SLOVENSKI STANDARD
oSIST prEN ISO 8996:2021

01-januar-2021

Ergonomija toplotnega okolja - Ugotavljanje presnovne toplote (ISO/DIS 8996:2020)

Ergonomics of the thermal environment - Determination of metabolic rate (ISO/DIS 8996:2020)

Ergonomie der thermischen Umgebung - Bestimmung des körpereigenen Energieumsatzes (ISO/DIS 8996:2020)

Ergonomie de l'environnement thermique - Détermination du métabolisme énergétique (ISO/DIS 8996:2020)

Ta slovenski standard je istoveten z: prEN ISO 8996

ICS:

13.180	Ergonomija	Ergonomics

oSIST prEN ISO 8996:2021 en,fr,de

DRAFT INTERNATIONAL STANDARD
ISO/DIS 8996

ISO/TC **159**/SC **5** Secretariat: **BSI**

Voting begins on: **2020-10-26** Voting terminates on: **2021-01-18**

Ergonomics of the thermal environment — Determination of metabolic rate

Ergonomie de l'environnement thermique — Détermination du métabolisme énergétique

ICS: 13.180

This document is circulated as received from the committee secretariat.

ISO/CEN PARALLEL PROCESSING

Reference number
ISO/DIS 8996:2020(E)

Contents

Page

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).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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*, Work Group WG 1, *Ergonomics of the thermal environment*.

This third edition cancels and replaces the second edition (ISO 8996:2004), which has been technically revised.

The main changes compared to the previous edition are as follows:

— The metabolic rate associated with a given task and estimated using the methods described in this document is expressed in watts.

— At Level 1, Screening, the method classifying metabolic rate according to occupation was removed, and revised procedures are provided for the evaluation of metabolic rate for given activities (Level 2, Observation), and when using heart rate (Level 3, Analysis).

— The accuracy of the methods for estimating the metabolic rate was re-evaluated in light of the recent literature, and consequently the integral method is no longer recommended at Level 4, Expertise.

Ergonomics of the thermal environment — Determination of metabolic rate

1 Scope

The metabolic rate, as a conversion of chemical into mechanical and thermal energy, measures the energetic cost of muscular load and gives a quantitative estimate of the activity. Metabolic rate is an important determinant of the comfort or the strain resulting from exposure to a thermal environment. In particular, in hot climates, the high levels of metabolic heat production associated with muscular work aggravate heat stress, as large amounts of heat need to be dissipated, mostly by sweat evaporation. On the contrary, in cold environments, high levels of metabolic heat production help to compensate for excessive heat losses through the skin and therefore reduce the cold strain.

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

The estimations, tables and other data included in this International Standard concern the general working population. Users should make appropriate corrections when they are dealing with special populations including children, aged persons, people with physical disabilities, etc. Personal characteristics, e.g. body mass, may be used if the body is moved due to walking or climbing (Annex A and B). Gender, age and body mass are considered in Annex C for the evaluation of the metabolic rate from heart rate.

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

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

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

3 Terms and definitions

No terms and definitions are listed in this document.

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

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

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

4 The units

The metabolic rate associated with a given task and estimated using the methods described in this document shall be expressed in watts.

If the task does not involve displacements, the metabolic rate will not vary as a function of the size and the weight of the subject. If it involves displacements, then the weight of the person must be taken into account (see Annex B).

As the heat associated to this metabolic rate and produced inside the body must leave it essentially through the skin, thermophysiologists usually express the metabolic rate per unit of body surface area (in $W \cdot m^{-2}$) and the estimations of thermal comfort and thermal constraints described in other standards of this series are always done using metabolic rates in $W \cdot m^{-2}$.

5 The 4 levels of methods for estimating the metabolic rate

The mechanical efficiency of muscular work — called the 'useful work' — is low. In most types of industrial work, it is so small (a few percent) that it is assumed to be nil. This means that the energy spent while working is assumed to be completely transformed into heat. For the purposes of this International Standard, the metabolic rate is assumed to be equal to the rate of heat production.

Table 1 lists the different approaches presented in this International Standard for determining the metabolic rate.

These approaches are structured following the philosophy exposed in ISO 15265 regarding the assessment of exposure. Four levels are considered:

— Level 1, ***Screening***: a method simple and easy to use is presented to quickly classify as light, moderate, high or very high the mean workload according to the kind of activity.

— Level 2, ***Observation***: a time and motion study is presented for people with full knowledge of the working conditions but without necessarily a training in ergonomics, to characterize, on average, a working situation at a specific time:

A procedure is described to successively record the activities with time, estimate the metabolic rate of each activity using formulas and data presented in Annex B and compute the time weighted average metabolic rate.

— Level 3, ***Analysis***: one method is addressed to people trained in occupational health and ergonomics of the thermal environment. The metabolic rate is evaluated from heart rate recordings over a representative period. This method for the indirect evaluation of metabolic rate is based on the relationship between oxygen uptake and heart rate under defined conditions. Another method at this level is based on the use of accelerometry to record body movement.

— Level 4, ***Expertise***: 3 methods are presented. They require very specific measurements made by experts:

— Method 4A: the oxygen consumption measured over short periods (10 min to 20 min);

— Method 4B: the so-called doubly labelled water method aiming at characterizing the average metabolic rate over much longer periods (1 to 2 weeks);

— Method 4C: a direct calorimetry method.

Table 1 — Levels for the evaluation of the metabolic rate

Level	Method	Accuracy	Inspection of the work place
1 **Screening**	Classification according to activity	Rough information Very great risk of error	Not required
2 **Observation**	Time and motion study	High error risk Accuracy: ± 20 %	Required
3 **Analysis**	3A: Heart rate measurement under defined conditions	Medium error risk Accuracy: ± 10 %	Study required to determine a representative period
	3B: Accelerometry	High risk of error	
4 **Expertise**	4A: Measurement of oxygen consumption	Errors within the limits of the accuracy of the measurement or of the time and motion study, if assumptions (10.1.1, 10.1.4) are met Accuracy: ± 5 %	Time and motion study necessary
	4B: Doubly labelled water method		Inspection of work place not required, but leisure activities must be evaluated.
	4C: Direct calorimetry	Errors within the limits of the accuracy of the measurement or of the time and motion study Accuracy: ± 5 %	Inspection of work place not required.

6 The accuracy of the estimation of the metabolic rate

The accuracy of the results are provided in Table 1 as coefficient of variation (CV), i.e. the percentage ratio of the standard deviation to the mean, and should be understood as indicative values, which might increase due to non-controlled influences discussed below. The accuracy increases from level 1 to level 4 and, as far as possible, the most accurate method should be used.

— At level 1, *Screening*, the method provides only a rough estimate and there is considerable scope for error. This limits its accuracy considerably. At this level, an inspection of the work place is not necessary.

— At level 2, *Observation*, the accuracy of the time and motion study depends upon the accuracy of the formulas used (see Annex B), but mostly upon the level of training of the observer and his/her knowledge of the working conditions: the possibility for errors is high.

— At level 3, *Analysis*,

— the accuracy of the estimated metabolic rate is influenced by the accuracy of the (HR – M) relationship used, as other stress factors can influence the heart rate;

— the accuracy level of 10 %–15 % (Malchaire et al. 2017) will only be achieved in field situations (Rodahl et al. 1974; Dubé et al. 2016), if the (HR – M) relationship is individually calibrated for each subject during a cardiac stress test with activities that are representative for the type of work under consideration (cf. 9.1.3), and if the estimates are corrected for the thermal HR component (Annex E) (Vogt et al. 1973; Kampmann et al. 2001). Otherwise, the error when using (HR – M) relationships defined for groups (Annex C) will rise dramatically and the accuracy level will fall behind level 2 methods (Bröde and Kampmann 2019);

— the accuracy of the evaluation using accelerometers is highly dependent upon the instruments used as well as on the type of work, and the method appears to be more appropriate for long term than short term evaluation.

— At level 4, *Expertise*, the accuracy is determined as well by the measurement system (gas volume and oxygen fraction) as by the dynamics of oxygen uptake.

It can be assumed that:

— For a person trained in the activity, the variation is about 5 % under laboratory conditions;

— Under field conditions, i.e. when the activity to be measured is not exactly the same from test to test, a variation of up to 20 % can be expected;

— In hot conditions, an increase of metabolic rate by 7 % per degree rise in core temperature related to the Q_{10}-effect with typical Q_{10} = 2 may be expected. This increase may vary largely between different persons with Q_{10} values between 1 and 8 (Kampmann and Bröde 2015) and may occur well below an oxygen uptake of 1 l $O_2 \cdot min^{-1}$.

— In cold conditions, an increase of up to 400 W may be observed when shivering occurs.

— Heavy clothing might also increase the metabolic rate by 20 % or more, by increasing the weight carried by the subject and decreasing the subject's ease of movement.

Attention must be drawn to the fact that the accuracy depends also upon:

— the representativeness of the time period observed;

— the possible disturbance of the normal activity by the observer and/or the procedure. In this regard, the method based on heart rate recordings appears to be one that interferes the least with the activity;

— the number of measurements: repetition is one method to reduce random measurement error. Based on the CV of an unbiased estimate, the formula *(actual CV/requested CV)*^{2} approximates the required number of repetitions (Vogt et al. 1976). This implies that in order to achieve the 10 % accuracy level, two measurements would be necessary with a method actually providing 14 %, while four repetitions would be needed with 20 % accuracy, and even 9 with 30 %. Of course, this improvement only will work if no systematic errors are inherent.

7 Level 1, Screening: Classification of metabolic rate by categories

The metabolic rate can be estimated approximately using the classification given in Annex A. Table A.1 defines five classes of metabolic rate: resting, low, moderate, high, very high. For each class, a range of metabolic rate values is given as well as a number of examples. These activities are supposed to include short rest pauses. The examples given in Table A.1 illustrate the classification.

As the accuracy of this method is low, it should only be used for classification purposes without interpolation between the 4 levels.

8 Level 2, Observation

8.1 Evaluation of metabolic rate for a given activity

Annex B gives mean values or formulas for estimating the metabolic rate in watts in the following cases:

— At rest;

— When walking with/without load at < 6 km·h^{-1};

— When running with/without load at ≥ 6 km·h^{-1};

— When going up or down stairs and ladders;

— When lifting or lowering loads without displacement;

— For activities without displacement, from the observation of the body segment involved in the work: both hands, one arm, two arms, the entire body;

— Taking into account the body posture: sitting, kneeling, crouching, standing, standing stooped;

8.2 Evaluation of the mean metabolic rate over a given period of time

To evaluate the average metabolic rate over a given period of time, it is necessary to carry out a detailed study of the work. This involves:

— Determining the list of activities performed during this period of time;

— Estimating the metabolic rate for each of these activities taking account of their characteristics and using the data in Annex B: speed of displacement, heights climbed, weights manipulated, number of actions carried out, etc.;

— Determining the time spent at each activity over the whole period of time considered.

The time weighted average metabolic rate for the time period can then be evaluated using the equation:

$$M = \frac{1}{T} \sum_{i=1}^{n} M_i t_i \qquad (1)$$

where

M is the average metabolic rate for the work cycle, W;

M_i is the metabolic rate for activity i, W;

t_i is the duration of activity i, min;

T is the total duration, min, of the period of time considered, and is equal to the sum of the partial durations t_i.

The procedure of this time and activity evaluation is further described in Annex B.

9 Level 3, Analysis

9.1 Evaluation of metabolic rate using heart rate

9.1.1 Principle of the method

In the case of dynamic work using major muscle groups, with only a small amount of static muscular and mental loads, the metabolic rate may be estimated by measuring the heart rate while working. Under such conditions, a linear relationship exists between the metabolic rate and the heart rate. If the above mentioned restrictions are taken into account, this method can be more accurate than the level 1 and level 2 methods of evaluation (see Table 1 and Clause 6) and is considerably less complex than the methods listed at level 4.

The relationship between heart rate and metabolic rate can be written as:

$$M = a + b\,\mathrm{HR} \qquad (2)$$

where

M is the metabolic rate, W;

HR is the heart rate measured, beats·min^{-1};

a and b are coefficients

The heart rate may be recorded continuously, for example by the use of telemetric equipment, or, with a reduction in accuracy, measured manually by counting the arterial pulse rate.

The mean heart rate may be computed over fixed time intervals, for example 1 min, over a given period of time or over the whole shift time.

The accuracy of this estimation of the metabolic rate depends upon:

— The accuracy and validity of the relation (2)

— The magnitude of the HR components not linked to the dynamic muscular load

9.1.2 Accuracy of the (HR – *M*) relationship

The relationship between heart rate and metabolic rate can be determined by different methods of decreasing accuracy:

— The most accurate method consists of recording the heart rate and corresponding oxygen consumption at different effort levels during a cardiac stress test, e.g. on an ergometer or a treadmill. The (HR – M) relation can be used provided the durations of the efforts at each level are such that stable HR and oxygen consumption values are reached. Such a procedure is very strenuous and is usually performed in a medical environment.

— A simpler procedure consists of recording the stable heart rate during a few dynamic efforts whose metabolic rates are known. The accuracy is then reduced as the oxygen consumption is not measured.

— Expression (3) can be derived from evaluations of:

— the heart rate at rest under neutral thermal conditions, HR_0, beats·min^{-1};

— the metabolic rate at rest, M_0, W;

— the maximum working capacity, MWC, W;

— the maximum heart rate HR_{max}, beats·min^{-1};

— the increase in heart rate per unit of metabolic rate: $RM = (HR_{max} - HR_0)/(MWC - M_0)$

The (HR – M) relation is then given by:

$$M = M_0 + (HR - HR_0)/RM \quad (3)$$

The accuracy of this relation is a function of the validity of the measurements or estimations of HR_0, M_0, HR_{max} and MWC. Annex C proposes formulas for estimating these 4 parameters

Table C.1 provides direct evaluations of the (HR – M) relationship for women and men with ages ranging from 20 years to 65 years and body masses ranging from 50 kg to 110 kg. The precision is then further reduced.

9.1.3 Validity of the (HR – M) relationship

The question relates to the relevance of the (HR – M) relation directly or indirectly derived from a cardiac stress test using the great muscular group of the legs, in the event of a work carried out with the upper limbs. Studies showed that the V_{O2max} during manual crank efforts was 23 % to 30 % lower than

