TECHNICAL SPECIFICATION

ISO/TS 16976-4

First edition
2012-06-15

Respiratory protective devices — Human factors —

Part 4: Work of breathing and breathing resistance: Physiologically based limits

Appareils de protection respiratoire — Facteurs humains —

Partie 4: Travail de respiration et de résistance à la respiration: Limites physiologiques

Reference number
ISO/TS 16976-4:2012(E)

Contents

Page

Foreword

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

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. 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.

In other circumstances, particularly when there is an urgent market requirement for such documents, a technical committee may decide to publish other types of document:

— an ISO Publicly Available Specification (ISO/PAS) represents an agreement between technical experts in an ISO working group and is accepted for publication if it is approved by more than 50 % of the members of the parent committee casting a vote;

— an ISO Technical Specification (ISO/TS) represents an agreement between the members of a technical committee and is accepted for publication if it is approved by 2/3 of the members of the committee casting a vote.

An ISO/PAS or ISO/TS is reviewed after three years in order to decide whether it will be confirmed for a further three years, revised to become an International Standard, or withdrawn. If the ISO/PAS or ISO/TS is confirmed, it is reviewed again after a further three years, at which time it must either be transformed into an International Standard or be withdrawn.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TS 16976-4 was prepared by Technical Committee ISO/TC 94, *Personal Safety — Protective clothing and equipment*, Subcommittee SC 15, *Respiratory protective devices*.

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*

— *Part 2: Anthropometrics*

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

— *Part 4: Work of breathing and breathing resistance: Physiologically based limits*

The following parts are under preparation:

— *Part 5: Thermal effects*

— *Part 7: Hearing and speech*

— *Part 8: Ergonomic factors*

Introduction

A respiratory protective device (RPD) is designed to offer protection from the inhalation of hazardous substances. However, this protection requires extra effort by the respiratory muscles as they need to generate higher pressures to overcome the associated respiratory loads imposed by the RPD.

Respiratory protective devices — Human factors —

Part 4:
Work of breathing and breathing resistance: Physiologically based limits

1 Scope

This Technical Specification describes how to calculate the work performed by a person's respiratory muscles with and without the external respiratory impediments that are imposed by RPD of all kinds, except diving equipment. This Technical Specification describes how much additional impediment people can tolerate and contains values that can be used to judge the acceptability of an RPD.

NOTE These calculations are explained in some textbooks on respiratory physiology (in the absence of an RPD), but most omit them or are incomplete in their explanations.

2 Normative references

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

ISO 16972, *Respiratory protective devices — Terms, definitions, graphical symbols and units of measurement*

ISO/TS 16976-1, *Respiratory protective devices — Human factors — Part 1: Metabolic rates and respiratory flow rates*

3 Terms and definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 16972 and the following apply.

3.1.1
body temperature pressure saturated
BTPS
standard condition for the expression of ventilation parameters

NOTE 1 Body temperature (37 °C), ambient pressure and water vapour pressure (6,27 kPa) in saturated air.

NOTE 2 Adapted from ISO 16972.

3.1.2
compliance
change in volume of the human lung that results from a change in pressure, measured in l kPa^{-1}

NOTE This term is the typical term for the elastic behaviour of the lungs and chest. **Compliance** is the inverse of **elastance**.

3.1.3
elastance
change in pressure that results from a given volume change of the human lung, measured in kPa/l

NOTE This term is the typical term for the elastic behaviour of an RPD. **Elastance** is the inverse of **compliance.**

3.1.4
relaxation volume
lung volume when respiratory muscles are relaxed, i.e. the volume at the beginning of an inspiration, also known as functional residual capacity (FRC) and expiratory reserve volume (ERV)

3.1.5
tidal volume
V_T
volume of a breath, measured in litres BTPS

3.1.6
vital capacity
VC
volume of the largest breath a person can take, i.e. the volume difference between a maximum inspiration and a maximum expiration, measured in litres BTPS

3.1.7
work of breathing
WOB
work required for an entire breathing cycle, measured in Joules

NOTE Adapted from ISO 16972.

3.1.8
work of breathing per tidal volume
WOB/V_T
normalized WOB (equivalent to volume-averaged pressure), measured in Joules per litre = kPa

3.2 Symbols and abbreviated terms

BTPS body temperature pressure saturated

ERV expiratory reserve volume

FRC functional residual capacity

RPD respiratory protective device

VC vital capacity

WOB work of breathing

p_{el} pressure required to overcome the elastance

p_{aw} pressure required to overcome the flow resistance of the airways

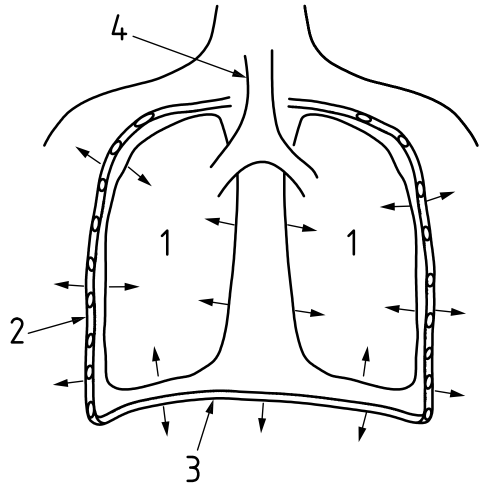
$p_{i,ext}$ pressure required to overcome the inspiratory flow resistance of the RPD

4 Pressure and volume changes during breathing

4.1 Pressure and volume changes in the absence of an RPD

During an inspiration the inspiratory muscles contract which makes the chest expand and the diaphragm flatten. This action causes the lungs to expand to a larger volume. Even in the absence of flow resistance, it takes a certain pressure to expand the chest and lungs. The term used in respiratory physiology for this elastic behaviour is **compliance**. The term **compliance** is also used in laws and regulations; to avoid confusion with this use of the word, the remainder of this Technical Specification will use the term **elastance** instead. By definition, **elastance** is the inverse of **compliance**. **Elastance** describes how much an elastic material changes when a force or a pressure is applied.

Figure 1 shows the lungs (Key 1) inside the chest wall (Key 2) and diaphragm (Key 3). The lungs are connected to the airway (Key 4). The elastance of the lungs tries to act to shrink them (shown by the arrows), similarly to a stretched balloon trying to shrink in volume. The elastance of the chest acts by trying to expand it. Thus, in the absence of muscle effort, the forces on the chest and lungs oppose each other and will, at some volume, be equal and opposite and come to a position of rest. The lung volume at which this happens is referred to as the relaxation volume. During an inhalation the chest wall expands and the diaphragm (Key 3) moves downwards.



Key

1 lungs

2 chest wall

3 diaphragm

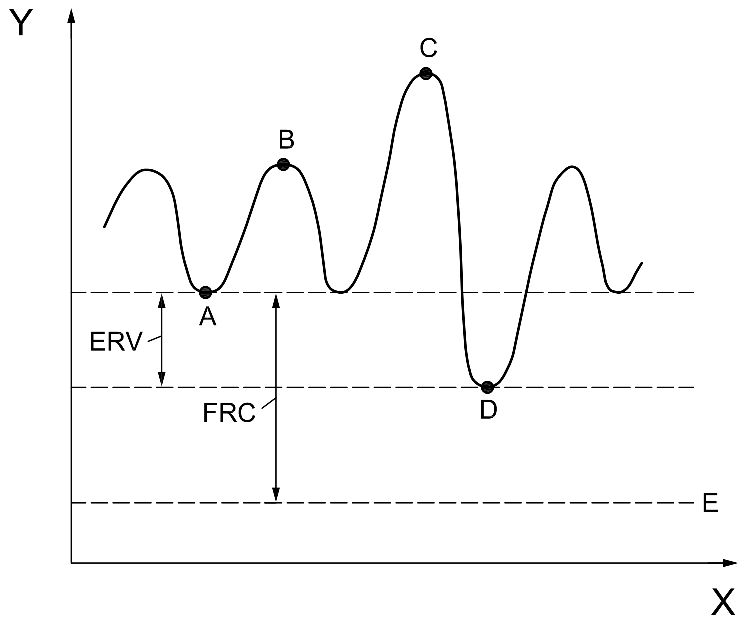
4 airway

Figure 1 — Schematic cross-section of a person's chest and lungs

Figure 2 illustrates/defines changes in breathing. An inspiration is shown to start at point A and the lung volume increases until it reaches its end, point B, where the following expiration starts. The volume difference between points A and B is the size of the breath, referred to as the tidal volume.

A maximum inspiration is shown at point C and a maximum expiration at point D. The volume difference between these two points is the maximum volume change achievable and is referred to as the vital capacity, VC. The range of VC varies from 3 l to 6 l and depends on a person's age, height and gender. Even with a maximum expiratory effort some volume remains in the lungs. Had the lungs been able to be emptied completely the volume illustrated by line E would have been reached.

Point A is the point where the respiratory muscles are relaxed and that volume is referred to as "relaxation volume". Another term used for this point is "expiratory reserve volume", ERV, which can be calculated as the difference between points A and D. A third term used is "functional residual capacity", FRC, which is the volume difference between points A and E.



Key

X time

Y lung volume

A start of an inspiration

B end of an inspiration and start of the following expiration

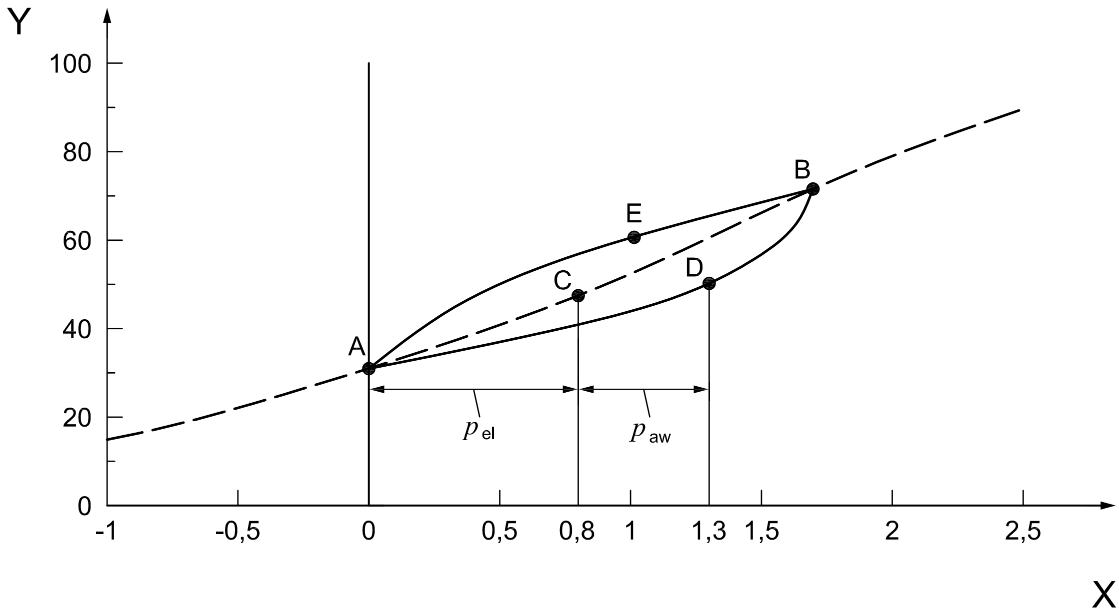
C maximum inspiration

D maximum expiration

E lungs and chest completely empty

Figure 2 — Definitions of volume changes

In order to inhale, effort is required to overcome the combined elastance of the chest and lungs, as well as the flow resistance in the airways. Figure 3 illustrates the pressure generated and the resulting volume changes.



Key

X alveolar pressure, in kPa

Y volume, in percent of VC

A start of an inspiration and end of the following expiration

B end of an inspiration and start of the following expiration

C point on the elastance line partway through an inspiration

D point on the combined elastance and pressure drop line during an inspiration

E point on the combined elastance and pressure drop line during an expiration

NOTE The interrupted line is not a straight line but becomes less steep at low and high volume.

Figure 3 — Lung volume versus pressure in the absence of an RPD (see 4.1 for details)

For a person, the muscles generate the pressure which in turn generates a change in lung volume. Therefore, the pressure is the independent variable and the volume is the dependent one. It is the opposite for an RPD, for which it is the change in volume in the lungs (i.e. gas flow) that generates pressure across a flow resistance. At the beginning of the inspiration (point A in Figure 3) no pressure is generated, i.e. it is the relaxation volume. At the end of the inspiration (point B) the greatest volume has been achieved, called the tidal volume, V_T. The interrupted line shows the interaction of the pressures and volumes from the combined elastance of the chest and lungs. For instance, at point C the elastance requires a pressure of about 0,8 kPa to change the volume to about 50 % of VC; values given are based on a VC of 4 l and a typical textbook value for elastance of 1 kPa/l. The lower solid line ADB shows the total pressure (elastance plus pressure due to flow resistance) generated by the respiratory muscles and the resulting change in volume during the inspiration. The expiration follows the upper solid line BEA. To reach the volume of 50 % VC during inspiration (point D), a total pressure of about 1,3 kPa is required. This is the sum of the pressure of about 0,8 kPa required for the total elastance, p_{el}, and an additional 0,5 kPa (approximately) for the flow resistance of the airway, p_{aw}. Towards the end of the inspiration the flow slows down and the pressure drop due to flow resistance decreases and the inspiration ends at point B where there is no flow. The tidal volume becomes 70 % VC – 30 % VC = 40 % VC. The inspiratory and expiratory curves combine to form a volume-pressure loop.

At the end of the inspiration (point B) pressure is stored due to the total elastance. During low breathing rates this pressure is sufficient to move the gas out during the following expiration. Thus, such an expiration is said to be passive because the expiratory muscles are inactive. However, the inspiratory muscles are active by controlling the flow. When more ventilation is desired, the pressure due to elastance is not sufficient and the expiratory muscles take an active part.

