporative resistance of a clothing ensemble	ISO 9920
Evaluation of thermal strain using physiological measures		Evaluation of thermal strain by physiological measurements	ISO 9886
Subjective assessment of thermal comfort		Assessment of the influence of the thermal environment using subjective judgement scales	ISO 10551
Selection of an appropriate system of medical supervision for different types of thermal exposure		Ergonomics of the thermal environment — Medical supervision of individuals exposed to extreme hot or cold environments	ISO/CD 12894 [1)]

Purpose	Title	Number
Contact with hot, moderate and cold surfaces		ISO/NP 13732 [1)]
Comfort of the disabled		ISO/NP 14415 [1)]
Design of work for cold environments		New work item proposed [1)]
Long-term assessment of environmental quality		New work item agreed [1)]
Vehicle environments		ISO/NP 14505 [1)]
1) Proposed International Standard not yet publically available.		

5 Description of International Standards concerning hot environments

5.1 ISO 7243:1989

ISO 7243:1989, *Hot environments — Estimation of the heat stress on working man, based on the WBGT-index (wet bulb globe temperature).*

5.1.1 Scope

This International Standard provides a method, which can easily be used in an industrial environment, for rapid evaluation of the heat stress to which an individual is subjected in a hot environment.

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.

5.1.2 Principle

ISO 7243 uses the wet bulb globe temperature (WBGT) heat stress index to assess hot environments.

Inside buildings and outside buildings without solar load, this is expressed as:

$$WBGT = 0{,}7t_{nw} + 0{,}3t_g$$

Outside buildings with solar load, this is expressed as:

$$WBGT = 0{,}7t_{nw} + 0{,}2t_g + 0{,}1t_a$$

where, as defined in ISO 7243,

t_{nw} is the natural wet bulb temperature;

t_g is the temperature at the centre of a 150 mm diameter black-globe thermometer;

t_a is the air temperature.

The WBGT value of the hot environment is compared with a WBGT reference value. WBGT reference values are supplied in ISO 7243 for five levels of metabolic rate for acclimatized and nonacclimatized persons. At high levels of metabolic rate, the reference values also depend upon air movement.

Reference values have been established allowing for a maximum rectal temperature of 38 °C for the persons concerned. The values correspond to levels of exposure to which almost all individuals can be ordinarily exposed without any harmfull effect, provided there are no pre-existing pathological conditions.

If the WBGT of the hot environment exceeds the WBGT reference value, then the heat stress at the workplace needs to be reduced or a more detailed analysis made (e.g. using ISO 7933). The method used in ISO 7243 therefore provides a method for simple, rapid evaluation of hot environments.

5.2 ISO 7933:1989

ISO 7933:1989, *Hot environments — Analytical determination and interpretation of thermal stress using calculation of required sweat rate.*

5.2.1 Scope

This International Standard specifies a method of analytical evaluation and interpretation of the thermal stress experienced by a subject in a hot environment. It describes a method of calculating the heat balance as well as the sweat rate that the human body should

produce to maintain this balance in equilibrium; the sweat rate is called the "required sweat rate".

The various terms used in the determination of the required sweat rate show the influence of the different physical parameters of the environment on the thermal stress experienced by the subject. In this way ISO 7933 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 strain.

The main objectives of ISO 7933 are:

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 the modifications to be brought to the work situation in order to reduce or exclude these effects;

c) the determination of the maximum allowable exposure times required to limit physiological strain to an acceptable value.

ISO 7933 does not predict the physiological response of individual subjects, but only considers standard subjects in good health and fit for the work they perform.

The method of computation and interpretation of thermal balance is based on scientific information then available. Future improvements concerning the calculation of the different terms of the heat balance equation, or its interpretation, will be taken into account when they become available. In its present form, this method is not applicable to cases where special protective clothing is worn.

5.2.2 Principle

ISO 7933 provides a rational approach to assessing hot environments. Measurement of the hot environment in terms of air temperature, mean radiant temperature, humidity and air velocity, and estimates of factors relating to persons exposed, in terms of clothing, metabolic rate and posture, are used to calculate the heat exchange between a standard person and the environment. This allows calculation of the required sweat rate, SW_{req} (for the maintenance of the thermal equilibrium of the body) from the following equations:

$$SW_{req} = E_{req}/r_{req}$$

and

$$E_{req} = M - W - C_{res} - E_{res} - C - R$$

where

E_{req} is the required evaporation for thermal equilibrium;

M is the metabolic rate;

W is the effective mechanical power;

C_{res} is the respiratory heat loss by convection;

E_{res} is the respiratory heat loss by evaporation;

C is the heat exchange on the skin by convection;

R is the heat exchange on the skin by radiation;

SW_{req} is the required sweat rate for thermal equilibrium;

r_{req} is the evaporative efficiency at the required sweat rate.

The required sweat rate is compared with the maximum values for skin wettedness (w_{max}) and sweat rate (SW_{max}) which can be achieved by persons. These are presented for acclimatized and nonacclimatized persons at work and rest.

In the case where equilibrium is not achieved, there will be heat storage and hence the body core temperature will rise. Limiting values are presented for warning and danger, in terms of heat storage and also in terms of the maximum allowable water loss compatible with the maintenance of the water and mineral equilibrium of the body.

The predicted sweat rate can be determined from the required sweat rate and the limiting values. If the required sweat rate can be achieved by persons and it will not cause unacceptable water loss, then there is no time limit due to heat exposure, over an eight-hour work shift. If this is not the case, then allowable exposure times can be calculated.

A computer program is provided to allow ease of calculation and efficient use of ISO 7933. This rational method of assessing hot environments allows identification of the relative importance of different components of the thermal environment and hence can be used in environmental design.

6 Description of International Standards concerning moderate thermal environments

6.1 ISO 7730:1994

ISO 7730:1994, *Moderate thermal environments — Determination of the PMV and PPD indices and specification of the conditions for thermal comfort.*

6.1.1 Scope

The purpose of ISO 7730 is:

a) to present a method for predicting the thermal sensation and the degree of discomfort (thermal dissatisfaction) of people exposed to moderate thermal environments;

b) to specify acceptable thermal environmental conditions for comfort.

This International Standard applies to healthy men and women. It was originally based on studies of North American and European subjects, but also agrees well with recent studies of Japanese subjects exposed to moderate thermal environments. ISO 7730 is expected to apply with good approximation in most parts of the world, but ethnic and national/geographic deviations may occur and require further studies. ISO 7730 applies to people exposed to indoor environments where the aim is to attain thermal comfort, or indoor environments where moderate deviations from comfort occur. In extreme thermal environments other International Standards apply. Deviations may occur for sick and disabled people. ISO 7730 may be used in the design of new environments or in assessing existing ones. It has been prepared for working environments, but can be applied to any kind of environment.

6.1.2 Principle

ISO 7730 provides a method of assessing moderate thermal environments using the PMV thermal comfort index. The PMV is the predicted mean of vote of a large group of persons, if they had been exposed to the thermal conditions under assessment, on the following thermal sensation scale:

+3	hot
+2	warm
+1	slightly warm
0	neutral
−1	slightly cool
−2	cool
−3	cold

The PMV is calculated from the air temperature, mean radiant temperature, humidity and air velocity of the environment and estimates of metabolic rate and clothing insulation. The PMV equation involves the heat balance equation for the human body and additional conditions for thermal comfort. The PPD index (predicted percentage of thermally dissatisfied persons) is calculated from the PMV.

ISO 7730 also considers discomfort caused by draught, where draught is defined as an unwanted local cooling of the body caused by air movement. A method for predicting the percentage of people bothered by draught is provided in terms of air temperature, air velocity and turbulence intensity. The model applies over a specified range of thermal conditions and for people performing light, mainly sedentary activity with a thermal sensation for the whole body close to neutral.

Guidance is provided on how to determine acceptable thermal conditions for comfort, based on the methods provided in this International Standard.

Tables and a computer program are provided to allow ease of calculation and efficient use of ISO 7730. This rational method for assessing moderate environments allows identification of the relative contribution which different components of the thermal environment make to thermal comfort (or discomfort) and hence can be used in environmental design.

7 Description of International Standard concerning cold environments

7.1 ISO/TR 11079:1993

ISO/TR 11079:1993, *Evaluation of cold environments — Determination of requisite clothing insulation (IREC).*

7.1.1 Scope

The aim of this Technical Report is to propose methods and strategies to assess the thermal stress associated with exposure to cold environments. They apply to continuous, intermittent as well as occasional exposure and different types of work, indoors and outdoors. Specific effects associated with certain meteorological phenomena (e.g. precipitation) are not covered and should be assessed by other methods.

7.1.2 Principle

The document has been produced as a Technical Report, and only proposed as a standard, as the methods

have yet to be validated. For cold environments there are few methods available and insufficient experimental support and practical experience with the use of IREQ. The purpose is to propose methods for the assessment of cold environments, encourage experimental work to validate and further elaborate the methods, and identify research needs and encourage research in the field. A decision will then be made regarding the nature of an International Standard for the assessment of cold environments.

It is suggested that cold stress be evaluated in terms of both general cooling of the body and local cooling of parts of the body (e.g. extremities, face). For general cooling, ISO/TR 11079 provides a rational method for assessment of cold environments. The clothing insulation required for thermal equilibrium ($IREQ_{min}$) and that required for thermal comfort ($IREQ_{neutral}$) are calculated by satisfying the following equations:

$$IREQ = (t_{sk} - t_{cl})/(M - W - E_{res} - C_{res} - E)$$

and

$$M - W - E_{res} - C_{res} - E = R + C$$

where

t_{sk} is the mean skin temperature;

t_{cl} is the clothing surface temperature;

M is the metabolic power;

W is the effective mechanical power;

E_{res} is the respiratory heat loss by evaporation;

C_{res} is the respiratory heat loss by convection;

E is the evaporative heat loss at the skin surface;

R is the radiative heat loss at the skin surface;

C is the convective heat loss at the skin surface.

For persons who wear clothing insulation which is less than $IREQ_{min}$, there is a risk of progressive body cooling. If clothing with an insulation greater than $IREQ_{neutral}$ is worn, then there will be an increasing feeling of warmth. The interval between $IREQ_{min}$ and $IREQ_{neutral}$ is the clothing regulatory zone, in which each individual chooses the appropriate protection level.

The calculated IREQ value can be used as a required clothing insulation value, for example to allow the selection of clothing for work in a cold environment. It should be remembered that IREQ is a calculated resultant clothing insulation (I_{clr}) value and hence includes the effects of body motion. It can also be used as a cold stress index. The higher the value of IREQ, at any given activity level, the greater the cooling power of the environment.

If the IREQ is used to select appropriate clothing, then it is emphasized that insulation provided by clothing is a dynamic property which varies with such factors as body posture, activity, moisture content and wind. If IREQ cannot be met, then a procedure is presented for calculating maximal exposure times and required recovery times with available insulation.

Local cooling of the hands, head and feet is also considered in this Technical Report. It is noted that knowledge is incomplete in this area. For indoor environments, draughts and lower limits for hand skin temperatures are discussed. For outdoor environments, the windchill index (WCI), expressed in watts per square metre, and the chilling temperature (t_{ch}) are used as indices:

where

$$WCI = 1{,}16[10{,}45 + 10v_{ar}^{1/2} - v_{ar}](33 - t_a)$$

and

$$t_{ch} = 33 - (WCI/25.5)$$

where

v_{ar} is the relative air velocity, in metres per second;

t_a is the air temperature, in degrees Celsius.

A computer program is provided to allow ease of calculation and efficient use of the standard. This rational method for assessing cold environments allows identification of the relative contribution that different components of the thermal environment make to cold stress and thermal comfort (or discomfort), and hence can be used in environmental design.

8 Description of International Standards concerning skin contact with solid surfaces

International Standards are under development to present methods for predicting and assessing the thermal sensation and skin damage caused by contact between bare and covered skin and hot, moderate and cold surfaces (see annex B for a more complete description).

9 Description of supporting and complementary International Standards

9.1 General

Application of the International Standards listed in clauses 4 to 7 requires measurement or estimation of a number of parameters and also the application of methods and techniques. The International Standards described below provide information which is required for the application of standards for assessing thermal environments. They can also be used independently in ergonomic and other investigations.

9.2 ISO 7726:1985

ISO 7726:1985, *Thermal environments — Instruments and methods for measuring physical quantities*

9.2.1 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 the 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 an index.

ISO 7726 should be 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 parameters.

It applies to the study of hot, comfortable or cold environments in any place occupied by people.

9.2.2 Principle

The use of standards for the assessment of thermal environments often requires measurement of the relevant parameters of the thermal environment. ISO 7726 provides definitions of the parameters (air temperature, mean radiant temperature, humidity, air velocity, natural wet bulb temperature, globe temperature, surface temperature), methods of measurement of these parameters and specifications of measuring devices. The parameter values can then be used in the assessment of hot, moderate or cold environments according to the relevant International Standard.

9.3 ISO 10551:1995

ISO 10551:1995, *Ergonomics of the thermal environment — Assessment of the influence of the thermal environment using subjective judgement scales.*

9.3.1 Scope

This International Standard provides a set of specifications for direct expert assessment of subjective thermal comfort/discomfort expressed by persons subjected to thermal stress. The methods supplement physical and physiological methods of assessing thermal loads.

9.3.2 Principle

Subjective scales are useful in the measurement of subjective responses of persons exposed to thermal environments. They are particularly useful in moderate environments and can be used independently or to complement the use of objective methods (e.g. thermal indices) which are described in the International Standards presented in clauses 5, 6 and 7. ISO 10551 presents the principles and methodology behind the construction and use of subjective scales which can be used to assess thermal environments. Examples of such scales are presented in an annex in several languages.

Judgement scales are divided into the five types given in table 3.

Table 3 — Subjective judgement scales from ISO 10551

Judgement	Example	Related to
Perceptual	How do you feel now? (e.g. hot)	Personal
Affective	How do you find it? (e.g. comfortable)	Thermal
Thermal preference	How would you prefer to be? (e.g. warmer)	State
Personal acceptance	Is the environment acceptable/ unacceptable?	Environment
Personal tolerance	Is the environment tolerable?	Environment

The principle of ISO 10551 is to provide background information to allow ergonomists to construct and use

subjective scales as part of the assessment of thermal environments. Examples of the construction, application and analysis of subjective scales are provided in an annex.

9.4 ISO 9886:1992

ISO 9886:1992, *Evaluation of thermal strain by physiological measurements.*

9.4.1 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 parameters to be measured and techniques to be used is at the discretion of those persons responsible for the health of subjects. Those persons will have to take into account not only the nature of the thermal conditions, but also the degree of acceptance of the techniques by the subjects concerned.

Il should be emphasized that direct measurements on the individual can only be carried out on two conditions:

a) if the individual 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 individual which is unacceptable in view of general or specific codes of ethics.

In order to simplify this choice, annex A of ISO 9886 presents a comparison of the different methods concerning their field of application, their technical complexity, the discomfort and the risks that they might involve. It also 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.

The International Standard is not concerned with experimental conditions, for which investigators may develop alternative methods intended to improve knowledge in this area. It is recommended, however, when conducting such studies in the laboratory, to use the methods described in 8.4.2, ISO 9886:1992, as references, so that results may be compared.

9.4.2 Principle

ISO 9886 presents the principles, methods and interpretation of measurements of relevant human physiological responses to hot, moderate and cold environments. This International Standard can be used independently or to complement the use of other standards. Four physiological responses are considered, as shown in table 4.

Comments are also provided on the technical requirements, relevance, convenience, annoyance to the individual, and cost of each of the physiological measurements.

The principle of ISO 9886 is to present information to allow the informed selection and correct application and evaluation of physiological measurements.

Table 4 — Physiological response to environment

Parameter	Measurement considered
Body core temperature	Oesophageal temperature Rectal temperature Intra-abdominal 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 partitioning method is used to identify the component due to thermal stress
Body mass loss	Due to respiration and sweating. Take account of body input (food and drink) and body output (urine and stools).

9.5 ISO 8996:1990

ISO 8996:1990, *Ergonomics — Determination of metabolic heat production.*

9.5.1 Scope

The metabolic rate, as a means of conversion of chemical energy into mechanical and thermal energy, measures the energetic cost of muscular load and gives a numerical index of activity. A knowledge of metabolic rate is necessary to measure metabolic heat production for the evaluation of human heat regulation. While specifying methods for the determination of metabolic rate, ISO 8996 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 energetic cost of activity.

9.5.2 Principle

It is a fundamental requirement of the International Standards referred to in clauses 5, 6 and 7 that an estimate be made of metabolic heat production. ISO 8996 describes methods of estimation as shown in table 5.

Three levels of method are proposed.

The first, level I, is by the use of tables in which estimates are provided based on a description of activity. These range from general description (e.g. light, heavy) to specific descriptions of occupations (e.g. bricklayer) and methods of summing the components of tasks (e.g. basal metabolic rate + posture component + movement component).

The second, level II, is by the use of heart rate. The total heart rate is regarded as a sum of several components and in general is linearly related to the metabolic heat production for heart rates above 120 beats per minute.

The third, level III, is to calculate the metabolic heat production from measurement of oxygen consumption and carbon dioxide production during activity and recovery.

The principle of ISO 8996 is therefore to provide methods of estimating metabolic heat production so that they can be used in other International Standards for the assessment of thermal environments, as presented in clauses 5, 6 and 7.

9.6 ISO 9920:1995

ISO 9920:1995, *Ergonomics of the thermal environment — Estimation of the thermal insulation and evaporative resistance of a clothing ensemble*

9.6.1 Scope

The purpose of ISO 9920 is to present 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.

The influence of body movement and air penetration on thermal insulation and evaporative resistance is discussed.

ISO 9920 does not deal with other effects of clothing, such as absorption of water, buffering and tactile comfort, and does not take into account the influence of rain and snow on the thermal characteristics. Special protective clothing (water-cooled suits, ventilated suits, heated clothing) is also not considered.

ISO 9920 does not deal with separate insulation on different parts of the body and discomfort due to the asymmetry of a clothing ensemble.

9.6.2 Principle

ISO 9920 provides methods for the determination of basic thermal insulation of clothing (I_{cl}) and the evaporative resistance (R_T), necessary information when evaluating the heat or cold stress or degree of comfort provided by the physical environment, according to the International Standards presented in clauses 5, 6 and 7.

ISO 9920 provides a large "database" of thermal insulation values which have been measured on a standing thermal manikin. Values are provided for dry thermal insulation, in terms of basic thermal insulation (I_{cl}), expressed in square metres degrees Celsius per watt, or Clo (where 1 Clo = 0,155 m^2 °C/W), and for resistance of clothing to water diffusion, in terms of the (nondimensional) permeability index, i_m. The i_m values range from around 0,5 for a nude person to around 0,2 for impermeable-type clothing. A typical value is around 0,4.

The tables of thermal insulation values of clothing are comprehensive. Thermal insulation values are supplied for total ensembles, as well as dry insulation values for individual garments (I_{clu}) which make up ensembles. If the thermal insulation value of a total ensemble is not provided in the tables, then a summation procedure is provided for estimating the insulation provided by the ensemble from the I_{clu} values.

Table 5 — Estimation of metabolic heat production

Level	Method	Accuracy	Inspection of the workplace
I	A - Classification according to kind of activity B - Classification according to occupation	Rough information; risk of error very great	Not necessary Information on technical equipment, work organization
II	A - Use of tables of group assessment of heart rate B - Use of estimation tables of heart rate for specific activities C - Use of heart rate under defined conditions	High error risk; accuracy ± 15 %	Time study necessary Time study necessary Not necessary
III	Direct measurement	Risk of errors within the limits of accuracy of the measurement and of the time study; accuracy ± 5 %	Time study necessary

9.7 ISO/CD 12894

ISO/CD 12894: *Ergonomics of the thermal environment — Medical supervision of individuals exposed to extreme hot or cold environments.*

9.7.1 Scope

This proposed International Standard provides advice to those concerned with the safety of human exposure to hot or cold thermal environments, and discusses health screening and surveillance that may be appropriate prior to and during such exposures.

The guidance is applicable to both occupational and laboratory exposure to extreme environments. In both cases, assessment should be made of the expected thermal stress on the individual but the details of medical supervision may differ in the two situations. Control of occupational exposure should also satisfy national health and safety legislation.

The laboratory or climatic chamber studies for which ISO 12894 will be relevant include those in which people may be exposed to high or low temperature ambient conditions or local heating or cooling. Studies may, for example, investigate physiological or psychological responses to the environment or the benefit of clothing or other protective equipment. Scientific investigations and demonstrations for teaching purposes are included in the scope. In some countries such studies are subject to specific legislation and in all cases experimental exposures should be conducted in the context of accepted ethical criteria as detailed in relevant national and international agreements.

Extremes of environment may be only one component of the total physiological stress imposed in a study. In such cases, appropriate advice should also be obtained with regard to any medical supervision required prior to exposure to the other stress factors involved.

In some cases ergonomic investigations are conducted in the field, for example to document the physiological stress of particular occupations. If the overall stress of the task is thereby increased or if invasive measurements are intended, then ISO 12894 is likely to be relevant.

ISO 12894 will not apply to work in, or the study of, moderate thermal environments in which comfort is being investigated. It will however be relevant where individuals are exposed to a moderate thermal environment as one phase of a study of an extreme environment, in either the same or a separate exposure, or if invasive measurements are made in a moderate thermal environment.

ISO 12894 will not apply to the use of hypothermia in the course of medical investigation or treatment.

9.7.2 Principle

The principle of ISO 12894 is to provide a method for the selection of the appropriate system of medical supervision, for ergonomic investigations, involving human exposure to thermal environments. It provides practical guidance on medical supervision and ethical considerations for laboratory, climatic chamber and occupational exposure to heat and cold.

Definitions are provided of methods and of responsible individuals and their roles. These include health screening and health surveillance, independent medical officer, experimenter, occupational physician and principal investigator. Recommendations, in terms of type of investigation, are presented for methods of health screening and surveillance, selection of health

screening protocols (from no special arrangements to questionnaire and medical examination) and level of health surveillance (required expertise of personnel, based on likely "core" temperatures achieved).

General principles concerning the ethics of human experimentation, an example of a subject consent form and a summary description of medical heat and cold disorders and their immediate first aid treatment, are provided in annexes A and B of the standard. Annex C presents a description of medical supervision in terms of health screening, the medical examination, temporary unfitness and health surveillance. Health screening questionnaires prior to hot and cold exposures are also provided. Annex D gives a description of a medical examination and annex E summarizes the recommendations given in the standard. ISO 12894 complements the application of the International Standards described in clauses 5, 6 and 7.

10 Description of future International Standards

10.1 General

A number of work items are under development which will lead to International Standards. The subjects are listed in 10.2 to 10.4. A fuller description of possible scope and principles of these proposed International Standards is provided in annex B.

10.2 Skin contact with hot, moderate and cold surfaces

a) Skin contact with hot surfaces.

b) Comfortable contact surface temperatures.

c) Skin contact with cold surfaces.

10.3 Application of International Standards

a) Application of International Standards to the thermal environment of disabled, elderly or handicapped persons.

b) The design of work for cold environments.

c) Application of International Standards to the long-term assessment of thermal environments in offices.

d) Assessment of thermal environments in vehicles.

10.4 Complementary standards

a) Definitions, symbols and units.

Annex A
(informative)

Ergonomics of the thermal environment — Principles of assessment

A.1 General

This annex describes the terms, concepts and principles used in the practical assessment of thermal environments with particular reference to the use of relevant International Standards.

Knowledge concerning assessment of thermal environments has been determined by much international research and experience over many years, such that certain general principles are now widely accepted. A simple description of these principles, sufficient for many practical applications, is provided below. For a more detailed description the reader should refer to the numerous papers and textbooks on the subject.

A.2 Basic parameters

It is a fundamental principle that human response to thermal environments is determined by at least six basic parameters. These are the air temperature, mean radiant temperature, air velocity, humidity, clothing insulation and metabolic heat production. It is important to recognize that humans respond to the interaction of all six parameters and not independently to one or a few. Assessments of thermal environments should therefore consider at least these six parameters (see note 2).

Knowledge of the six basic parameters is required in the application of International Standards for the assessment of hot (ISO 7933), moderate (ISO 7730) and cold (ISO/TR 11079) environments. The first four environmental parameters and how they are measured are described in ISO 7726. Estimates of the thermal insulation of clothing are provided in ISO 9920. Methods for the determination of metabolic heat production are provided in ISO 8996.

NOTE 2 For some practical applications, reasonable assumptions may be made about some of the parameters. For example it may be reasonable, for a specific well-defined application, to assume that radiant temperature is equal to air temperature at low relative air velocity, 50 % relative humidity and persons performing light activity in light clothing. Comfort conditions may then be described by air temperature alone. This will be true however only if the assumptions are correct.

Another example is in the use of a thermal index which integrates important factors into a single value. The index value may be obtained using a simple measuring instrument [e.g. wet bulb globe temperature (WBGT) instrument]. With experience, it will be satisfactory to use the measurement from the instrument (with other factors) to assess an environment. The main point, however, is that it is the six basic parameters which determine human response and all assessments should be viewed from this perspective. The use of single (or a few) parameters or some simple thermal indices to assess environments are therefore (often acceptable) approximations to a more complete assessment involving at least the six basic parameters.

A.3 Body heat balance equation

Humans attempt to maintain internal body temperature within an optimum range (around 37 °C). For any object to maintain a constant temperature it must be in heat balance, that is net heat input to the object must equal net heat output from the object, such that rate of heat storage (S) is zero. This provides a fundamental method for the assessment of human response to thermal environments. If heat storage in the body is positive, the body temperature will rise. If it is negative the body temperature will fall. A tendency for the body temperature to rise or fall will greatly influence human reaction. A calculation of the body heat balance equation provides an important contribution to the assessment methods presented in ISO 7933, ISO 7730 and ISO/TR 11079 for hot, moderate and cold environments respectively.

The heat balance equation for the body is given in terms of heat production [metabolic power (M) minus external work achieved (W)], heat losses from the skin by convection (C), radiation (R), and evaporation (E) and heat losses due to respiration by convection (C_{res}) and evaporation (E_{res}). Heat transfer by conduction (K) is usually negligible and often ignored. A conceptual form of the body heat balance equation is:

$$M - W = C + R + E + C_{res} + E_{res} + S$$

All terms in the above equation are expressed in watts per square metre of body surface area (W/m^2,

see note 3). Values can therefore be added and subtracted and the relative contribution of each to the overall heat balance can be easily identified.

NOTE 3 The body surface area can be estimated from a calculation involving the height and weight of a person. It can also be taken as a fixed value based on an estimate made for a standard person (e.g. 1,8 m^2).

The main practical consideration in the application of the body heat balance equation is to provide equations for each of the components in terms of parameters which can be measured or estimated (e.g. the six basic parameters). Methods of achieving this are provided in ISO standards for assessing hot (ISO 7933), moderate (ISO 7730) and cold (ISO/TR 11079) conditions.

A.4 Human thermoregulation

A.4.1 General

Heat exchange between the body and the environment is continuous and dynamic. If there is a tendency for body temperature to rise or fall, human reaction is to attempt to restore the thermal balance and maintain optimum internal body temperature. The reaction can be behavioural (e.g. put on clothing or change posture) or physiological (e.g. change the physiological condition of the body).

The physiological reaction of the body is determined by a thermoregulatory control system with a control centre in the brain. Temperature sensors in the body (skin, deep body, nervous system) provide information to the control centre. If the body temperature is too high, then to increase heat loss, blood is directed to the skin (skin vasodilation) and, if necessary, sweating will occur. If body temperature is too low, then to decrease heat loss, blood is withdrawn from the skin (vasoconstriction) and, if necessary, metabolic heat production will increase (e.g. shivering).

The thermoregulatory system of the body therefore plays a determining role in the human reaction to the environment and hence in the principles of assessment of hot, moderate and cold environments. That is, the assessement of thermal environments can often be considered in terms of the strain on the body caused by its attempts to maintain heat balance.

A.4.2 Hot conditions

When the body is hot, vasodilation causes an increase in skin temperature and heart rate. At an increased level of heat stress, sweating occurs. The calculated level of sweat required to maintain heat balance (SW_{req}) provides an index of the stress of a hot environment (ISO 7933). If SW_{req} cannot be achieved in physiological terms, or will cause unacceptable fluid loss, this provides criteria for determining permissible exposure times for humans in hot environments. ISO 7933 provides these criteria and physiological data for both acclimatized and unacclimatized persons. ISO 9886 provides guidance on the measurement and interpretation of internal body (core) temperature, skin (shell) temperature, heart rate and body mass loss due to respiration and sweating.

A.4.3 Moderate conditions

Moderate conditions impose minimal demands on the thermoregulatory mechanisms of the body. Both subjective and environmental measurement and analytical techniques are used in assessment (ISO 10551, ISO 7730). Investigations are commonly concerned with thermal comfort, which is defined as "that condition of mind which expresses satisfaction with the thermal environment."

Environmental measurement and analytical methods of assessment often consider both "whole-body" and "local" thermal discomfort. The predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) thermal indices used in ISO 7730 for assessing "whole-body" discomfort are derived from three requirements for thermal comfort. They are:

a) that the body is in heat balance;

b) that sweat rate is within comfort limits; and

c) that mean skin temperature is within comfort limits.

For thermal comfort conditions, local thermal discomfort shall be avoided in terms of draughts, asymmetric radiation thermal gradients and floor temperature.

For a complementary assessment when considering individuals or specific populations, subjective assessment methods can give direct information concerning thermal comfort and discomfort.

A.4.4 Cold conditions

When the body is cold, vasoconstriction causes low skin temperatures (especially in hands and feet) which causes discomfort and significant behavioural reaction to avoid the cold. The conservation of heat by clothing is of major importance. A calculation of the clothing insulation required for heat balance and for thermal comfort (for IREQ see ISO/TR 11079) provides an

index of cold stress and an indication of the clothing ensemble required to be worn in a cold environment (e.g. from ISO 9920). Physiological measurement of internal body temperature and skin temperatures (mean skin temperature over the body and skin temperatures of fingers and toes) will provide an indication of the strain on the body (ISO 9886).

A.5 Thermal indices

Much fundamental and applied research into the human response to thermal environments has been concerned with developing thermal indices. The principle is that relevant factors (e.g. the six basic parameters) are "combined" to provide a single index value, such that the value varies as human response varies and can be used to predict the effects of the environment. For an "ideal" index, two different thermal environments with the same thermal index value would produce identical human responses.

Thermal indices can be conveniently divided into three types. Rational thermal indices are based upon a calculation involving the body heat balance equation. Empirical indices are derived from "fitting" mathematical models (e.g. curves) to data from the responses of human subjects. Direct indices are measurements taken from a simple instrument which responds to thermal environments in a way similar to that in which humans respond. Although it is convenient to divide indices into three types, there are many different thermal indices used throughout the world and some could be considered as combinations of these types.

For the assessment of thermal environments, methods presented in International Standards use indices for which there is international experience. For hot environments, the wet bulb globe temperature (WBGT) index can be considered as a direct index (ISO 7243) and the required sweat rate SW_{req} index provides a rational analytical approach (ISO 7933). For moderate environments, the predicted mean vote (PMV, ISO 7730) index is used and for cold environments, the clothing insulation required (IREQ, ISO/TR 11079) index. Both of these indices involve the use of the body heat balance equation.

A.6 Metabolic heat production

The body utilizes oxygen and food to produce energy, and the rate at which this occurs is termed the metabolic rate (M). Most energy is produced as heat (H); however some will produce mechanical work (W). The metabolic heat production is then $H = M - W$, and is usually given in units of watts per square metre of body surface area $\left(\mathrm{W/m^2}\right)$. W ranges from about 0 to 20 % of M, but is difficult to measure and is often taken as 0.

The assessment of thermal environments requires an estimate of metabolic heat production. ISO 8996 provides methods of estimation ranging from those involving the collection of expired air from subjects to the use of simple tables of values for different activities. All methods have inaccuracies and these should be considered in any assessment.

A.7 Clothing

Mechanisms which determine the thermal insulation provided by clothing are complex and fully understood. Clothing assemblies should provide heat exchange to maintain thermal balance (and comfort). A simple model of clothing evaluates a clothing layer directly next to the skin. Resistance to dry heat transfer and to vapour transfer act separately, and on the surface of the clothing there is a resistance to the environment.

For this model, the resistance to the environment will be affected by the environmental conditions. Basic (intrinsic) resistance values of clothing are provided in tables (ISO 9920). Most available data are for resistance to dry heat transfer, although there are some data for resistance to vapour transfer. Clothing insulation values are of importance in calculating the heat balance equation for a clothed body (ISO 7933, ISO/TR 11079). The simple two-parameter model described above can be limited in practical application. Body movement causes pumping effects and greater heat loss, for example. Information on these and other effects is not fully available.

A.8 Practical considerations

The main objective of the ergonomics of the thermal environment is to match work requirements and human capabilities. The application of ergonomics provides the means for identifying the nature of a problem and providing solutions, for example in terms of the optimum design of the thermal environment. Design options include providing target values for climatic variables, manipulating the nature of the work and its organization, providing personal protective systems, and an appropriate combination of these parameters.

Consequently it is important to note that ergonomics has an important role in providing extra design flexibility, especially in the industrial context and where technical difficulties and cost constraints limit optimum climatic control. While each ergonomics investigation will have features unique to a particular