TECHNICAL SPECIFICATION

ISO/TS 16976-1

Second edition
2015-12-01

Respiratory protective devices — Human factors —

Part 1: Metabolic rates and respiratory flow rates

Appareils de protection respiratoire — Facteurs humains —

Partie 1: Régimes métaboliques et régimes des débits respiratoires

Reference number
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Foreword

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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 meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 94, *Personal safety — Protective clothing and equipment*, Subcommittee SC 15, *Respiratory protective devices*.

This second edition cancels and replaces the first edition (ISO/TS 16976-1:2007), of which it constitutes a major revision with the following technical change:

— 7.3 has been added.

ISO/TS 16976 consists of the following parts, under the general title *Respiratory protective devices — Human factors*:

— *Part 1: Metabolic rates and respiratory flow rates* [Technical Specification]

— *Part 2: Anthropometrics* [Technical Specification]

— *Part 3: Physiological responses and limitations of oxygen and limitations of carbon dioxide in the breathing environment* [Technical Specification]

— *Part 4: Work of breathing and breathing resistance: Physiologically based limits* [Technical Specification]

— *Part 5: Thermal effects* [Technical Specification]

— *Part 6: Psycho-physiological effects* [Technical Specification]

— *Part 7: Hearing and speech* [Technical Specification]

— *Part 8: Ergonomic factors* [Technical Specification]

Introduction

For an appropriate design, selection, and use of respiratory protective devices, it is important to consider the basic physiological demands of the user. The type and intensity of work affect the metabolic rate (energy expenditure) of the wearer. The weight and weight distribution of the device on the human body also may influence metabolic rate. Metabolic rate is directly correlated with oxygen consumption, which determines the respiratory demands and flow rates. The work of breathing is influenced by the air flow resistances of the device and the lung airways. The work (or energy cost) of a breath is related to the pressure gradient created by the breathing muscles and the volume that is moved in and out of the lung during the breath. Anthropometric and biomechanical data are required for the appropriate design of various components of a respiratory protective device, as well as for the design of relevant test methods.

This part of ISO/TS 16976 is the first part of a series of documents providing basic physiological and anthropometric data on humans. It contains information about metabolic rates and respiratory flow rates for various types of physical activity.

Respiratory protective devices — Human factors —

Part 1: Metabolic rates and respiratory flow rates

1 Scope

This part of ISO/TS 16976 provides information on factors related to human anthropometry, physiology, ergonomics, and performance for the preparation of standards for performance requirements, testing, and use of respiratory protective devices. This part of ISO/TS 16976 contains information related to respiratory and metabolic responses to rest and work at various intensities. Information is provided for the following:

— metabolic rates associated with various intensities of work;

— oxygen consumption as a function of metabolic rate and minute ventilation for persons representing three body sizes;

— peak inspiratory flow rates during conditions of speech and no speech for persons representing three body sizes as a function of metabolic rates.

The information contained within this part of ISO/TS 16976 represents data for healthy adult men and women of approximately 30 years of age, but is applicable for the age range of the general population.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 8996:2004, *Ergonomics of the thermal environment — Determination of metabolic rate*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
aerobic energy production
biochemical process in the human cells that delivers energy by combustion of fat, carbohydrates and, to a lesser extent, protein in the presence of oxygen, with water and carbon dioxide as end products

3.2
anaerobic energy production
biochemical process in the human cells that delivers energy by combustion of carbohydrates without oxygen, with lactic acid as the end product

3.3
ambient temperature pressure saturated
ATPS
standard condition for the expression of ventilation parameters related to expired air

Note 1 to entry: Actual ambient temperature and atmospheric pressure; saturated water vapour pressure.

3.4
ambient temperature pressure humidity
ATPH
standard condition for the expression of ventilation parameters related to inspired air

Note 1 to entry: Actual ambient temperature, atmospheric pressure and water vapour pressure.

3.5
breath cycle
respiratory period comprising an inhalation and an exhalation phase

3.6
body temperature pressure saturated
BTPS
standard condition for the expression of ventilation parameters

Note 1 to entry: Body temperature (37 °C), atmospheric pressure 101,3 kPa (760 mmHg), and water vapour pressure (6,27 kPa) in saturated air.

3.7
peak inspiratory flow rate
highest instantaneous flow rate during the inhalation phase of a breath cycle

Note 1 to entry: It is expressed in l/s BTPS.

Note 2 to entry: L/s is the preferred unit as the flow takes place during only a short fraction of the breath cycle.

3.8
minute ventilation
$\boldsymbol{V}_{\mathbf{E}}$
total volume of air inspired (or expired) in the lungs during 1 min

Note 1 to entry: It is expressed in l/s BTPS.

3.9
oxygen consumption
$\boldsymbol{V}_{\mathbf{O2}}$
amount of oxygen consumed by the human tissues for aerobic energy production

Note 1 to entry: It is expressed in l/min STPD.

3.10
physical work capacity
ability of a person to engage in muscular work

3.11
standard temperature pressure dry
STPD
standard conditions for expression of oxygen consumption

Note 1 to entry: Standard temperature (0 °C) and pressure (101,3 kPa, 760 mmHg), dry air (0 % relative humidity).

4 Activity and metabolic rate

Users of respiratory protective devices (RPD) perform physical work at various intensities. Physical work, in particular when associated with large muscle groups as is the case with firefighting, requires high levels of metabolic energy production (metabolic rate). The energy is produced in human cells by aerobic or anaerobic processes.

Aerobic energy production is by far the most common form of energy yield for all types of human cells. It is also the normal form of energy production for the muscles. Depending on physical fitness and other factors, humans can sustain high levels of aerobic energy production for long periods of time. Very high activity levels, however, can only be sustained for short periods of time (minutes) and they also engage the anaerobic energy yielding processes. The associated production of lactic acid is one reason for the early development of fatigue and exhaustion.

Aerobic energy production is strictly dependent on the constant delivery of oxygen to the active cells. Oxygen is extracted from inspired air, bound to haemoglobin in red blood cells in the alveolar capillaries and transported to the target tissues via the circulation. Consequently, there is a direct, linear relationship between the rate of oxygen consumption and the metabolic rate. The relationship is described in ISO 8996.

Table 1 of this part of ISO/TS 16976 is derived from ISO 8996:2004, Table A.2, which defines five classes of metabolic rate. This table forms the basis for developing a standard for the assessment of heat stress. The classes represent types of work found in industry. The figures represent average metabolic rates for work periods or full work shifts, generally including breaks. Metabolic rate shall not be confused with external work rates, such as those defined on a bicycle ergometer.

Rescue work and firefighting are by nature temporary and often unpredictable. Activities may become very demanding and high levels of metabolic rate have been reported in References [1], [13], [14], [16], [17], [21], [23], and [25]. According to Reference [21], mean values for oxygen uptake of between 40 ml/(kg × min) and 45 ml/(kg × min) are reported for the most demanding tasks in firefighting drills (see References [6], [8], and [13]). Assuming an average body weight of 80 kg, the absolute oxygen uptake is between about 3,2 l/min and 3,6 l/min. In Reference [21], mean values of (2,4 ± 0,5) l/min for a 17-min test drill exercise were reported; Reference [16] reported a mean value of (2,75 ± 0,3) l/min for a 22-min test drill. The average value for the most demanding task (ascending a tower) was (3,55 ± 0,27) l/min. The range of values for this task was between 3,24 l/min and 4,13 l/min. This corresponded to average metabolic rates of 474 W/m^2 and 612 W/m^2, respectively.

Table 1 — Classification of work based on metabolic rate (MR)

Class	Work	Average metabolic rate W/m^2
1	Resting	65
2	Light work	100
3	Moderate work	165
4	Heavy work	230
5	Very heavy work	290
6	Very, very heavy work (2 h)	400
7	Extremely heavy work (15 min)	475
8	Maximal work (5 min)	600
NOTE The first five classes in this table are derived from ISO 8996. These classes are valid for repeated activities during work shifts in every day occupational exposure. Classes 6 to 8 are added as examples of metabolic rates associated with temporary activities of an escape and rescue nature while wearing RPD.		

Table 1 of this part of ISO/TS 16976 contains three additional classes compared with ISO 8996:2004, Table A.2, in order to cover work that is, by its nature, limited by time, such as firefighting and rescue. One class refers to sustained rescue action, as can be found in mining or in wild land firefighting, with time periods of up to 2 h of work (class 6). The other two classes refer to firefighting or rescue operations of short duration and very high intensity, i.e. 15 min (class 7) and 5 min (class 8), respectively. Table 1 presents values expected from individuals with a high level of physical fitness. The highest class (class 8) represents maximal or close to maximal work and can only be endured by fit men for durations of 3 min to 5 min. The three new classes are defined by metabolic rates at 400 W/m^2, 475 W/m^2, and 600 W/m^2, respectively. The values represent the average metabolic rate for the specified period of time, excluding any breaks.

For natural reasons, many types of rescue and emergency work are carried out with personal protective equipment. This adds to the physical workload and is one reason for the high values of metabolic rate in classes 6 to 8. The data given for the types of work shown in classes 1 to 5 are carried out without wearing RPD and/or personal protective equipment.

5 Metabolic rate and oxygen consumption

The energetic equivalent (EE) of oxygen as described in ISO 8996:2004, 7.1.2, is determined using Formula (1):

$$EE = (0{,}23 \times RQ + 0{,}77) \times 5{,}88 \tag{1}$$

where RQ is the respiratory quotient [the ratio of the amount of carbon dioxide produced to the amount of oxygen consumed (V_{CO_2} / V_{O_2})] and the energetic equivalent of oxygen is 5,88 Wh/l O_2, which corresponds approximately to the value of 5 kcal/l O_2, a value that is commonly found in the physiological literature.

Assuming a value of 5 kcal/l O_2 (equal to 5,815 Wh/l O_2), the following expressions apply for the conversion of metabolic rates (in W/m^2) to V_{O_2} (in l/min):

$$V_{O_2} = \frac{M \times A_{Du}}{EE} = \frac{M \times A_{Du}}{60 \times 5{,}815} = \frac{M \times A_{Du}}{349} \tag{2}$$

where

V_{O_2} is the oxygen consumption, in l/min;

M is the metabolic rate, in W/m^2;

A_{Du} is the Dubois body surface area, in m;

60 is the conversion factor for min/h;

and the energy equivalent of oxygen is 5,815 Wh/l O_2.

For the same metabolic rate, the oxygen consumption will vary dependant on body size. Examples are given in Tables 3, 4, and 5 for persons representing three body sizes. The associated body surface area is 1,69 m^2, 1,84 m^2, and 2,11 m^2, respectively. As defined in ISO 8996, a person's body surface area, A_{Du}, is determined on the basis of values for body weight, W_b, in kg, and body height, H_b, in m, by Formula (3):

$$A_{Du} = 0{,}202 \times W_b^{0{,}425} \times H_b^{0{,}725} \tag{3}$$

Values for V_{O_2} in Tables 3, 4, and 5 are based on Formulae (4), (5), and (6).

A small-sized person is defined by W_b = 60 kg, H_b = 1,7 m, and A_{Du} = 1,69 m^2. The oxygen consumption, V_{O_2}, is calculated by Formula (4):

$$V_{O_2} = \frac{M}{207} \quad (4)$$

A medium-sized person is defined by W_b = 70 kg, H_b = 1,75 m, and A_{Du} = 1,84 m^2. The oxygen consumption, V_{O_2}, is calculated by Formula (5):

$$V_{O_2} = \frac{M}{190} \quad (5)$$

A large-sized person is defined by W_b = 85 kg, H_b = 1,88 m, and A_{Du} = 2,11 m^2. The oxygen consumption, V_{O_2}, is calculated by Formula (6):

$$V_{O_2} = \frac{M}{160} \quad (6)$$

6 Oxygen consumption and minute volume

Oxygen transport to tissues requires its extraction from inspired air in the lungs. Concentration of oxygen in inspired air is equivalent to atmospheric concentration of 20,93 % by volume in dry air. Normally, only 15 % to 30 % of this fraction is consumed. The expired air still contains approximately 15 % to 18 % O_2 by volume. This means that the minute ventilation of air, V_E, required for most levels of oxygen consumption, is about 20 to 25 times higher (see Reference [3]). At high activity levels, the value may be even higher, as there is a tendency for hyperventilation.

Reference [9] contains a review of 19 papers published in the relevant literature. The data for 14 non-respirator studies are plotted again in Figure 1, together with data from References [7], [17], and [18]. Each data point represents the mean value of several individual subjects. The linear regression line for the mean values is plotted. A power function regression line differs only marginally from the linear model. The Hagan equation (at the bottom of the graph) provides an exponential regression that overestimates V_E at low and very high V_{O_2} levels and underestimates at medium levels. Exponential relations have also been proposed by others (see References [1] and [12]). All three of the studies mentioned used incremental exercise as a means of increasing the workload. It can be questioned if V_E and V_{O_2} equilibrate in such a short time. In particular, V_{O_2} should have a time constant of more than a minute. In the Hagan study, workload was increased every minute.

From a physiological point of view, one would not expect an exponential relationship. Indeed, individual curves show that, up to 60 % to 70 % of maximum V_{O_2}, the relation is almost linear. At higher levels of V_{O_2}, hyperventilation increases V_E in a curvilinear manner (see Reference [3]). Respiratory adaptation to increased workloads is likely to represent a two-component equation: one linear and one power or exponential. The model equation would be described by Formula (7):

$$y = (a \times x) + e^{b \times x} \quad (7)$$

where

a, b	are constants;
y	represents V_E;
x	represents V_{O_2}.

At low values of *x*, the first term is determinant. With increasing *x*, the second component becomes more and more important. The highest correlation coefficient is obtained for $a = 27{,}1$ and $b = 0{,}839$. The value of $R^2 = 0{,}90$.

Applying a linear regression forced through zero provides a value of $R^2 = 0{,}90$. For simplicity, the linear regression is selected. The regression equation for the mean values is given by Formula (8). Calculating V_E for two times the standard error (S_E) of the average V_E, representing 95 % of the populations, gives Formula (9). S_E defines the error in the prediction of V_E, based on the regression equation, Formula (7). These equations are subsequently used for estimations of V_E and peak flows (see Tables 3 to 5).

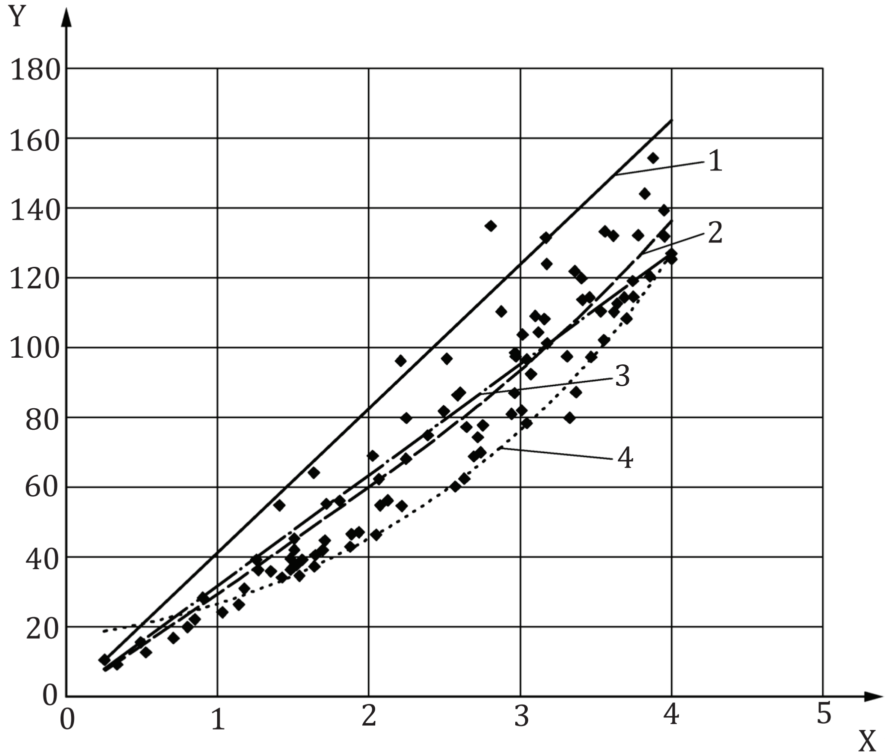
$$V_{\mathrm{E}} = 31{,}85 \times \overline{V_{\mathrm{O_2}}} \tag{8}$$

$$V_{\mathrm{E}} = \left(41{,}48 \times \overline{V_{\mathrm{O_2}}}\right) + 2S_E \tag{9}$$

where

$\overline{V_{\mathrm{O_2}}}$ is the mean value of $V_{\mathrm{O_2}}$;

S_{E} is the standard error.



Key

X oxygen consumption, V_{O_2} , in l/min STPD

Y minute ventilation, V_E, in l/min BTPS

1 $y = 41{,}48 \times x$

2 $y = (27{,}18 \times x) + \exp(0{,}839 \times x)$

3 $y = 31{,}85 \times x$

4 Hagen equation

NOTE 1 Each dot represents the average of a sample of subjects exposed to various conditions of work (without respiratory protective device).

NOTE 2 Data include 14 studies reported in References [9] and [16].

Figure 1 — Relation between minute ventilation, V_E, and oxygen consumption, V_{O_2}

7 Minute volume and peak inspiratory flow rates

7.1 Normal breathing

During the respiratory cycle, the inspired (and expired) volume and its flow rate changes with time. A simple description of the respiratory cycle can be described by a sinus curve.

The mean flow rate during an inhalation is the inspired volume (tidal volume) divided by the time. The minute ventilation is the total volume of air exchanged in the lungs during 1 min.

The instantaneous flow rate during the respiratory cycle is described by the derivative of the volume curve, which is in fact a sinus curve. Peak inspiratory flow rate (PIFR) is mathematically defined by the minute ventilation multiplied by π, if the respiratory pattern follows a sinus curve. PIFR occurs for fractions of a second within the inhalation cycle and is best expressed in l/s.

As ventilation increases in response to increasing workload, the breathing pattern transforms from a predominantly sinusoidal to a trapezoidal pattern, indicating that flow rates and in particular peak flow rates may be different than for the sinus cycle (see Reference [20]). It was concluded that peak inspiratory flow rates were 2,5 to 3,7 times as high as the mean minute volumes. The highest ratio was achieved at rest and reduced with exercise intensity. During work, the ratio was lower and relatively constant, independent of workload. At maximal voluntary hyperventilation, the peak values were 2,5 times as high as the mean minute volume values.

Similar results were reported in Reference [28], which re-analysed data reported in Reference [29]. The ratio for peak flows and mean minute ventilation was also calculated, with the ranges found to be from 2,5 to 3,9.

Reference [21] provides an analysis of several independent sets of data for PIFR/V_E. The data (see Figure 2) were well correlated (R^2 = 0,986 7) and fitted Formula (10):

$$\text{PIFR} = (2{,}346 \times V_E) + 20{,}828 \quad (10)$$

In Reference [7], PIFR during incremental bicycle exercise, breathing through several types of negative pressure filtering devices, is reported. Similar data have been obtained in Reference [18]. The relation between PIFR and V_E is shown in Figure 3. The data in Reference [9] have been converted and are included in Figure 3 a). There is a tendency for higher ratio at low minute volumes.

7.2 Speech and breathing

Several investigators report that speech during use of respiratory protective devices changes the respiratory dynamics. Speech is performed during the expiration phase of the breathing cycle. This shortens the inspiration phase accordingly and it may become critically short during very high activity levels (see References [10], [18] and [30]). This shortening of the inspiratory phase suggests that speech becomes very difficult at very high activity levels.

Minute ventilation during speech is related almost linearly to minute ventilation without speech. In Reference [7], a regression line of $V_{E,speech}$ = 0,83 × V_E is reported. Similarly, a regression line of $V_{E,speech}$ = 0,78 × V_E is reported in Reference [18]. It can be assumed that V_E during speech reduces by about 20 % compared with V_E in no speech conditions. The reduction appears to be similar, independent of work rate. Accordingly, the following relation is applied:

$$V_{E,speech} = 0{,}8 \times V_E \quad (11)$$

With shorter inspiration time, the peak flow rates are reported to increase even more than during a normal breath. Peak inspiratory flow rates about six times higher than the mean minute ventilation have been reported (see References [7] and [18]).

In References [7] and [18], PIFR was investigated during work sessions with standardized speech communication. Results are given in Figure 3 b). In Reference [7], incremental bicycle exercise was used, whereas in Reference [18], treadmill walking with incremental increases in slope was used. Results for the PIFR/V_E ratio are in good agreement. It is apparent that the ratio is high at low minute volumes, but that it approaches the “no speech” values at high minute volumes. The power function regression line shows a high correlation factor. It is apparent from these data that speech is not a significant contributor to PIFR at extremely heavy work, most probably because it is difficult to sustain continuous speech, but it is still possible to say single words at very high ventilation rates.

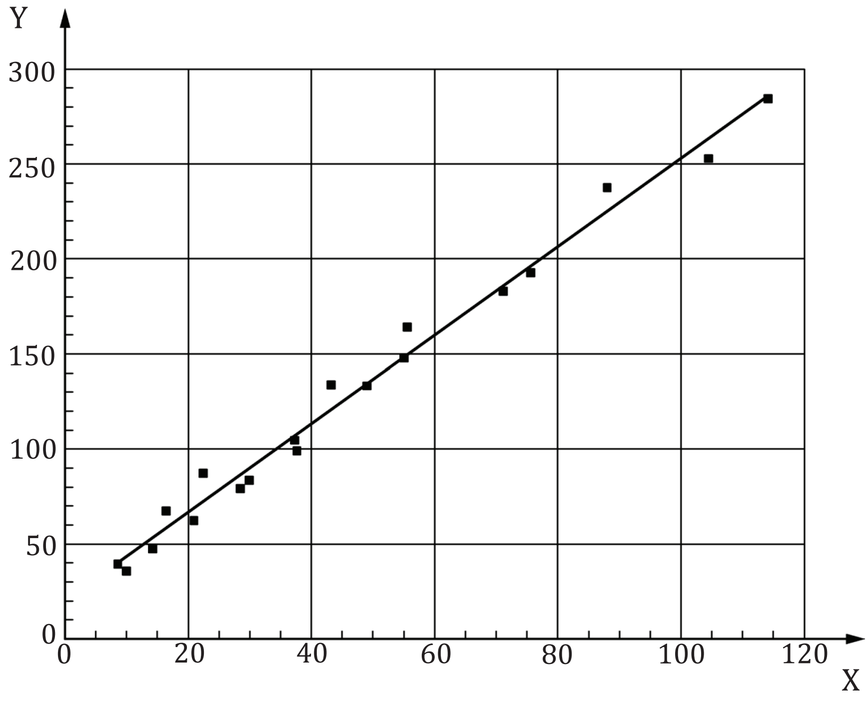
Formulae (12) and (13) apply to the calculation of PIFR from V_E.

For no speech:

$$\text{PIFR} = 5{,}605 \times V_\text{E}^{-0{,}167\,5} \times V_\text{E} = 5{,}605 \times V_\text{E}^{0{,}832\,5} \text{ for no speech} \tag{12}$$

For speech:

$$\text{PIFR} = 36{,}707 \times (0{,}8 \times V_\text{E})^{-0{,}474\,3} \times (0{,}8 \times V_\text{E}) = 36{,}707 \times (0{,}8 \times V_\text{E})^{0{,}525\,7} \text{ for speech} \tag{13}$$



$y = (2{,}346 \times x) + 20{,}828$; $R^2 = 0{,}986\,7$

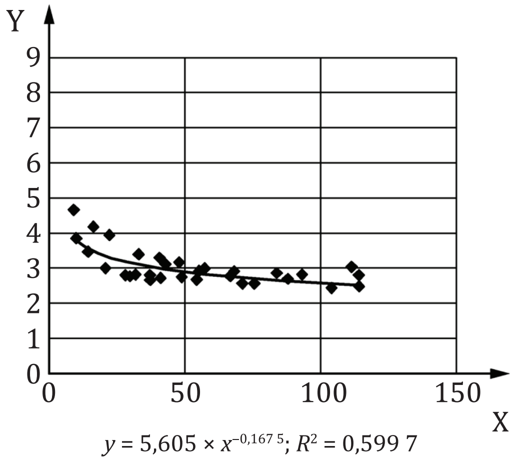
Key

X minute ventilation, V_E, in l/min BTPS

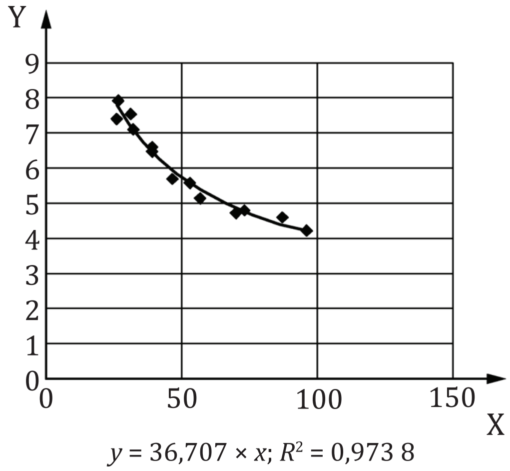
Y peak inspiratory flow, in l/min

NOTE For details, see Reference [21].

Figure 2 — Relation between peak inspiratory flow rate and minute ventilation



a) Relation for no speech conditions



b) Relation measured when subjects read a standard text during exercise

Key

X minute ventilation, V_E, in l/min BTPS

Y ratio PIFR/V_E

NOTE 1 Figure 3 a) is based on mean values for 37 conditions in four independent studies.

NOTE 2 In Figure 3 b), the data report mean values from 13 conditions in two independent studies.

Figure 3 — Ratio of peak inspiratory flow rate to minute ventilation as a function of minute ventilation during work using negative pressure (filter) breathing apparatus

7.3 Sneezing and coughing

7.3.1 General

During use of respiratory devices, it may happen that wearers will sneeze or cough, which has a different aerodynamic effect from a typical breathing pattern. A number of studies have been performed which give measurements of effects of these phenomena.

7.3.2 Maximum pressures

7.3.2.1 Maximum expiratory pressures

In Reference [10], the reported maximum expiratory pressures were 14,9 (SD = 3,5) kPa in women, 24,2 (SD = 4,6) kPa in 29-year-old men, and 15,6 (SD = 6,4) kPa in 59-year-old men. In Reference [23], the measured maximum expiratory pressures were (13 ± 2,6) kPa in men and (10 ± 1,8) kPa in women.

ISO/TC 94/SC 15/PG 5 N 178 quotes maximum expiratory pressures of (8 ± 3) kPa in women and (14 ± 4) kPa in men, respectively.

NOTE ISO/TC 94/SC 15/PG 5 N 178 is available from the secretariat of ISO/TC 94/SC 15 on request.

7.3.2.2 Maximum inspiratory pressures

In Reference [10], the reported maximum inspiratory pressures were −10,2 (SD = 1,9) kPa in women, −13,6 (SD = 4,0) kPa in 29-year-old men, and −11,1 (SD = 3,1) kPa in 59-year-old men. In Reference [25], it was reported to be −15 kPa.

ISO/TC 94/SC 15/PG 5 N 178 quotes maximum inspiratory pressures of (−6 ± 3) kPa and (−10 ± 4) kPa in women and men, respectively.

NOTE ISO/TC 94/SC 15/PG 5 N 178 is available from the secretariat of ISO/TC 94/SC 15 on request.

7.3.2.3 Expulsive pressure

People can generate quite high pressures during a rapid exhalation (e.g. a sneeze or a cough during a rapid inhalation).

In Reference [1], it was reported that expulsive pressures vary with lung volumes and may vary from 25 kPa to close to 50 kPa. As shown in Reference [2], if the cough started at maximum lung volume, the average maximum pressure was about (15 ± 1) kPa (mean ± SE) and the person exhaled (4,3 ± 0,3) l with a peak flow of (8,4 ± 0,5) l/s. If the cough started at the lung volume where the respiratory muscles were relaxed (start of a normal inspiration), then the average maximum pressure was about (11 ± 0,5) kPa and the person exhaled (1,0 ± 0,1) l with a peak flow of about (2 ± 0,5) l/s.

7.3.3 Maximum air flows and air velocities

7.3.3.1 Expiration

The measured expiratory peak in Reference [32] ranged from 2,2 m/s to 5 m/s while in Reference [33] it ranged from 1,5 m/s to 29 m/s (90 % of the velocity was less than 10 m/s). The time to the peak flow has been measured as 20 ms to 40 ms (see Reference [30]) and 30 ms to 40 ms (see Reference [14]).

As shown in Reference [21], the peak flows can vary between 2 l/s and 10 l/s. The measured peak oesophageal pressure (the pressure that compresses the lungs) varied between 6 kPa and 22 kPa and it occurs after the peak flow.

7.3.3.2 Inspiration

In Reference [4], the recorded inspiratory peak flows were 5,5 l/s in men and 4,0 l/s in women and they occurred after 0,3 s to 0,4 s.

Table 2 — Empirical values for breathable gas velocities, flows, and pressures during expirations and inspirations (calculated as averages of values given in the text)

	Velocity m/s	Time to peak flow ms	Flow l/s	Static peak pressure kPa	Expulsive pressure kPa	Expulsive volume l
Expiration	(6 ± 4)	(30 ± 10)	(6 ± 4)	(14 ± 6)	(25 ± 10)	(2,6 ± 0,4)
Inspiration		(350 ± 50)	(5 ± 1)	(–11 ± 4)		

8 Individual variation and gender aspects

The metabolic requirements (and the associated minute ventilation) for a given work task depends among other things on body dimensions and work efficiency, e.g. walking at a given speed requires a higher metabolic rate the taller and heavier the person is (see ISO 8996 for further information). Standard formulae are available for the prediction of such effects (see References [19] and [27]). In Tables 3, 4, and 5, the minute volumes are given not only for the mean of collected samples, but also for the mean value at $+2S_E$ (S_E being used as a statistical means for comparison of a number of samples). S_E is the standard error for the prediction of V_E based on the calculated regression equation for several samples of data (Excel Analysis ToolPak™1)). The standard error of the minute volume in Figure 1 is 12,46 l/min and $2S_E$ corresponds to 24,91 l/min. The regression line for this population [Formula (7)] is plotted in Figure 1 and the values for the defined classes of metabolic rate are given in Tables 3, 4, and 5.

Based on Table 1, values for oxygen consumption [see Formulae (4), (5), and (6)], minute ventilation [see Formulae (8) and (9)], and PIFR [Formulae (10)] can be calculated from Tables 3, 4, and 5 for persons of different body sizes (body height, H_b, in m) and body mass (body weight, W_b, in kg). The different values for oxygen consumption are used as base values for calculation of minute volume and peak flow rates.

Table 3 comprises values for a person with a body surface area, A_{Du}, of 1,69 m^2 (e.g. H_b = 1,7 m and W_b = 60 kg). This value may be representative for the men in some Asian populations; it is also the defined value for the ISO standard woman, in terms of height and weight (see ISO 8996).

Table 4 comprises values for a person with a body surface area, A_{Du}, of 1,84 m^2 (e.g. H_b = 1,75 m and W_b = 70 kg). This value may be representative for the men in many parts of the world; it is also the defined value for the ISO standard man, in terms of height and weight (see ISO 8996).

Table 5 comprises values for a person with a body surface area, A_{Du}, of 2,11 m^2 (e.g. H_b = 1,88 m and W_b = 85 kg). This value may be representative for the men in many European and North American populations.

1) Excel Analysis Toolpak is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.

Table 3 — Estimation of minute volume and peak inspiratory flow rate values for conditions of speech and no speech for a person with a body surface area of 1,69 m²

Class	Average metabolic rate W/m²	Oxygen consumption V_{O_2} l/min (STPD)	Minute volume V_E l/min (BTPS)	$V_E + 2S_E$ l/min (BTPS)	Peak flow rate (no speech)[a] l/s (BTPS)	Peak flow rate (speech)[b] l/s (BTPS)
1	65	0,315	10	13	0,79	2,10
2	100	0,485	15	20	1,14	2,64
3	165	0,800	25	33	1,72	3,43
4	230	1,115	36	46	2,27	4,08
5	290	1,406	45	58	2,76	4,61
6	400	1,939	62	80	3,60	5,46
7	475	2,302	73	95	4,16	5,98
8	600	2,908	93	121	5,05	6,76

NOTE Values are calculated for a person with a body surface area of 1,69 m² (1,7 m and 60 kg).

[a] Peak inspiratory flow rate calculated from $V_E + 2S_E$ using Formula (12).

[b] Peak inspiratory flow rate calculated from $V_E + 2S_E$ using Formula (13).

Table 4 — Estimation of minute volume and peak inspiratory flow rate values for conditions of speech and no speech for a person with a body surface area of 1,84 m²

Class	Average metabolic rate W/m²	Oxygen consumption V_{O_2} l/min (STPD)	Minute volume V_E l/min (BTPS)	$V_E + 2S_E$ l/min (BTPS)	Peak flow rate (no speech)[a] l/s (BTPS)	Peak flow rate (speech)[b] l/s (BTPS)
1	65	0,344	11	14	0,85	2,20
2	100	0,528	17	22	1,22	2,76
3	165	0,872	28	36	1,85	3,59
4	230	1,215	39	50	2,44	4,27
5	290	1,533	49	64	2,96	4,83
6	400	2,114	67	88	3,87	5,72
7	475	2,510	80	104	4,47	6,26
8	600	3,171	101	132	5,43	7,07

NOTE Values are calculated for a person with a body surface area of 1,84 m² (1,75 m and 70 kg).

[a] Peak inspiratory flow rate calculated from $V_E + 2S_E$ using Formula (12).

[b] Peak inspiratory flow rate calculated from $V_E + 2S_E$ using Formula (13).

Table 5 — Estimation of minute volume and peak inspiratory flow rate values for conditions of speech and no speech, for a person with a body surface area of 2,11 m²

Class	Average metabolic rate W/m²	Oxygen consumption V_{O_2} l/min (STPD)	Minute volume V_E l/min (BTPS)	$V_E + 2S_E$ l/min (BTPS)	Peak flow rate (no speech)[a] l/s (BTPS)	Peak flow rate (speech)[b] l/s (BTPS)
1	65	0,393	13	16	0,95	2,36
2	100	0,605	19	25	1,37	2,96
3	165	0,997	32	41	2,07	3,85
4	230	1,390	44	58	2,73	4,59
5	290	1,753	56	73	3,31	5,18
6	400	2,418	77	100	4,33	6,13
7	475	2,872	91	119	5,00	6,71
8	600	3,627	116	150	6,07	7,59

NOTE Values are calculated for a person with a body surface area of 2,11 m² (1,88 m and 85 kg).

[a] Peak inspiratory flow rate calculated from $V_E + 2S_E$ using Formula (12).

[b] Peak inspiratory flow rate calculated from $V_E + 2S_E$ using Formula (13).

Annex A
(informative)

Examples for the use of data

A.1 Correction of body size

Tables 3, 4, and 5 provide values for persons of different body sizes. They are characterized by their body weight and height. It is possible to derive sets of values that apply to specific populations once they are defined by body size characteristics. Based on height and weight for a representative sample of the population, the body surface area can be determined. Oxygen consumption, minute ventilation, and PIFR are then calculated in accordance with the procedure described in 7.2.

A.2 Example of activities

Table A.1 gives examples of typical activities or types of work and the associated metabolic rates, in W/m^2. For each level of metabolic rate, there is an associated value for the required oxygen consumption by the active person. This value depends on body size. The values in Tables 3, 4, and 5 are calculated for three populations of body sizes characterized by their body weight and height.

The values given for classes 1 to 5 are average values for a shift comprised of work and break elements. This type of work is repeated every day and is associated with an individual workload of less than 50 % of the maximal capacity. The examples shown for classes 1 to 5 in Table A.1 are derived from ISO 8996 and do not include the use of respiratory protective devices. When respiratory protective devices are needed in this kind of work, the workload differs (e.g. depending on breathing resistance and weight of equipment). If the same external work is required (e.g. walking at 5 km/h), the addition of a compressed air breathing apparatus, weighing approximately 15 kg, may increase the oxygen consumption by 10 % to 20 %; as a result, the work belongs to a higher class and the required minute ventilation and peak flow rates become higher. Alternatively, the use of a respiratory protective device may require a reduction of the external work in order to remain within the same class.

The values for classes 6 to 8 are the average values for the specified work period and assume continuous work without breaks. In most cases of emergency and rescue work, people wear personal protective equipment and/or RPD, which add to the metabolic rate. In this kind of work, the individual often paces himself and the final load is determined by the work capacity of the individual. The classes represent workloads from 50 % to almost 100 % of the maximal individual capacity.

A work operation of the type performed in fire and rescue services may require work bouts of various intensities over a period of 1 h to 2 h. If work of classes 7 and 8 occurs once or several times, it needs to be interspaced by periods of sufficient length for the person to recover. The recovery period may comprise rest pauses or work periods of significantly lighter work. The individual will need to adjust his pacing in every work bout in order to be able to cope with the overall task. Age, physical fitness, heat, hydration level, and other factors determine the individual’s ability to recover quickly.

Table A.1 — Classification of metabolic rate and examples of corresponding activities

Class	Average metabolic rate Wm^{-2}	Examples of work and activities
1	65	Resting.
2	100	Average for full work shifts including breaks. Sitting at ease: light manual work (writing; typing; drawing; sewing; bookkeeping); 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 2,5 km/h).
3	165	Average for full work shifts including breaks. 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 a 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 2,5 km/h to 5,5 km/h; forging).
4	230	Average for full work shifts including breaks. Intense arm and trunk work (carrying heavy material; shovelling; sledgehammer work; sawing; planning 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).
5	290	Average for full work shifts including breaks. Very intense activity at a fast 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).
6	400	Continuous work for up to 2 h without breaks. Safety and rescue work with heavy equipment and/or personal protective equipment; mine or tunnel escape; fit individuals pacing themselves at 50 % to 60 % of their maximal aerobic capacity; walking quickly or running with protective equipment and/or tools and goods; walking at 5 km/h and 10 % elevation.
7	475	Continuous work for up to 15 min without breaks. Rescue and firefighting work at high intensity; fit and well-trained individuals pacing themselves at 70 % to 80 % of their maximal aerobic capacity; searching contaminated spaces; crawling under and climbing over obstacles; removing debris; carrying a hose; walking at 5 km/h and 15 % elevation.
8	600	Continuous work for less than 5 min without breaks. Rescue and firefighting work at maximal intensity; fit and well-trained individuals pacing themselves at 80 % to 90 % of their maximal physical work capacity; climbing stairs and ladders at high speed; removing and carrying victims; walking at 5 km/h and 20 % elevation.

NOTE 1 Table modified from ISO 8996:2004, Table A.2.

NOTE 2 Classes 1 to 5 describe activities of an everyday nature that can be repeated several times a day, 5 days a week, e.g. in industrial work. Values are mean values for a shift including breaks.

NOTE 3 Classes 6 to 8 describe time-limited activities, which may be repeated during safety, rescue, and firefighting work. Values for classes 6 to 8 are the average for the work period only and include the use of respiratory protective devices.

A.3 Use of tabulated values

The type of activity is identified in Table A.1 and the associated value for metabolic rate is determined. The required oxygen consumption for this metabolic rate is determined for the appropriate user population (body size). Oxygen consumption determines the required minute ventilation and the anticipated peak inspiratory flow rate within each breath. The values for minute ventilation and peak flow rates are among the determinants of the requirements on respiratory protective devices for use under the defined type of activity.

Some measurements of expired air are obtained under actual laboratory conditions with regard to temperature and pressure. Expired air is assumed to be saturated under these conditions, e.g. when volumes are measured in a spirometer, hence the measured values are expressed in ATPS. Values for minute ventilation and peak flow rates are given in BTPS.

For practical testing of properties related to the performance of equipment on the inspiratory side, the values should be converted to laboratory conditions defined by ATPH, i.e. actual ambient temperature, atmospheric pressure, and water vapour pressure.

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