SLOVENSKI STANDARD
oSIST prEN ISO 7933:2022

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Ergonomija toplotnega okolja - Analitično ugotavljanje in razlaga toplotnega stresa z izračunom predvidene toplotne obremenitve (ISO/DIS 7933:2021)

Ergonomics of the thermal environment - Analytical determination and interpretation of heat stress using calculation of the predicted heat strain (ISO/DIS 7933:2021)

Ergonomie der thermischen Umgebung - Analytische Bestimmung und Interpretation der Wärmebelastung durch Berechnung der vorhergesagten Wärmebeanspruchung (ISO/DIS 7933:2021)

Ergonomie des ambiances thermiques - Détermination analytique et interprétation de la contrainte thermique fondées sur le calcul de l'astreinte thermique prévisible (ISO/DIS 7933:2021)

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

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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

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

This third edition supersedes the second edition (ISO 7933:2004), which has been technically revised. The main changes compared to the previous edition are as follows:

— The maximum sweat rate SW_{max} described in section B.4 of Annex B is fixed; that is, it is no longer adjusted for metabolic rate.

— As the model has not been extensively validated for conditions with unsteady environmental parameters, metabolic rate and/or clothing, a caution was added for cases where these parameters vary substantially with time.

Introduction

ISO 15265 [1] describes the assessment strategy for the prevention of discomfort or health effects 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 document, 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 a detailed analysis of working conditions in heat.

This document makes it possible to predict the evolution of a few physiological parameters (skin and rectal temperatures, as well as sweat rate) over time for a person working in a hot environment. This prediction is made according to the climatic parameters, the energy expenditure of the person and his/her clothing. This prediction is made for an average person and should be used to assess the risk of heat stress for a group of people; and it cannot predict a particular person's responses.

This document 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 be taken into account in the future when they become available.

Occupational health specialists are responsible for evaluating the risk encountered by a given individual, taking into consideration their specific characteristics that can differ from those of a standard person. ISO 9886[4] describes how physiological parameters are used to monitor the physiological behaviour of a particular person and ISO 12894[5] describes how medical supervision is organized.

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

1 Scope

This document describes a model (the predicted heat strain (PHS)model) for the analytical determination and interpretation of the thermal stress (in terms of water loss and rectal temperature) experienced by an average person in a hot environment and determines the “maximum allowable exposure times”, with which the physiological strain is acceptable for 95 % of the exposed population (the maximum tolerable rectal 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 average person. In this way, this document 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.

In its present form, this method of assessment is not applicable to cases where special protective clothing (such as fully reflective clothing, active cooling and ventilation, impermeable coveralls...) is worn.

The model has not been extensively validated for conditions with unsteady environmental parameters, metabolic rate and/or clothing and therefore must be used cautiously in cases where these parameters vary substantially with time. It does not permit to determine validly the duration of time needed for an average person whose rectal temperature has risen to 38 °C or more, to recover a rectal temperature of 36,8 °C.

This document does not predict the physiological response of an individual person, but only considers average persons in good health and fit for the work they perform. It is therefore intended to be used by ergonomists, industrial hygienists, etc. as the outcomes may require expert interpretations. Recommendations about how and when to use this model are given in ISO 16595/WP.

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 dated references, only the edition cited applies. 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*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13731 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

4 Symbols

The symbols and abbreviated terms are listed in Table 1

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_{cl}	emissivity of outer clothing surface assuming this is non-reflective	—
$\varepsilon_{cl,r}$	emissivity of outer clothing surface	—
θ	angle between walking direction and wind direction	—
A	age	years
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	$J{\cdot}kg^{-1}$
$Corr,i_m$	correction factor for the static moisture permeability index	—
$Corr,I_a$	correction factor for the static boundary layer thermal insulation	—
$Corr,I_{cl}$	correction factor for the static clothing thermal insulation	—
$Corr,I_T$	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	—

Table 1 *(continued)*

Symbol	Term	Unit
F_r	reflection coefficients for different special materials	—
H_b	body height	m
$h_{c,dyn}$	dynamic convective heat transfer coefficient	$W·m^{-2}·K^{-1}$
h_r	radiative heat transfer coefficient	$W·m^{-2}·K^{-1}$
$I_{a,r}$	resultant boundary layer thermal insulation	$m^2·K·W^{-1}$
I_a	static (or basic) boundary layer thermal insulation	$m^2·K·W^{-1}$
$I_{cl,r}$	resultant clothing thermal insulation	$m^2·K·W^{-1}$
I_{cl}	static (or basic) clothing thermal insulation	$m^2·K·W^{-1}$
$i_{m,r}$	resultant moisture permeability index	—
i_m	static (or basic) moisture permeability index	—
$incr$	time increment from time t_{i-1} to time t_i	min
$I_{T,r}$	resultant total clothing thermal insulation	$m^2·K·W^{-1}$
I_T	static (or basic) total clothing thermal insulation	$m^2·K·W^{-1}$
K	conductive heat flow	$W·m^{-2}$
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	$W·m^{-2}$
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	$W·m^{-2}$
$R_{e,T,r}$	resultant clothing total water vapour resistance	$m^2·Pa·W^{-1}$
r_{req}	required evaporative efficiency of sweating	—
S	body heat storage rate	$W·m^{-2}$
S_{eq}	body heat storage for increase of core temperature associated with the metabolic rate	$W·m^{-2}$
SW_{max}	maximum sweat rate capacity	$W·m^{-2}$
SW_p	predicted sweat rate	$W·m^{-2}$
$SW_{p,i}$	predicted sweat rate at time t_i	$W·m^{-2}$
$SW_{p,i-1}$	predicted sweat rate at time t_{i-1}	$W·m^{-2}$
SW_{req}	required sweat rate	$W·m^{-2}$
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

Table 1 *(continued)*

Symbol	Term	Unit
t_{re}	rectal temperature	°C
$t_{re,max}$	maximum rectal 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 person	°C
$t_{sk,eq,nu}$	steady-state mean skin temperature for nude person	°C
$t_{sk,i}$	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	—

5 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:

a) the parameters of the thermal environment as measured or estimated according to ISO 7726:

— air temperature, t_a;

— mean radiant temperature, t_r;

— water vapour partial pressure, p_a; and

— air velocity, v_a.

b) the metabolic rate, M, as measured or estimated using ISO 8996 or other methods of equal or greater accuracy;

c) the static clothing thermal characteristics, as measured or estimated using ISO 9920 or other methods of equal or greater accuracy.

Clause 6 describes the principles of the calculation of the different heat exchanges occurring in the heat balance equation, as well as those of the water loss necessary for the maintenance of the thermal equilibrium of the body. The mathematical expressions given in Annex A shall be used for these calculations.

Clause 7 describes the method for interpreting the results from Clause 6, which leads to the determination of the predicted sweat rate, the predicted rectal temperature and the allowable exposure

