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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:

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

Outside buildings with solar load, this is expressed as:

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

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).