# INTERNATIONAL STANDARD

# ISO 8996

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## Ergonomics — Determination of metabolic heat production

*Ergonomie — Détermination de la production de chaleur métabolique*



Reference number
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## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.



International Standard ISO 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<br>Accuracy: ± 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<br>Accuracy: ± 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/m$^2$ for men and 41 W/m$^2$ 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

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

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:

a) work technique;

b) work speed;

c) 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 ± 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/m to 10 W/m$^2$ may be expected due to increased heart rate and sweating.

In cold conditions a maximum increase of up to 200 W/m$^2$ 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 I (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 ± 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 $O_2$/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.

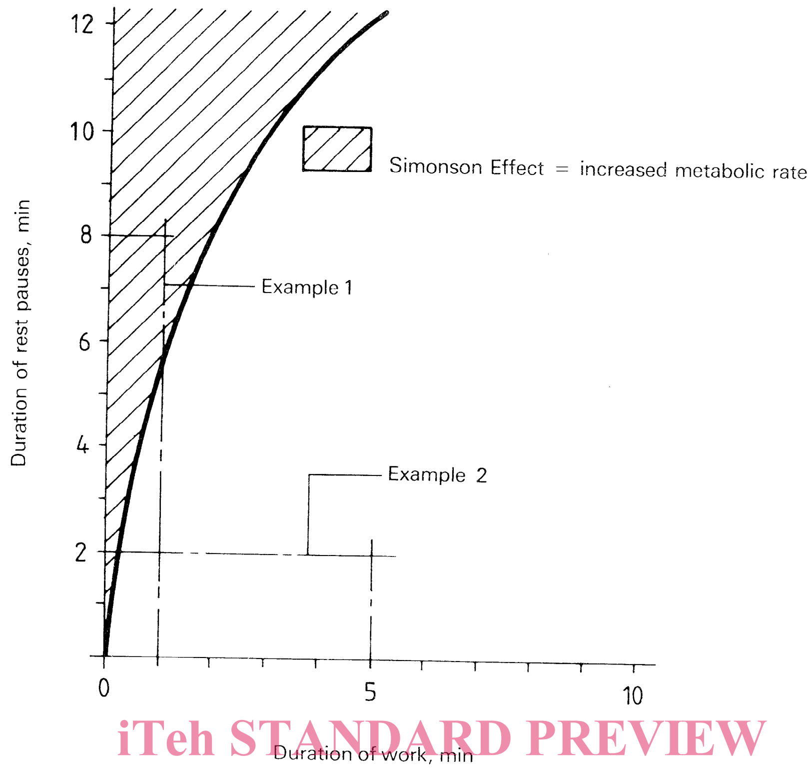




Figure 1 — Domain of the increase in metabolic rate



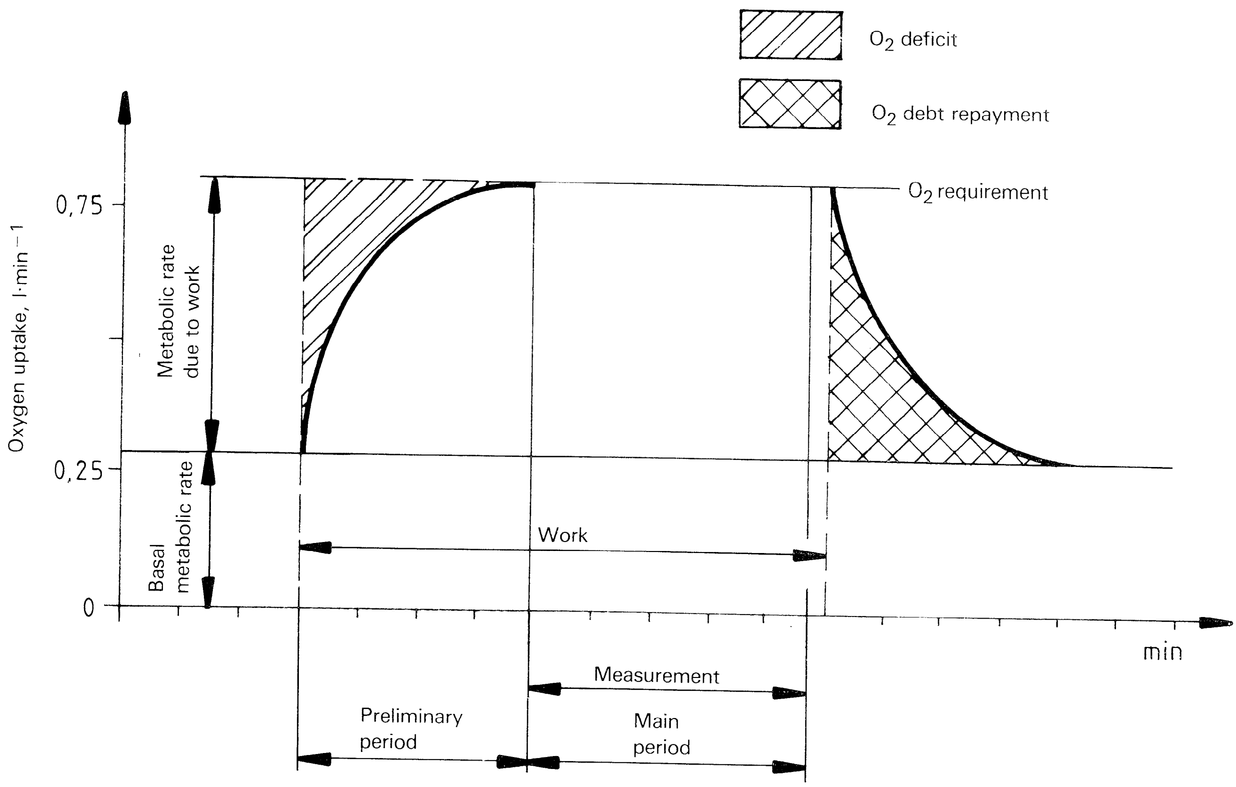


Figure 2 — Measurement of metabolic rate using the partial method

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 W·h/l $O_2$ is often sufficient. In that case, measurement of carbon dioxide production is not required. The maximum possible error is ± 3,5 %, but generally the error will not exceed 1 %.

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

$$EE = (0,23\,RQ + 0,77) \times 5,88 \qquad \ldots (2)$$



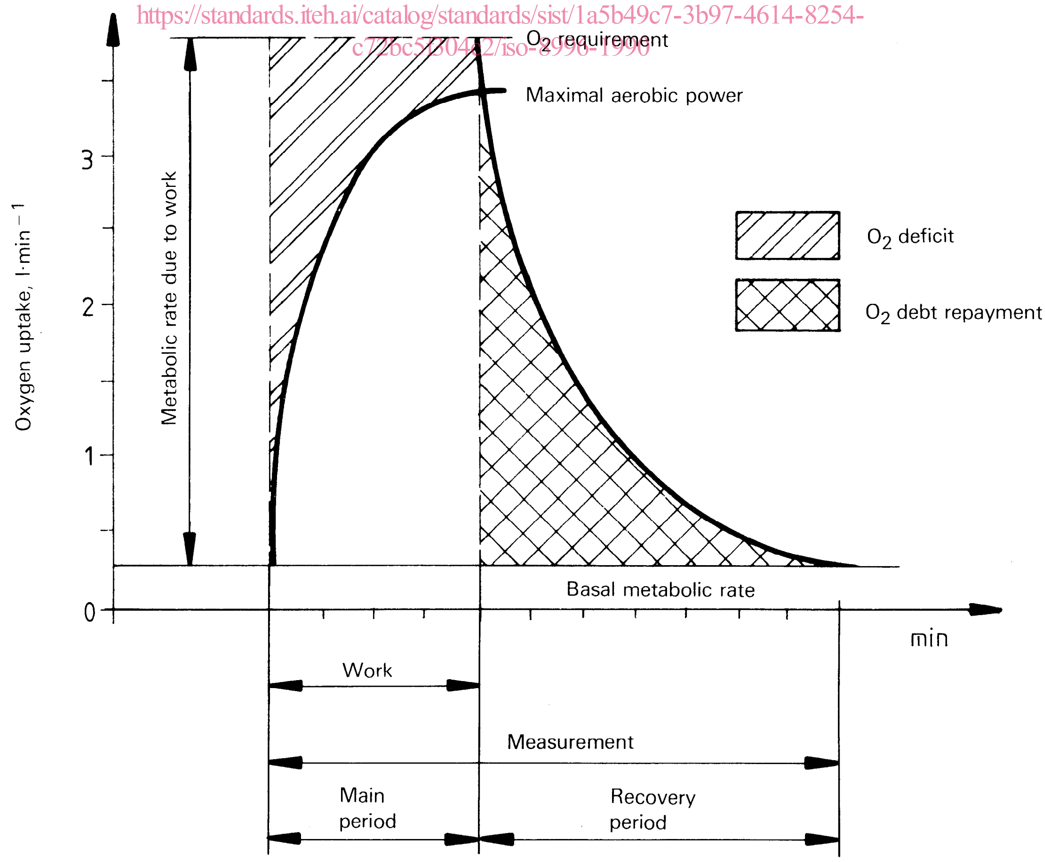


**Figure 3 — Measurement of metabolic rate using the integral method**

$$\mathrm{RQ} = \frac{\dot{V}_{CO_2}}{\dot{V}_{O_2}} \qquad \ldots (3)$$

$$M = \mathrm{EE} \times \dot{V}_{O_2} \times \frac{1}{A_{Du}} \qquad \ldots (4)$$

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 $t = 0$ °C, $p = 101{,}3$ kPa (normal pressure) for a dry gas (STPD conditions: Standard condition for Temperature °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).

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

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 °C, the pressure of the saturated water vapour at a temperature of 37 °C shall be used:

$t \leqslant 37$ °C (see table 2)

$t > 37$ °C $\quad p_{H_2O} = 6{,}27$ kPa

**5.1.3.2** Calculation of the expiration volume for STPD

$$V_{ex}\,\mathrm{STPD} = V_{ex}\,\mathrm{ATPS} \times f \qquad \ldots (6)$$

where

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

$V_{ex}$ 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 °C and 37 °C shown in steps of 1 °C**

| Temperature (°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

$$\dot{V}_{ex} = \frac{V_{ex}\,\mathrm{STPD}}{T} \qquad \ldots (7)$$

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

$$\dot{V}_{O_2} = \dot{V}_{ex} \times (0{,}209 - F_{O_2}) \qquad \ldots (8)$$

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

$$\dot{V}_{CO_2} = \dot{V}_{ex} \times (F_{CO_2} - 0{,}000\,3) \qquad \ldots (9)$$

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:

$$\dot{V}_{O_2} = \dot{V}_{ex}\,[0{,}265\,(1 - F_{O_2} - F_{CO_2}) - F_{O_2}] \qquad \ldots (10)$$

$$\dot{V}_{CO_2} = \dot{V}_{ex}\,[F_{CO_2} - (1 - F_{O_2} - F_{CO_2})\,0{,}380 \times 10^{-3}] \qquad \ldots (11)$$

### 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.

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

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.

$$\mathrm{HR_{0H}} = \mathrm{HR_0} + \Delta\mathrm{HR_M} + \Delta\mathrm{HR_S} + \Delta\mathrm{HR_T} + \Delta\mathrm{HR_N} + \Delta\mathrm{HR_E} \qquad \ldots (13)$$

where

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

$\Delta\mathrm{HR_M}$ is the increase in heart rate, in beats per minute, due to dynamic muscular load under neutral thermal conditions;

$\Delta\mathrm{HR_S}$ is the increase in heart rate, in beats per minute, due to static muscular work;

$\Delta\mathrm{HR_T}$ is the increase in heart rate, in beats per minute, due to heat stress;

$\Delta\mathrm{HR_N}$ is the increase in heart rate, in beats per minute, due to mental load;

$\Delta\mathrm{HR_E}$ is the residual component of heart rate, in beats per minute, due, for example, to respiratory effects.