SLOVENSKI STANDARD
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Ergonomija toplotnega okolja - Analitično ugotavljanje in razlaga toplotnega stresa s predvideno toplotno obremenitvijo (ISO/DIS 7933:2018)

Ergonomics of the thermal environment - Analytical determination and interpretation of heat stress using the predicted heat strain model (ISO/DIS 7933:2018)

Ergonomie der thermischen Umgebung - Analytische Bestimmung und Interpretation der Wärmebelastung mit dem Modell der vorhergesagten Wärmebeanspruchung (ISO/DIS 7933:2018)

Ergonomie des ambiances thermiques - Détermination analytique et interprétation de la contrainte thermique fondées sur le calcul de l'astreinte thermique prévisible (ISO/DIS 7933:2018)

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Ergonomics of the thermal environment — Analytical determination and interpretation of heat stress using the predicted heat strain model

Ergonomie des ambiances thermiques — Détermination analytique et interprétation de la contrainte thermique fondées sur le calcul de l'astreinte thermique prévisible

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. 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.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 7933 was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 5, *Ergonomics of the physical environment*.

This third edition cancels and replaces the second edition (ISO 7933:2004).

Introduction

This series of International Standards describe a coordinated set of methods for the evaluation of working conditions as a function of the thermal environment. ISO 15265[1] describes the assessment strategy for the prevention of discomfort or health in any thermal working condition, while ISO 16595/WP [2] recommends specific practices concerning hot working environments. For these hot environments, these standards propose to rely on the wet bulb globe temperature (WBGT) heat stress index described in ISO 7243 [3] as a screening method - for establishing the presence or absence of heat stress and on the more elaborate method presented in this International standard, to make a more accurate estimation of stress, to determine the allowable durations of work in these conditions and to optimize the methods of protection. This method, based on an analysis of the heat exchange between a person and the environment, is intended to be used directly when it is desired to carry out an intensive analysis of working conditions in heat.

This International Standard standardizes the method that occupational health specialists are expected to use to approach a given problem and progressively collect the information needed to control or prevent the problem.

This third edition of the standard is based on the latest scientific information. Future improvements concerning the calculation of the different terms of the heat balance equation, or its interpretation, will still be taken into account in the future when they become available.

In its present form, this method of assessment is not applicable to cases where special protective clothing (reflective clothing, active cooling and ventilation, impermeable, with personal protective equipment) is worn. It does not either account for transients in environmental conditions, metabolic rate and/or clothing and therefore makes possible to predict the evolution of the core temperature and the water loss in conditions where these parameters remain steady. In addition, occupational health specialists are responsible for evaluating the risk encountered by a given individual, taking into consideration their specific characteristics that might differ from those of a standard subject. ISO 9886[4] describes how physiological parameters are used to monitor the physiological behaviour of a particular subject and ISO 12894[5] describes how medical supervision is organized.

Ergonomics of the thermal environment — Analytical determination and interpretation of heat stress using the predicted heat strain model

1 Scope

The main objective of this International Standard is to describe a mathematical model (the predicted heat strain model) for the analytical determination and interpretation of the thermal stress (in terms of water loss and core temperature) experienced by a subject in a hot environment and to determine the "maximum allowable exposure times", with which the physiological strain is acceptable for 95% of the exposed population. (the maximum tolerable core temperature and the maximum tolerable water loss are not exceeded by 95% of the exposed people).

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 can be changed, and to what extent, in order to reduce the risk of physiological strains.

This International Standard 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. Recommendations about how and when to use this model are given in ISO 15265, Ergonomics of the thermal environment -- Risk assessment strategy for the prevention of stress or discomfort in thermal working conditions

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 7726, *Ergonomics of the thermal environment — Instruments for measuring physical quantities*

ISO 8996, *Ergonomics of the thermal environment — Determination of metabolic rate*

ISO 9886, *Ergonomics — Evaluation of thermal strain by physiological measurements*

ISO 9920, *Ergonomics of the thermal environment — Estimation of thermal insulation and water vapour resistance of a clothing ensemble*

ISO 13731, *Ergonomics of the thermal environment — Vocabulary and symbols*

ISO 13732-1, *Ergonomics of the thermal environment — Methods for the assessment of human responses to contact with surfaces — Part 1: Hot surfaces*

ISO 15265, *Ergonomics of the thermal environment — Risk assessment strategy for the prevention of stress or discomfort in thermal working conditions*

ISO 16595/WP, *Ergonomics of the thermal environment: Working practices in hot environments*

3 Symbols

For the purposes of this document, the symbols and abbreviated terms, designated in Table 1 as "symbols" with their units, are in accordance with ISO 13731.

However, additional symbols are used for the presentation of the predicted heat strain index. A complete list of symbols used in this International standard is presented in Table 2.

Table 1 — Symbols and units conforming to ISO 13731

Symbol	Term	Unit
α	fraction of the body mass at the skin temperature	–
α_i	skin-core weighting at time t_i	–
α_{i-1}	skin-core weighting at time t_{i-1}	–
ε	skin emissivity	–
ε_{cl}	emissivity of clothing	–
θ	angle between walking direction and wind direction	°
A_{Du}	DuBois body area surface	m^2
A_p	fraction of the body surface covered by the reflective clothing	–
A_r	effective radiating area of a body	m^2
C	convective heat flow	$W \cdot m^{-2}$
c_e	water latent heat of vaporization	$J \cdot kg^{-1}$
$C_{orr,im}$	correction factor for the static moisture permeability index	–
$C_{orr,Ia,st}$	correction factor for the static boundary layer thermal insulation	–
$C_{orr,Icl,st}$	correction factor for the static clothing thermal insulation	–
$C_{orr,Itot,st}$	correction factor for the static total clothing thermal insulation	–
c_p	specific heat of dry air at constant pressure	$J \cdot kg^{-1} \cdot K^{-1}$
$c_{p,b}$	specific heat of the body	$J \cdot kg^{-1} \cdot K^{-1}$
C_{res}	respiratory convective heat flow	$W \cdot m^{-2}$
D_{lim}	allowable exposure time	min
$D_{lim,tcr}$	allowable exposure time for heat storage	min
$D_{lim,loss}$	allowable exposure time for water loss, 95 % of the working population	min
D_{max}	maximum water loss	g
$D_{max,95}$	maximum water loss to protect 95 % of the working population	g
dS_i	body heat storage at the time i	$W \cdot m^{-2}$
dS_{eq}	body heat storage rate due to increase of core temperature associated with the metabolic rate	$W \cdot m^{-2}$
E	evaporative heat flow at the skin surface	$W \cdot m^{-2}$
E_{max}	maximum evaporative heat flow at the skin surface	$W \cdot m^{-2}$
E_p	predicted evaporative heat flow at the skin surface	$W \cdot m^{-2}$
E_{req}	required evaporative heat flow at the skin surface	$W \cdot m^{-2}$
E_{res}	respiratory evaporative heat flow	$W \cdot m^{-2}$
f_{cl}	clothing area factor	–
$F_{cl,R}$	reduction factor for radiation heat exchange due to wearing reflective clothes	–
F_r	Reflection coefficients for different special materials	–
H_b	body height	m
$h_{c,dyn}$	dynamic convective heat transfer coefficient	$W \cdot m^{-2} \cdot K^{-1}$
h_r	radiative heat transfer coefficient	$W \cdot m^{-2} \cdot K^{-1}$
$I_{a,dyn}$	dynamic boundary layer thermal insulation	$m^2 \cdot K \cdot W^{-1}$
$I_{a,st}$	static boundary layer thermal insulation	$m^2 \cdot K \cdot W^{-1}$
$I_{cl,dyn}$	dynamic clothing thermal insulation	$m^2 \cdot K \cdot W^{-1}$
$I_{cl,st}$	static clothing thermal insulation	$m^2 \cdot K \cdot W^{-1}$

Table 1 *(continued)*

Symbol	Term	Unit
$i_{m,dyn}$	dynamic moisture permeability index	–
$i_{m,st}$	static moisture permeability index	–
incr	time increment from time t_{i-1} to time t_i	min
$i_{T,dyn}$	dynamic total clothing thermal insulation	$m^2 \cdot K \cdot W^{-1}$
$i_{T,st}$	static total clothing thermal insulation	$m^2 \cdot K \cdot W^{-1}$
K	conductive heat flow	$W \cdot m^{-2}$
k_{sw}	time constant of the increase of the sweat rate	min
k_{tcreq}	time constant of the variation of the core temperature as function of the metabolic rate	min
k_{tsk}	time constant of the variation of the skin temperature	min
M	metabolic rate	$W \cdot m^{-2}$
p_a	water vapour partial pressure at air temperature	kPa
$p_{sk,s}$	saturated water vapour pressure at skin temperature	kPa
R	radiative heat flow	$W \cdot m^{-2}$
$R_{e,T,dyn}$	dynamic clothing total water vapour resistance	$m^2 \cdot Pa \cdot W^{-1}$
r_{req}	required evaporative efficiency of sweating	–
S	body heat storage rate	$W \cdot m^{-2}$
S_{eq}	body heat storage for increase of core temperature associated with the metabolic rate	$W \cdot m^{-2}$
Sw_{max}	maximum sweat rate capacity	$W \cdot m^{-2}$
Sw_p	predicted sweat rate	$W \cdot m^{-2}$
$Sw_{p,i}$	predicted sweat rate at time t_i	$W \cdot m^{-2}$
$Sw_{p,i-1}$	predicted sweat rate at time t_{i-1}	$W \cdot m^{-2}$
Sw_{req}	required sweat rate	$W \cdot m^{-2}$
t	time	min
t_a	air temperature	°C
t_{cl}	clothing surface temperature	°C
t_{cr}	core temperature	°C
$t_{cr,eq}$	steady state core temperature as a function of the metabolic rate	°C
$t_{cr,eq\ i}$	core temperature as a function of the metabolic rate at time t_i	°C
$t_{cr,eq\ i-1}$	core temperature as a function of the metabolic rate at time t_{i-1}	°C
$t_{cr,eq,m}$	steady state value of core temperature as a function of the metabolic rate	°C
$t_{cr,i}$	core temperature at time t_i	°C
$t_{cr,i-1}$	core temperature at time t_{i-1}	°C
t_{ex}	expired air temperature	°C
t_r	mean radiant temperature	°C
t_{re}	rectal temperature	°C
$t_{cr,max}$	maximum acceptable core temperature	°C
$t_{re,i}$	rectal temperature at time t_i	°C
$t_{re,i-1}$	rectal temperature at time t_{i-1}	°C
t_{sk}	skin temperature	°C
$t_{sk,eq}$	steady state mean skin temperature	°C
$t_{sk,eq,cl}$	steady state mean skin temperature for clothed subjects	°C
$t_{sk,eq,nu}$	steady state mean skin temperature for nude subjects	°C

Table 1 *(continued)*

Symbol	Term	Unit
$t_{sk,i}$	mean skin temperature at time t_i	°C
$t_{sk,i-1}$	mean skin temperature at time t_{i-1}	°C
V_{ex}	expired volume flow rate	$L \cdot min^{-1}$
v_a	air velocity	$m \cdot s^{-1}$
v_{ar}	relative air velocity	$m \cdot s^{-1}$
v_w	walking speed	$m \cdot s^{-1}$
w	skin wettedness	–
W	effective mechanical power	$W \cdot m^{-2}$
W_a	humidity ratio of inhaled air	kg_{water}/kg_{air}
W_b	body mass	kg
W_{ex}	humidity ratio of expired air	kg_{water}/kg_{air}
w_{max}	maximum skin wettedness	–
w_p	predicted skin wettedness	–
w_{req}	required skin wettedness	–

4 Principles of the predicted heat strain (PHS) model

The PHS model is based on the thermal energy balance of the body which requires the values of the following parameters, which are estimated or measured according to ISO 7726:

a) the parameters of the thermal environment:

— air temperature, t_a;

— mean radiant temperature, t_r;

— partial vapour pressure, p_a; and

— air velocity, v_a;

b) the mean characteristics of the subjects exposed to this working situation:

— the metabolic rate, M, estimated on the basis of ISO 8996; and

— the clothing thermal characteristics, estimated on the basis of ISO 9920.

Clause **5** describes the principles of the calculation of the different heat exchanges occurring in the thermal balance equation, as well as those of the water loss necessary for the maintenance of the thermal equilibrium of the body. The mathematical expressions for these calculations are given in Annex A.

Clause **6** describes the method for interpreting the results from Clause **5**, which leads to the determination of the predicted sweat rate, the predicted core temperature and the allowable exposure times. The determination of the allowable exposure times is based on two strain criteria: maximum core temperature increase and maximum body water loss, given in Annex B.

The precision with which the predicted sweat rate and the exposure times are estimated is a function of the model (i.e. of the expressions in Annex A) and the maximum values which are adopted. It is also a function of the accuracy of estimation and measurement of the physical parameters and of the precision with which the metabolic rate and the thermal insulation of the clothing are estimated.

5 Main steps of the calculation

5.1 Heat balance equation

The thermal energy balance of the human body may be written as:

$$M - W = C_{res} + E_{res} + K + C + R + E + S \tag{1}$$

This equation expresses that the internal heat production of the body, which corresponds to the metabolic rate, M, minus the effective mechanical power, W, are balanced by the heat exchanges in the respiratory tract by convection, C_{res}, and evaporation, E_{res}, as well as by the heat exchanges on the skin by conduction, K, convection, C, radiation, R, and evaporation, E.

If the balance is not satisfied, some energy is stored in the body, S.

The different terms of Equation (1) are successively reviewed in **5.1.1** to **5.1.10** in terms of the principles of calculation (detailed expressions are shown in Annex A).

5.1.1 Metabolic rate, *M*

The estimation or measurement of the metabolic rate is described in ISO 8996. Indications for the evaluation of the metabolic rate are given in Annex C.

5.1.2 Effective mechanical power, *W*

In most industrial situations, the effective mechanical power is small and can be neglected.

5.1.3 Heat flow by respiratory convection, C_{res}

The heat flow by respiratory convection may be expressed, in principle, by the following equation:

$$C_{res} = 0{,}00002 c_p \times V_{ex} \times \left(\frac{t_{ex} - t_a}{A_{Du}} \right) \tag{2}$$

5.1.4 Heat flow by respiratory evaporation, E_{res}

The heat flow by respiratory evaporation can be expressed, in principle, by the following equation:

$$E_{res} = 0{,}00002 c_e \times V_{ex} \times \left(\frac{W_{ex} - W_a}{A_{Du}} \right) \tag{3}$$

5.1.5 Heat flow by conduction, *K*

Heat flow by thermal conduction occurs on the body surfaces in contact with solid objects. It is usually quite small, not directly taken into account and quantitatively assimilated to the heat losses by convection and radiation which would occur on these surfaces if they were not in contact with any solid body.

ISO 13732-1[6] deals specifically with the risks of pain and burns when parts of the body contact hot surfaces.

