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Ergonomics — Determination of metabolic heat production

Ergonomie — Détermination de la production de chaleur métabolique

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Foreword

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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 8996 was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Sub-Committee SC 5, *Ergonomics of the physical environment*.

Annexes A to G form an integral part of this International Standard.

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Introduction

This International Standard is one of a series intended for use in the study of thermal environments. It covers the evaluation of metabolic heat production by determining the metabolic rate needed to evaluate comfort and thermal stress using the methods given in this series of International Standards.

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Ergonomics — Determination of metabolic heat production

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 numerical index of activity. A knowledge of metabolic rate is necessary to measure metabolic heat production for the evaluation of human heat regulation. Specifying methods for determination metabolic rate, this International Standard can also be used for other applications — for example: the assessment of working practices, the cost of specific jobs or sport activities, the total cost of activity, etc.

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

ISO 9886 : — ¹⁾, *Ergonomics — Evaluation of thermal strain by physiological measurements.*

3 Principle and accuracy

Since most of the energy produced by an organism is converted into thermal energy, the mechanical fraction — called the “useful work” (W) — can normally be neglected and the metabolic heat production can be equated with the metabolic rate (see ISO 7933).

Table 1 gives three approaches for determining metabolic rate.

Table 1 — Levels for the determination of the metabolic rate

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

1) To be published.

At level I, two methods are given for the estimation of metabolic rate. Method A is a classification according to the kind of activity, method B is a classification according to occupation. Both methods provide a rough estimate and there is considerable scope for error. This limits their accuracy considerably. At this level an inspection of the work place is not necessary.

At level II, using method A, the metabolic rate is determined by adding the basal metabolic rate to the metabolic rate for body posture, the metabolic rate for type of work and the metabolic rate for body motion related to work speed (tables of group assessment). Using method B the metabolic rate is determined by means of the tabulated values for various activities. The possibility that errors may arise is high. A time study is necessary to determine the metabolic rate of work which involves a cycle of different activities. Using method C the metabolic rate is determined by measuring heart rate. This method for indirect determination of metabolic rate is based on the relationship between oxygen uptake and heart rate under defined conditions.

At level III the metabolic rate is determined by direct measurement. A detailed time study is necessary during measurement.

The accuracy of each method is limited by several factors.

When looking at a single person performing a task at one time the main factors can be described as follows.

NOTE — The accuracy values given in table 1 take these factors into account.

In the case of the tables, differences between the observers and their level of training mainly influence the results. Using method C of level II, the accuracy of the relationship between oxygen uptake and heart rate because of existing other stress factors, which cannot be neglected, must be taken into account.

Cultural differences also influence the results. At level III, the measurement accuracy (determination of gas volume and oxygen fraction) will determine the degree of error.

In case of standardization of the results — for example a general statement relating to work places — other factors such as

- individual variability
- differences in work equipment
- differences in work speed
- differences in work technique

influence the possible accuracy of each method (see 4.6.2).

Thus the accuracy of the results and also the costs involved increase from level I to level III. Direct measurement gives the most accurate values. As far as possible the most accurate method should be used.

4 Tables for the estimation of metabolic rate

4.1 Classification of metabolic rate by kinds of activities

The metabolic rate can be estimated approximately using the classification given in annex A. Here the metabolic rate for a given activity is classified into one of five classes (resting, low

metabolic rate, moderate metabolic rate, high metabolic rate, very high metabolic rate). The examples given in annex A, table A.1, include short rest pauses and illustrate the classification.

4.2 Table for the estimation of metabolic rate by occupations

Annex B, table B.1 shows the metabolic rate for some different occupations. The values are mean values for the whole working time, but without considering longer rest pauses, for example, lunch time. Significant variation may arise due to differences in technology, work elements, work organization, etc.

4.3 Tables for the estimation of metabolic rate by task-components

The metabolic rate of a man at work may be estimated by adding its various components. An inspection of the work place is usually necessary for this purpose.

The metabolic rate is analytically determined by adding the values of the following:

- a) basal metabolic rate;
- b) the component for body posture;
- c) the component for type of work;
- d) the component for body motion related to work speed.

The basal metabolic rate is the metabolic rate of a person lying down at rest under defined conditions.

The basal metabolic rate (BM) is a function of weight, height, age and sex. As these factors have little influence on BM, values of 44 W/m² for men and 41 W/m² for women can be used as a good approximation. In order to give comparable values, the values in this International Standard refer to a standard person, defined in annex C, table C.1.

In annex D, table D.1 gives the metabolic rate for body posture, table D.2 the metabolic rate for different types of work and table D.3 the metabolic rate for body motion related to work speed. Tables D.4 and D.5 give some examples of the use of this method.

4.4 Table indicating the metabolic rate for typical activities

Values of metabolic rate may be obtained from annex E, table E.1. These values are based on measurements.

4.5 Metabolic rate of a work cycle

To determine the overall metabolic rate of a work cycle it is necessary to carry out a time and performance study which includes a detailed description of the work. This involves classifying each activity, and taking account of factors such as the duration of each activity, the distances walked, heights climbed, weights manipulated, the number of actions carried out, etc.

The metabolic rate for a work cycle can be determined from the metabolic rate of the respective activity and the respective duration from the equation

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

where

M is the average metabolic rate of the work cycle, in watts per square metre;

M_i is the metabolic rate of the respective activity, in watts per square metre;

T is the duration, in seconds, of the considered work cycle;

t_i is the duration, in seconds, of the respective activity.

Annex F gives an example.

4.6 Requirements for the application of metabolic rate tables

4.6.1 Standardization of values

Values have been standardized with respect to the standard person defined in annex C to allow a comparison of values from different sources.

This is necessary for particular activities which require a movement associated with the body weight, for example walking upwards or lifting weights.

4.6.2 Variation of values

The values indicated vary within certain limits due to the influence of the following factors:

- work technique;
- work speed;
- differences between the work equipment.

For the same work and under the same working conditions the metabolic rate can vary from person to person by about $\pm 5\%$.

For someone used to 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 up to 20 % or more can be expected.

4.6.3 Influence of climate

The metabolic rates given in this International Standard apply to moderate thermal environments. In a hot or cold environment the metabolic rate may increase.

In hot conditions a maximum increase of 5 W/m² to 10 W/m² may be expected due to increased heart rate and sweating.

In cold conditions a maximum increase of up to 200 W/m² may be expected when shivering occurs. The wearing of heavy clothing will also increase metabolic rate.

4.6.4 Influences of the length of rest periods and work

Tables D.1 to D.5 and table E.1 (see 4.3 and 4.4) cannot be applied to an intermittent sequence of short activities and longer rests because this leads to higher levels of metabolic rate. The limits are shown in figure 1 where the hatched area shows the region in which the tables (see 4.3 and 4.4) cannot be used. Figure 1 only applies when the muscles are completely relaxed during a rest period.

Example 1 (see figure 1) shows a work rhythm of 8 min of resting time to 1 min of working time. In this case the metabolic rate tables (see 4.3 and 4.4) cannot be used. For activities showing a proportion of working time within the white field, as shown in example 2, the tables can be used safely.

As an increase in the metabolic rate due to the Simonson Effect depends on the type of work and the muscle groups used, further information on this problem is not given on account of its complexity.

4.6.5 Interpolation of the values

Interpolation of metabolic rate values is possible. Where working speeds differ from those given in the tables (see 4.3 and 4.4), conversion is only possible within a range of $\pm 25\%$ of the indicated speed.

5 Measurement of metabolic rate

5.1 Direct determination of metabolic rate

The methods of measurement described below were checked in many field studies and laboratory analyses; other methods have to be verified by the collected data using this method.

5.1.1 Methods of measurement

The metabolic rate can be determined by two principal methods:

- partial method;
- integral method.

The partial method shall be used for light and moderately heavy work, the integral method shall be used for heavy work of short duration. Different methods have to be used for the following reasons. In the case of light and moderately heavy work the oxygen uptake reaches the oxygen requirement after a short period of work. The oxygen uptake reaches a steady state and equals the oxygen requirement. In the case of heavy work, oxygen requirement is above the long term limit of aerobic power and, in the case of very heavy work, above the maximal aerobic power. During heavy work, oxygen uptake cannot reach oxygen requirement. The oxygen deficit is balanced after work ceases. Thus, the measurement includes the working and the subsequent resting period. The integral method should be used for an oxygen consumption of more than 60 litres of oxygen per hour (60 l O₂/h), equivalent to 1 litre of oxygen per minute.

Figure 2 shows the procedure followed using the partial method. The work begins first without collecting any expired air.

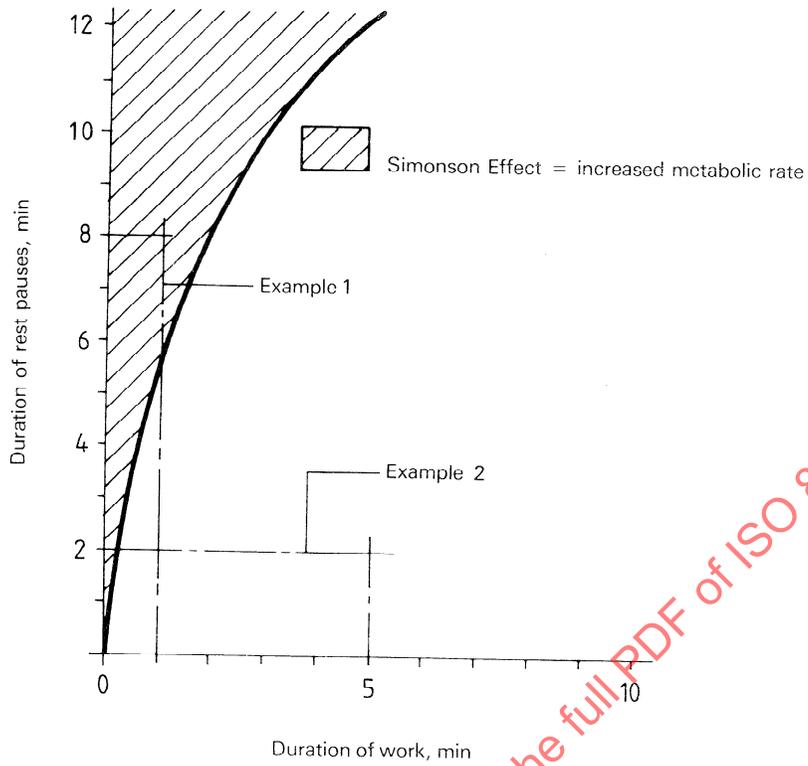


Figure 1 – Domain of the increase in metabolic rate

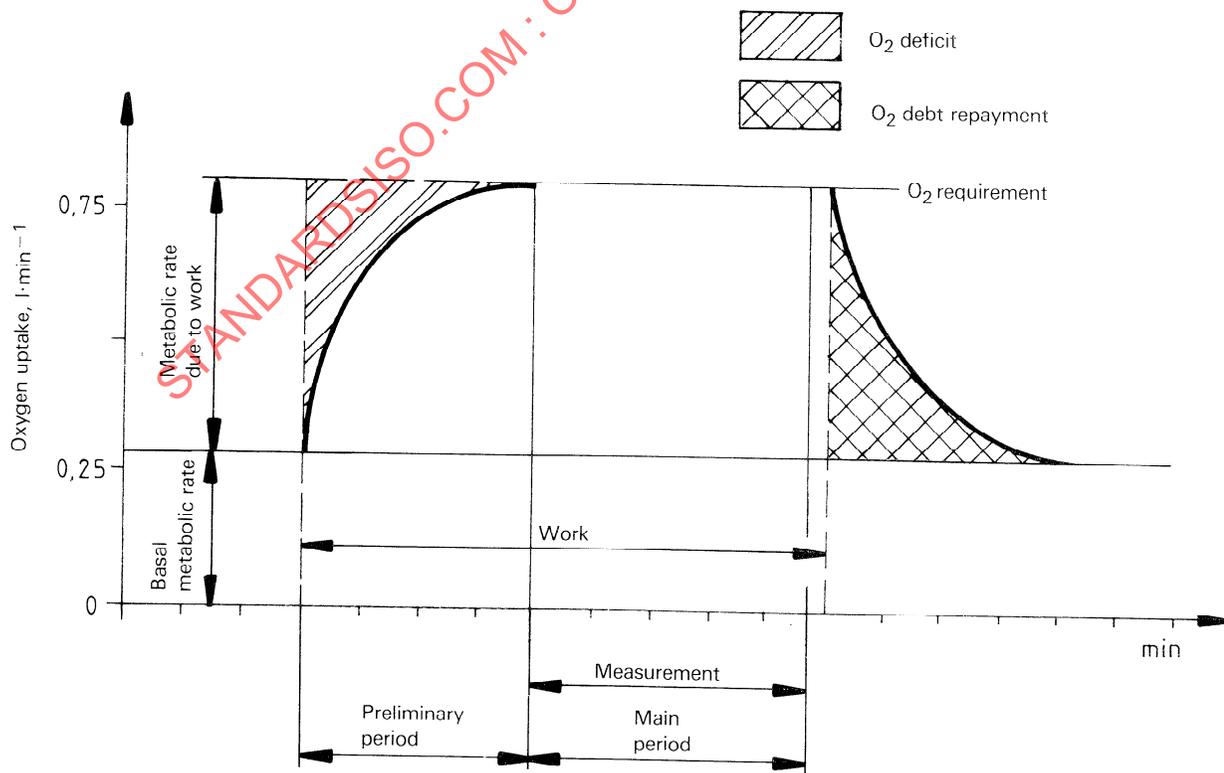


Figure 2 – Measurement of metabolic rate using the partial method

Since the steady state is reached after 3 min to 5 min, the collection of expired air starts, without interrupting the work, after about 5 min (preliminary period). The work continues for 5 min to 10 min (main period). Gas collection, either complete — for example with a Douglas bag — or regular sampled — for example with a gas meter, stops when work ceases. Thus a part has been removed from the “steady-state” of the work. When using the partial method it is essential that the metabolic rate during work be less than the long-term stress limit.

With the integral method (see figure 3), expired gas collection is started immediately at the beginning of the work, and the work continues for a certain time, usually for not more than 2 min to 3 min (main period). At the end of the work the subject sits down, while the measurement continues until the resting value is attained. During this recovery period, the oxygen debt incurred during the work is repaid. Since the measurement includes the working (main period) and sitting (recovery period) activity, the metabolic rate needed for sitting has to be subtracted from the measured value in order to obtain the metabolic rate related to work alone (see 5.1.4.2).

It is necessary to record the course of the work (time study) and the frequency of repeated activities, etc., for the further evaluation of the results and for the comparison of the metabolic rate with data in the literature. Examples of the calculation of metabolic rate are given in annex G.

5.1.2 Determination of metabolic rate from oxygen consumption

Since the human body can only store very small amounts of oxygen, it must be continuously taken up from the atmosphere by respiration. Muscles can work for a short time without being directly provided with oxygen (anaerobic work), but for longer periods of work, oxidative metabolism is the major energy source.

The metabolic rate can be determined, therefore, by measuring oxygen consumption. The energetic equivalent (EE) for oxygen is used to convert oxygen consumption into metabolic rate.

The energetic equivalent depends on the type of metabolism which is indicated by the respiratory quotient (RQ) [see equation (2)]. In the determination of the metabolic rate, the use of a mean RQ of 0,85 and thereby of an energetic equivalent (EE) of $EE = 5,68 \text{ W}\cdot\text{h}/\text{l O}_2$ is often sufficient. In that case, measurement of carbon dioxide production is not required. The maximum possible error is $\pm 3,5 \%$, but generally the error will not exceed 1 %.

Thus the metabolic rate can be determined from equations (2), (3) and (4)

$$EE = (0,23 \text{ RQ} + 0,77) \times 5,88 \quad \dots (2)$$

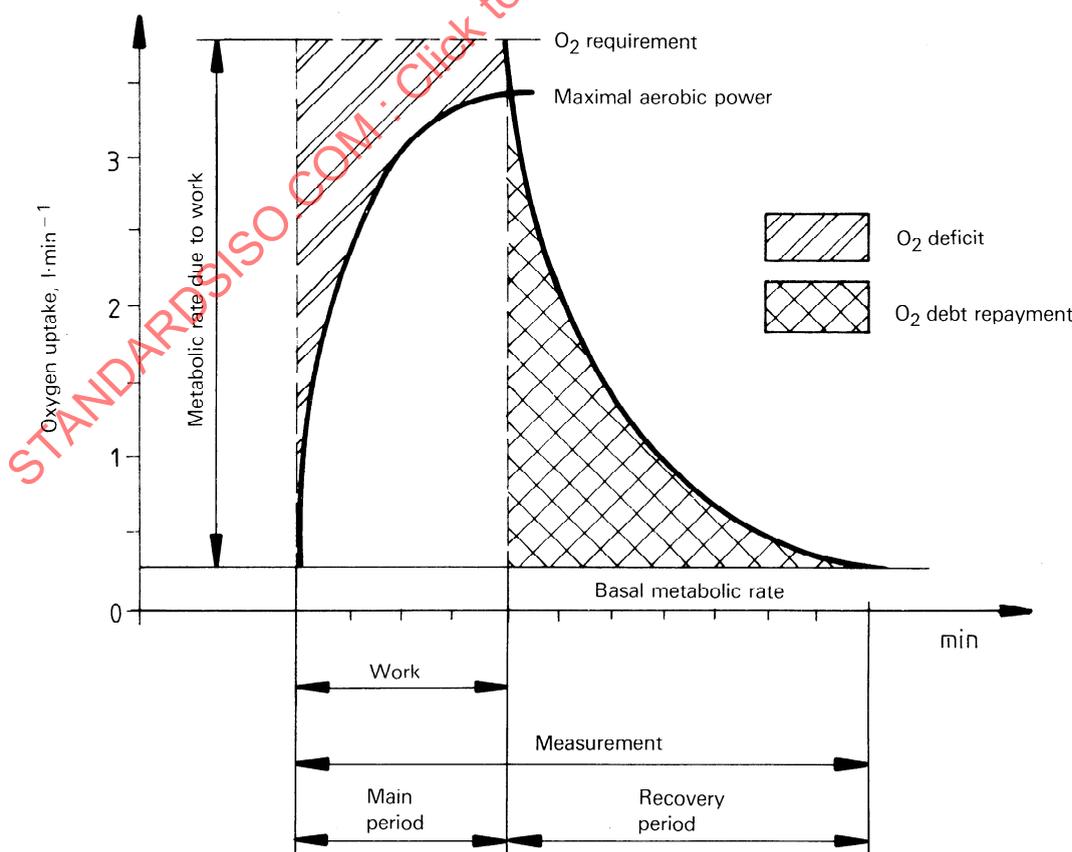


Figure 3 — Measurement of metabolic rate using the integral method

$$RQ = \frac{\dot{V}_{CO_2}}{\dot{V}_{O_2}} \quad \dots (3)$$

$$M = EE \times \dot{V}_{O_2} \times \frac{1}{A_{Du}} \quad \dots (4)$$

where

EE is the energetic equivalent, in watts hours per litre of oxygen;

RQ is the respiratory quotient;

\dot{V}_{O_2} is the oxygen consumption, in litres of oxygen per hour;

\dot{V}_{CO_2} is the carbon dioxide production, in litres of carbon dioxide per hour;

M is the metabolic rate, in watts per square metre;

A_{Du} is the body surface, in square metres, according to Du Bois;

$$A_{Du} = 0,202 \times W_b^{0,425} \times H_b^{0,725}$$

where

W_b is the body weight, in kilograms;

H_b is the body height, in metres.

5.1.3 Determination of oxygen uptake

It is necessary to measure or to record the following data to determine oxygen uptake:

- a) personal data: sex, weight, height, age;
- b) method of measurement;
- c) duration of the measurement;
 - 1) partial method: main period;
 - 2) integral method: main and subsequent period;
- d) atmospheric pressure;
- e) volume of air expired;
- f) temperature of the expired air;

g) fraction of oxygen in the expired air if determination of RQ is required;

h) fraction of carbon dioxide in the expired air.

5.1.3.1 Calculation of the STPD reduction factor

The gas volume shall be related to $t = 0 \text{ }^\circ\text{C}$, $p = 101,3 \text{ kPa}$ (normal pressure) for a dry gas (STPD conditions: Standard condition for Temperature $^\circ\text{C}$, barometric Pressure 101,3 kPa, Dry). As the collected air is saturated with water vapour (the saturation pressure of which is a function of temperature) and its temperature is determined by ambient temperature (ATPS conditions: Atmospheric condition for Temperature and barometric Pressure, Saturated), the reduction factor f can be calculated from the following equation using the partial pressure of the water vapour (see table 2).

$$f = \frac{273(p - p_{H_2O})}{(273 + t) 101,3} \quad \dots (5)$$

where

f is the STPD reduction factor;

p is the measured atmospheric pressure, in kilopascals;

p_{H_2O} is the partial pressure of the saturated water vapour, in kilopascals (see table 2);

t is the temperature of the expired air, in degrees Celsius, measured in the gas-meter or assumed to be ambient temperature when a Douglas bag is used.

If the collected expired air is heated up by the environment to a temperature in excess of $37 \text{ }^\circ\text{C}$, the pressure of the saturated water vapour at a temperature of $37 \text{ }^\circ\text{C}$ shall be used:

$t \leq 37 \text{ }^\circ\text{C}$ (see table 2)

$t > 37 \text{ }^\circ\text{C}$ $p_{H_2O} = 6,27 \text{ kPa}$

5.1.3.2 Calculation of the expiration volume for STPD

$$V_{ex \text{ STPD}} = V_{ex \text{ ATPS}} \times f \quad \dots (6)$$

where

$V_{ex \text{ STPD}}$ is the expiration volume, in litres, at STPD;

$V_{ex \text{ ATPS}}$ is the expiration volume, in litres, at ATPS;

f is as defined in 5.1.3.1.

Table 2 — Pressure of saturated water vapour (kPa) between $10 \text{ }^\circ\text{C}$ and $37 \text{ }^\circ\text{C}$ shown in steps of $1 \text{ }^\circ\text{C}$

| Temperature ($^\circ\text{C}$) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|----------------------------------|------|------|------|------|------|------|------|------|------|------|
| 10 | 1,23 | 1,31 | 1,40 | 1,50 | 1,60 | 1,70 | 1,82 | 1,94 | 2,06 | 2,20 |
| 20 | 2,34 | 2,49 | 2,64 | 2,81 | 2,98 | 3,17 | 3,36 | 3,56 | 3,78 | 4,00 |
| 30 | 4,24 | 4,49 | 4,75 | 5,03 | 5,32 | 5,62 | 5,94 | 6,27 | — | — |

5.1.3.3 Calculation of the volume flow

$$\dot{V}_{\text{ex}} = \frac{V_{\text{ex}} \text{ STPD}}{T} \quad \dots (7)$$

where

\dot{V}_{ex} is the volume flow, in litres per hour;

T is the test duration in hours, i.e. the main period for the partial method and the main and recovery period for the integral method.

5.1.3.4 Calculation of oxygen consumption

$$\dot{V}_{\text{O}_2} = \dot{V}_{\text{ex}} \times (0,209 - F_{\text{O}_2}) \quad \dots (8)$$

where

\dot{V}_{O_2} is the oxygen consumption, in litres of oxygen per hour;

F_{O_2} is the fraction of oxygen in the expired air.

5.1.3.5 Calculation of carbon dioxide production

$$\dot{V}_{\text{CO}_2} = \dot{V}_{\text{ex}} \times (F_{\text{CO}_2} - 0,0003) \quad \dots (9)$$

where

\dot{V}_{CO_2} is the carbon dioxide production, in litres of carbon dioxide per hour;

F_{CO_2} is the fraction of carbon dioxide in the expired air.

5.1.3.6 The effect of contraction of the expired volume

The inspired and expired volumes are not equal if $RQ \neq 1$. Contraction can be taken into account using the following equations:

$$\dot{V}_{\text{O}_2} = \dot{V}_{\text{ex}} [0,265 (1 - F_{\text{O}_2} - F_{\text{CO}_2}) - F_{\text{O}_2}] \quad \dots (10)$$

$$\dot{V}_{\text{CO}_2} = \dot{V}_{\text{ex}} [F_{\text{CO}_2} - (1 - F_{\text{O}_2} - F_{\text{CO}_2}) 0,380 \times 10^{-3}] \quad \dots (11)$$

5.1.4 Calculation of metabolic rate

5.1.4.1 Partial method

The metabolic rate is determined from the oxygen uptake and the energetic equivalent using equation (4).

5.1.4.2 Integral method

The following calculation shall be carried out when using the integral method, as only the difference between the total measured metabolic rate and the known metabolic rate of the activity during the recovery period, i.e. sitting, is related to the work itself.

First the metabolic rate is derived as in the partial method, and then the following conversion is performed.

$$M = \left(M_p \times \frac{t_m + t_r}{t_m} \right) - \left(M_s \times \frac{t_r}{t_m} \right) \quad \dots (12)$$

where

M is the metabolic rate, in watts per square metre;

M_p is the metabolic rate, in watts per square metre, for the partial method;

M_s is the metabolic rate, in watts per square metre, when seated;

t_m is the duration of the main period, in minutes;

t_r is the duration of the recovery period, in minutes.

5.2 Estimation of metabolic rate using heart rate

In the case of dynamic work using major muscle groups, with only a small amount of static muscular load and in the absence of thermal strain and mental loads, the metabolic rate may be estimated by measuring the heart rate during work. If the above-mentioned restrictions are taken into account, this method can be more accurate than the level I and level II methods of estimation (see table 1), but is less complex than the measurement of oxygen consumption, which provides the most accurate results.

The heart rate may be registered continuously, for example by the use of telemetric equipment, or, with a further reduction of accuracy, measured manually by counting the arterial pulse (see ISO 9886).

The total heart rate may be regarded as a sum of several components.

$$HR_{\text{OH}} = HR_0 + \Delta HR_M + \Delta HR_S + \Delta HR_T + \frac{\Delta HR_N + \Delta HR_E}{\dots} \quad \dots (13)$$

where

HR_0 is the heart rate, in beats per minute, at rest in a prone position under neutral thermal conditions ($M = BM$);

ΔHR_M is the increase in heart rate, in beats per minute, due to dynamic muscular load under neutral thermal conditions;

ΔHR_S is the increase in heart rate, in beats per minute, due to static muscular work;

ΔHR_T is the increase in heart rate, in beats per minute, due to heat stress;

ΔHR_N is the increase in heart rate, in beats per minute, due to mental load;

ΔHR_E is the residual component of heart rate, in beats per minute, due, for example, to respiratory effects.

The static component ΔHR_S depends on the relationship between the force used and the maximal voluntary force of the working muscle group. The thermal component ΔHR_T is discussed in ISO 7933.

The mean heart rate $HR_{\Delta t}$ may be computed over fixed time intervals, for example 1 min, over different working cycles or over the whole shift time.

A linear relationship exists between metabolic rate and heart rate, if dynamic muscle work using heavy muscle groups is considered, and thermal conditions are neutral with respect to the metabolic rate.

In the presence of considerable thermal load, static muscular work, dynamic work with small muscle groups and/or mental loads, the slope and form of the heart rate to metabolic rate relationship can change.

5.3 Relationship between heart rate and metabolic rate

The relationship between heart rate and metabolic rate can be measured by recording the heart rate at different stages of defined muscular load. Heart rate and corresponding oxygen consumption or physical work performed is measured during dynamic muscular work at different load stages. As there is an influence of work type (cycle-ergometer, step test, treadmill), sequence and duration of load stages on both parameters, it is necessary to use a standardized procedure.

In general, linearity holds true for the range

- above 120 beats per minute (bpm), because the mental component can then be neglected;

- up to 20 beats below the maximum heart rate for that person, because above this value, the heart rate has a tendency to level off. The individual maximum heart rate may be estimated at 200 less the age of the person.

By regression of the data within this range the coefficients HR_0 and RM of equation (14) can be determined.

$$HR = HR_0 + RM (M - BM) \quad \dots (14)$$

where

M is the metabolic rate, in watts per square metre;

BM is the basal metabolic rate, in watts per square metre;

RM is the increase in heart rate per unit of metabolic rate.

HR_0 is the heart rate at rest in a prone position under neutral thermal conditions.

Transforming equation (14) into

$$M = 1/RM (HR - HR_0) + BM \quad \dots (15)$$

gives the relationship between measured heart rate and metabolic rate.

With a further loss of accuracy a rough estimation may be computed by

$$M = 4,0 \cdot HR - 255$$

Annex A (normative)

Classification of metabolic rate for kinds of activities

Table A.1 — Classification of metabolic rate

| Class | Value to be used for calculation of mean metabolic rate | | Examples |
|-------------------------------|---|-----|---|
| | (W/m ²) | W | |
| 0 Resting | 65 | 115 | Resting |
| 1 Low metabolic rate | 100 | 180 | Sitting at ease: light manual work (writing, typing, drawing, sewing, book-keeping); hand and arm work (small bench tools, inspection, assembly or sorting of light materials); arm and leg work (driving vehicle in normal conditions, operating foot switch or pedal). Standing: drilling (small parts); milling machine (small parts); coil winding; small armature winding; machining with low power tools; casual walking (speed up to 3,5 km/h). |
| 2 Moderate metabolic rate | 165 | 295 | Sustained hand and arm work (hammering in nails, filing); arm and leg work (off-road operation of lorries, tractors or construction equipment); arm and trunk work (work with pneumatic hammer, tractor assembly, plastering, intermittent handling of moderately heavy material, weeding, hoeing, picking fruits or vegetables, pushing or pulling light-weight carts or wheelbarrows, walking at a speed of 3,5 km/h to 5,5 km/h, forging). |
| 3 High metabolic rate | 230 | 415 | Intense arm and trunk work; carrying heavy material; shovelling; sledgehammer work; sawing; planing or chiselling hard wood; hand mowing; digging; walking at a speed of 5,5 km/h to 7 km/h. Pushing or pulling heavily loaded hand carts or wheelbarrows; chipping castings; concrete block laying. |
| 4 Very high metabolic rate | 290 | 520 | Very intense activity at fast to maximum pace; working with an axe; intense shovelling or digging; climbing stairs, ramp or ladder; walking quickly with small steps; running; walking at a speed greater than 7 km/h. |

Annex B
(normative)

Classification of metabolic rate by occupation

Table B.1 – Metabolic rate for various occupations

| Occupation | Metabolic rate (W/m ²) |
|---|---------------------------------------|
| Craftsmen | |
| Bricklayer | 110 to 160 |
| Carpenter | 110 to 175 |
| Glazier | 90 to 125 |
| Painter | 100 to 130 |
| Baker | 110 to 140 |
| Butcher | 105 to 140 |
| Clock and watch repairer | 55 to 70 |
| Mining industry | |
| Haulage operator | 70 to 85 |
| Coal hewer (low stratification) | 140 to 240 |
| Coke-oven man | 115 to 175 |
| Iron and steel industry | |
| Blast furnace man | 170 to 220 |
| Electric furnace man | 125 to 145 |
| Hand moulder | 140 to 240 |
| Machine moulder | 105 to 165 |
| Foundryman | 140 to 240 |
| Iron- and metal-working industry | |
| Smith | 90 to 200 |
| Welder | 75 to 125 |
| Turner | 75 to 125 |
| Drilling machine operator | 80 to 140 |
| Precision mechanic | 70 to 110 |
| Graphic profession | |
| Hand compositor | 70 to 95 |
| Book-binder | 75 to 100 |
| Agriculture | |
| Gardener | 115 to 190 |
| Tractor driver | 85 to 110 |
| Traffic | |
| Car driver | 70 to 90 |
| Bus driver | 75 to 125 |
| Tramway driver | 80 to 115 |
| Electric trolley driver | 80 to 125 |
| Crane driver | 65 to 145 |
| Various professions | |
| Laboratory assistant | 85 to 100 |
| Teacher | 85 to 100 |
| Shop-girl | 100 to 120 |
| Secretary | 70 to 85 |

Annex C (normative)

Data for standard person

In this International Standard the metabolic rate values used are based on a standard person. This shall particularly be taken into account for activities that require an associated movement of the body weight, for example, walking upwards or lifting weights, because the body weight influences the metabolic rate of these activities.

Table C.1 – Data for the standard person

| Data | Male | Female |
|--|------|--------|
| Body height, H_b , in metres | 1,7 | 1,6 |
| Body weight, W_b , in kilograms | 70 | 60 |
| Body surface A_{Du} , in square metres | 1,8 | 1,6 |
| Age, A , in years | 35 | 35 |
| Basal metabolic rate, in watts per square metre | 44 | 41 |

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Annex D (normative)

Metabolic rate for body posture, type of work and body motion related to work speed

D.1 Tables for the estimation of metabolic rate from its components

The values in the following tables do not include the basal metabolic rate, because the different portions have to be added subsequently.

Table D.1 – Metabolic rate for body posture, values excluding basal metabolism

| Body posture | Metabolic rate (W/m ²) |
|------------------|------------------------------------|
| Sitting | 10 |
| Kneeling | 20 |
| Crouching | 20 |
| Standing | 25 |
| Standing stooped | 30 |

The type of work is classified by means of the values given in table D.2. When applying this table, the mean value for the type of work should be used first. Only after further experience can the specified range be used (by comparison with measured values).

Table D.2 – Metabolic rate for different types of work, values excluding basal metabolism

| Type of work | Metabolic rate (W/m ²) | |
|--------------|------------------------------------|------------|
| | Mean value | Range |
| Hand work | | |
| light | 15 | < 20 |
| average | 30 | 20 to 35 |
| heavy | 40 | > 35 |
| One-arm work | | |
| light | 35 | < 45 |
| average | 55 | 45 to 65 |
| heavy | 75 | > 65 |
| Two-arm work | | |
| light | 65 | < 75 |
| average | 85 | 75 to 95 |
| heavy | 105 | > 95 |
| Trunk work | | |
| light | 125 | < 155 |
| average | 190 | 155 to 230 |
| heavy | 280 | 230 to 330 |
| very heavy | 390 | > 330 |

Although metabolic rate can vary with the speed of movement, it has a constant value for a work activity within a specified speed range. This allows the metabolic rate to be calculated from the values for the activity being considered by multiplying the given values and the work speed.

Table D.3 – Metabolic rate related to work speed; values excluding basal metabolism

| Type of work | Metabolic rate related to work speed (W·m ⁻²) / (m·s ⁻¹) |
|---------------------------------------|--|
| Work speed related to distance | |
| Walking, 2 km/h to 5 km/h | 110 |
| Walking uphill, 2 km/h to 5 km/h | |
| Inclination 5° | 210 |
| Inclination 10° | 360 |
| Walking downhill, 5 km/h | |
| Declination 5° | 60 |
| Declination 10° | 50 |
| Walking with load on back, 4 km/h | |
| 10 kg load | 125 |
| 30 kg load | 185 |
| 50 kg load | 285 |
| Work speed related to height | |
| Walking upstairs | 1 725 |
| Walking downstairs | 480 |
| Mounting inclined ladder | |
| Without load | 1 660 |
| 10 kg load | 1 870 |
| 50 kg load | 3 320 |
| Mounting vertical ladder | |
| Without load | 2 030 |
| 10 kg load | 2 335 |
| 50 kg load | 4 750 |

D.2 Examples for the application of the tables of group assessment

The values in the following examples are applicable only for the specific work situation and should therefore not be considered universal. For example, depending on the hardness of the wood, it is possible that a lower or a higher value would be obtained for the activity "planing".

Table D.4 – Examples for the assessment of various types of work by means of the tables of group assessment

| No. | Activity | Metabolic rate (W/m ²) | | | | Result |
|-----|--|------------------------------------|--------------|--------------|-------------|--------|
| | | Basal metabolic rate, male | Body posture | Type of work | Body motion | |
| 1 | Raking leaves on a lawn (walking slowly, light two-arm work) | 44 | 0 | 65 | 60 | 170 |
| 2 | Planing planks by hand (standing stooped, light trunk work) | 44 | 30 | 125 | 0 | 200 |
| 3 | Filling railway lines with a tamping pick (standing stooped, heavy trunk work) | 44 | 30 | 280 | 0 | 355 |
| 4 | Pushing a car (walking, heavy trunk work) | 44 | 0 | 280 | 120 | 445 |

NOTE — Due to the limited accuracy of this method the results may be rounded to the nearest 5 W/m².

Table D.5 – Examples for calculating metabolic rate using metabolic rate related to work speed

| Activity | Duration (s) | Distance (m) Height (m) | Speed (m/s) | Metabolic rate related to work speed (W·m ⁻²) / (m·s ⁻¹) | Basal metabolism (W/m ²) | Metabolic rate (W/m ²) |
|-------------------------|--------------|----------------------------|-------------|--|--------------------------------------|------------------------------------|
| Walking with 50 kg load | 180 | 200 | 1,11 | 285 | 45 | 360 |
| Walking | 300 | 350 | 1,17 | 110 | 45 | 175 |
| Walking upstairs | 45 | 10 | 0,22 | 1 725 | 45 | 425 |

Annex E (normative)

Metabolic rate for typical activities

Table E.1 — Metabolic rate for typical activities

| No. | Activity | Metabolic rate (W/m ²) | No. | Activity | Metabolic rate (W/m ²) |
|-------|--|------------------------------------|-------|---|--|
| 1 | Basic activities | | 2.2.4 | Fettling shop working with pneumatic hammer grinding, cutting | 175 175 |
| 1.1 | Walking on the level, even path 2 km/h 3 km/h 4 km/h 5 km/h | 110 140 165 200 | 2.3 | Forestry | |
| 1.2 | Walking uphill, 3 km/h gradient 5° gradient 10° gradient 15° | 195 275 390 | 2.3.1 | Transporting and working with an axe walking and transporting (weight 7 kg) in the forest, 4 km/h carrying a power saw (18 kg) in the hands, 4 km/h working with an axe (weight 2 kg, 33 blows/min) cutting root stolons with an axe chopping off branches (spruce tree) | 285 385 500 375 415 |
| 1.3 | Walking downhill, 5 km/h gradient 5° gradient 10° gradient 15° | 130 115 120 | 2.3.2 | Sawing cutting across the grain, two-man crosscut saw 60 double pulls/min, 20 cm ² per double pull 40 double pulls/min, 20 cm ² per double pull felling with a power saw one-man power saw two-man power saw cutting across the grain one-man power saw two-man power saw stripping off bark mean value, summer mean value, winter | 415 240 235 205 205 190 225 390 |
| 1.4 | Going upstairs (0,172 m/step) 80 stairs per minute | 440 | 2.4 | Agriculture digging with a spade (24 lifts/min) ploughing with a team of horses ploughing with a tractor fertilizing farmland hand sowing sowing with manure spreader drawn by horses sowing with a tractor hoeing turnips (weight of the hoe 1,25 kg) | 380 235 170 280 250 95 170 |
| 1.5 | Going downstairs (0,172 m/step) 80 stairs per minute | 155 | 2.5 | Sports | |
| 1.6 | Transporting a load on the level, 4 km/h weight 10 kg weight 30 kg weight 50 kg | 185 250 360 | 2.5.1 | Running 9 km/h 12 km/h 15 km/h | 435 485 550 |
| 2 | Professions | | 2.5.2 | Skiing on the level, good snow 7 km/h 9 km/h 12 km/h | 350 405 510 |
| 2.1 | Building industry | | 2.5.3 | Ice-skating 12 km/h 15 km/h 18 km/h | 225 285 360 |
| 2.1.1 | Brick-laying (building a wall of the same area) solid brick (weight 3,8 kg) hollow brick (weight 4,2 kg) hollow block (weight 15,3 kg) hollow block (weight 23,4 kg) | 150 140 125 135 | 2.6 | Domestic work house cleaning cooking washing dishes, standing washing by hand and ironing shaving, washing and dressing | 100 to 200 80 to 135 145 120 to 220 100 |
| 2.1.2 | Fabrication of finished concrete, part- forming and stripping the mould (prestressed concrete cover) putting in the steel stretchers pouring in concrete (prestressed concrete cover) | 180 130 180 | | | |
| 2.1.3 | Building a dwelling mixing cement pouring in the concrete for the foundations compacting concrete by vibrations forming the mould loading a wheelbarrow with stones and mortar | 155 275 220 180 275 | | | |
| 2.2 | Iron and steel industry | | | | |
| 2.2.1 | Blast furnace preparing runners for tapping tapping | 340 430 | | | |
| 2.2.2 | Moulding (hand moulding) moulding medium-sized pieces ramming with pneumatic hammer moulding small pieces | 285 175 140 | | | |
| 2.2.3 | Machine moulding pouring off castings casting, one-man ladle casting, two-man ladle casting from a ladle hanging on a crane | 125 220 210 190 | | | |

Annex F (normative)

Example of the calculation of the average metabolic rate for a work cycle

Table F.1 gives an example of a calculation of the metabolic rate for the activities in a work cycle; their duration and the corresponding metabolic rates are given. The respective values are taken from annexes D and E (by adding the basal metabolic rate). The metabolic rate is calculated from these values using equation (1).

Table F.1 — Example of the calculation of the average metabolic rate

| Kind of activity | Duration (s) | Metabolic rate (W/m ²) | Total energy consumption during activity (J/m ²) |
|---|-----------------------|---------------------------------------|---|
| Walking in the factory interior at about 4 km/h | 35 | 165 | 5 775 |
| Transporting a sack (30 kg) | 50 | 250 | 12 500 |
| Standing | 25 | 70 | 1 750 |
| Moulding medium-sized castings | 135 | 285 | 38 475 |
| Ramming the mould with a pneumatic hammer | 55 | 175 | 9 625 |
| Total | 300 | | 68 125 |
| Average metabolic rate (rounded) | | 225 | |
| NOTE — Total energy consumption = duration × metabolic rate | | | |

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