

Industrial fans — Performance testing using standardized airways

ICS 23.120

National foreword

This British Standard is the UK implementation of EN ISO 5801:2008. It is identical to ISO 5801:2007, incorporating corrigendum 1:2008. It supersedes BS ISO 5801:2007 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee MCE/17, Fans for general purposes.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 29 February 2008

© BSI 2010

ISBN 978 0 580 63724 7

Amendments/corrigenda issued since publication

Date	Comments
31 May 2009	This corrigendum renumbers BS ISO 5801:2007 as BS EN ISO 5801:2008
31 October 2010	Implementation of ISO corrigendum July 2008. Correction of equation in Note 2 for Figure 19

English Version

Industrial fans - Performance testing using standardized airways
(ISO 5801:2007 including Cor 1:2008)

Ventilateurs industriels - Essais aérauliques sur circuits
normalisés (ISO 5801:2007, Cor 1:2008 inclus)

This European Standard was approved by CEN on 2 October 2008.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN Management Centre or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN Management Centre has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.



EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: rue de Stassart, 36 B-1050 Brussels

Foreword

The text of ISO 5801:2007 including Cor 1:2008 has been prepared by Technical Committee ISO/TC 117 “Industrial fans” of the International Organization for Standardization (ISO) and has been taken over as EN ISO 5801:2008 by Technical Committee CEN/TC 156 “Ventilation for buildings” the secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by April 2009, and conflicting national standards shall be withdrawn at the latest by April 2009.

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

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

Endorsement notice

The text of ISO 5801:2007 including Cor 1:2008 has been approved by CEN as a EN ISO 5801:2008 without any modification.

Contents

Page

Foreword.....	vii
Introduction	viii
1 Scope	1
2 Normative references	1
3 Terms and definitions.....	1
4 Symbols and units	16
4.1 Symbols	16
4.2 Subscripts	19
5 General.....	19
6 Instruments for pressure measurement.....	20
6.1 Barometers	20
6.2 Manometers	21
6.3 Damping of manometers.....	21
6.4 Checking of manometers	21
6.5 Position of manometers	22
7 Determination of average pressure in an airway.....	22
7.1 Methods of measurement	22
7.2 Use of wall tapplings	22
7.3 Construction of tapplings	22
7.4 Position and connections	23
7.5 Checks for compliance.....	23
7.6 Use of Pitot-static tube.....	23
8 Measurement of temperature	24
8.1 Thermometers	24
8.2 Thermometer location	24
8.3 Humidity.....	24
9 Measurement of rotational speed	25
9.1 Fan shaft speed.....	25
9.2 Acceptable instruments	25
10 Determination of power input.....	25
10.1 Measurement accuracy	25
10.2 Fan shaft power	25
10.3 Determination of fan shaft power by electrical measurement	25
10.4 Impeller power.....	26
10.5 Transmission systems	26
11 Measurement of dimensions and determination of areas	26
11.1 Flow-measurement devices	26
11.2 Tolerance on dimensions	26
11.3 Determination of cross-sectional area	27
12 Determination of air density, humid gas constant and viscosity	27
12.1 Density of air in the test enclosure at section x	27
12.2 Determination of vapour pressure	28
12.3 Determination of air viscosity	30
13 Determination of flow rate	31
13.1 General.....	31

13.2	In-line flowmeters (standard primary devices).....	31
13.3	Traverse methods	32
14	Calculation of test results	34
14.1	General	34
14.2	Units	34
14.3	Temperature.....	34
14.4	Mach number and reference conditions.....	36
14.5	Fan pressure.....	40
14.6	Calculation of stagnation pressure at a reference section of the fan from gauge pressure, p_{ex} , measured at a section x of the test duct	43
14.7	Inlet volume flow rate	44
14.8	Fan air power and efficiency.....	44
15	Rules for conversion of test results.....	52
15.1	Laws on fan similarity.....	52
15.2	Conversion rules	54
16	Fan characteristic curves.....	57
16.1	General.....	57
16.2	Methods of plotting.....	58
16.3	Characteristic curves at constant speed.....	58
16.4	Characteristic curves at inherent speed.....	58
16.5	Characteristic curves for adjustable-duty fan.....	59
16.6	Complete fan characteristic curve	60
16.7	Test for a specified duty.....	61
17	Uncertainty analysis	62
17.1	Principle	62
17.2	Pre-test and post-test analysis	62
17.3	Analysis procedure	62
17.4	Propagation of uncertainties	62
17.5	Reporting uncertainties	63
17.6	Maximum allowable uncertainties measurement	63
17.7	Maximum allowable uncertainty of results.....	64
18	Selection of test method	65
18.1	Classification	65
18.2	Installation categories	65
18.3	Test report.....	65
18.4	User installations	66
18.5	Alternative methods.....	66
18.6	Duct simulation	66
19	Installation of fan and test airways	66
19.1	Inlets and outlets.....	66
19.2	Airways.....	66
19.3	Test enclosure	67
19.4	Matching fan and airway	67
19.5	Outlet area.....	67
20	Carrying out the test	67
20.1	Working fluid	67
20.2	Rotational speed	67
20.3	Steady operation	67
20.4	Ambient conditions.....	68
20.5	Pressure readings.....	68
20.6	Tests for a specified duty.....	68
20.7	Tests for a fan characteristic curve	68
20.8	Operating range	68
21	Determination of flow rate.....	68
21.1	Multiple nozzle.....	68
21.2	Conical or bellmouth inlet.....	68

21.3	Orifice plate	68
21.4	Pilot-static tube traverse (see ISO 3966 and ISO 5221)	69
22	Determination of flow rate using multiple nozzles	69
22.1	Installation	69
22.2	Geometric form	69
22.3	Inlet zone	70
22.4	Multiple-nozzle characteristics	70
22.5	Uncertainty	72
23	Determination of flow rate using a conical or bellmouth inlet	73
23.1	Geometric form	73
23.2	Screen loading	74
23.3	Inlet zone	75
23.4	Conical inlet performance	75
23.5	Bellmouth inlet performance	75
23.6	Uncertainties	77
24	Determination of flow rate using an orifice plate	77
24.1	Installation	77
24.2	Orifice plate	77
24.3	Ducts	81
24.4	Pressure tapplings	81
24.5	Calculation of mass flow rate	81
24.6	Reynolds number	82
24.7	In-duct orifice with D and $D/2$ taps [see Figure 20 a) and ISO 5167-1]	82
24.8	Outlet orifice with wall tapplings [see Figure 20 c) and e)]	86
25	Determination of flow rate using a Pitot-static tube traverse	88
25.1	General	88
25.2	Pitot-static tube	88
25.3	Limits of air velocity	93
25.4	Location of measurement points	93
25.5	Determination of flow rate	94
25.6	Flow rate coefficient	94
25.7	Uncertainty of measurement	95
26	Installation and setup categories	95
26.1	Category A: free inlet and free outlet	95
26.2	Category B: free inlet and ducted outlet	95
26.3	Category C: ducted inlet and free outlet	96
26.4	Category D: ducted inlet and ducted outlet	96
26.5	Test installation type	96
27	Flow straighteners	96
27.1	Types of straightener	97
27.2	Rules for use of a straightener	98
28	Common-segment airways for ducted fan installations	99
28.1	Common segments	99
28.2	Common segment at fan outlet	99
28.3	Common segment at fan inlet	101
28.4	Outlet duct simulation	103
28.5	Inlet duct simulation	103
28.6	Loss allowances for standardized airways	104
29	Standardized test chambers	107
29.1	Test chamber	107
29.2	Variable supply and exhaust systems	112
29.3	Standardized inlet test chambers	112
29.4	Standardized outlet test chambers	115
30	Standard methods with test chambers — Category A installations	118
30.1	Types of fan setup	118

30.2	Inlet-side test chambers	118
30.3	Outlet-side test chambers	131
31	Standard test methods with outlet-side test ducts — Category B installations	136
31.1	Types of fan setup	136
31.2	Outlet-side test ducts with antiwhirl device	137
31.3	Outlet chamber test ducts without antiwhirl device	149
32	Standard test methods with inlet-side test ducts or chambers — Category C installations	156
32.1	Types of fan setup	156
32.2	Inlet-side test ducts	157
32.3	Inlet-side test chambers	170
33	Standard methods with inlet- and outlet-side test ducts — Category D installations	180
33.1	Types of fan setup	180
33.2	Installation category B with outlet antiwhirl device and with an additional inlet duct or inlet-duct simulation	184
33.3	Installation category B without outlet antiwhirl device nor common segment, modified with addition of an inlet duct or inlet-duct simulation	190
33.4	Installation category C with common inlet duct, modified with the addition of an outlet common segment with antiwhirl device	193
33.5	Installation category C, modified with the addition of an outlet-duct simulation without antiwhirl device	197
Annex A (normative)	Fan pressure and fan installation category	205
Annex B (normative)	Fan-powered roof exhaust ventilators	209
Annex C (informative)	Chamber leakage test procedure	211
Annex D (informative)	Fan outlet elbow in the case of a non-horizontal discharge axis	217
Annex E (informative)	Electrical input power consumed by a fan installation	220
Annex F (informative)	Preferred methods of performance testing	227
Bibliography		228

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.

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 5801 was prepared by Technical Committee ISO/TC 117, *Industrial fans*.

This second edition cancels and replaces the first edition (ISO 5801:1997), which has been technically revised.

Introduction

This International Standard is the result of almost 30 years of discussion, comparative testing and detailed analyses by leading specialists from the fan industry and research organizations throughout the world.

It was demonstrated many years ago that the codes for fan performance testing established in different countries do not always lead to the same results.

The need for an International Standard has been evident for some time and Technical Committee ISO/TC 117 started its work in 1963. Important progress has been achieved over the years and, although the International Standard itself was not yet published, the successive revisions of various national standards led to much better agreement among them.

It has now become possible to complete this International Standard by agreement on certain essential points. It must be borne in mind that the test equipment, especially for large fans, is very expensive and it was necessary to include in this International Standard many setups from various national codes in order to authorize their future use. This explains the sheer volume of this document.

Essential features of this International Standard are as follows:

a) Categories of installation

Since the connection of a duct to a fan outlet and/or inlet modifies its performance, it has been agreed that four standard installation categories should be recognized (see 18.2).

A fan adaptable to more than one installation category will have more than one standardized performance characteristic. Users should select the installation category closest to their application.

b) Common parts

The differences obtained by testing the same fan according to various test codes depend chiefly on the flow pattern at the fan outlet and, while often minor, can be of substantial significance. There is general agreement that it is essential that all standardized test airways to be used with fans have portions in common adjacent to the fan inlet and/or outlet sufficient to ensure consistent determination of fan pressure.

Geometric variations of these common segments are strictly limited.

However, conventional agreement has been achieved for some particular situations:

- 1) For fans where the outlet swirl is less than 15° , i.e. centrifugal, cross-flow or vane-axial fans, it is possible to use a simplified outlet duct without straightener when discharging to the atmosphere or to a measuring chamber. If there is any doubt about the degree of swirl, then a test should be performed to establish how much is present.
- 2) For large fans (outlet diameter exceeding 800 mm), it may be difficult to carry out the tests with standardized common airways at the outlet including a straightener. In this case, by mutual agreement between the parties concerned, the fan performance may be measured using a duct of length $3D$ on the outlet side. Results obtained in this way may differ to some extent from those obtained using the normal category D installation, especially if the fan produces a large swirl. Establishment of a possible value of differences, is still a subject of research.

c) Calculations

Fan pressure is defined as the difference between the stagnation pressure at the outlet of the fan and the stagnation pressure at the inlet of the fan. The compressibility of air must be taken into account when high accuracy is required. However, simplified methods may be used when the reference Mach number does not exceed 0,15.

A method for calculating the stagnation pressure and the fluid or static pressure in a reference section of the fan, which stemmed from the work of the ad hoc group of Subcommittee 1 of ISO/TC 117, is given in Annex C.

Three methods are proposed for calculation of the fan power output and efficiency. All three methods give very similar results (difference of a few parts per thousand for pressure ratios equal to 1,3).

d) Flow rate measurement

Determination of flow rate has been completely separated from the determination of fan pressure. A number of standardized methods may be used.

Industrial fans — Performance testing using standardized airways

1 Scope

This International Standard deals with the determination of the performance of industrial fans of all types except those designed solely for air circulation, e.g. ceiling fans and table fans.

Estimates of uncertainty of measurement are provided and rules for the conversion, within specified limits, of test results for changes in speed, gas handled and, in the case of model tests, size, are given.

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 3966, *Measurement of fluid flow in closed conduits — Velocity area method using Pitot static tubes*

ISO 5167-1, *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full — Part 1: General principles and requirements*

ISO 5168, *Measurement of fluid flow — Procedures for the evaluation of uncertainties*

ISO 5221, *Air distribution and air diffusion — Rules to methods of measuring air flow rate in an air handling duct*

IEC 60034-2:1972, *Rotating electrical machines — Part 2: Methods for determining losses and efficiency of rotating electrical machinery from tests (excluding machines for traction vehicles)*

IEC 60051-2, *Direct acting indicating analogue electrical measuring instruments and their accessories — Part 2: Special requirements for ammeters and voltmeters*

IEC 60051-3, *Direct acting indicating analogue electrical measuring instruments and their accessories — Part 3: Special requirements for wattmeters and varmeters*

IEC 60051-4, *Direct acting indicating analogue electrical measuring instruments and their accessories — Part 4: Special requirements for frequency meters*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5168 and the following apply.

NOTE All the symbols used in this International Standard are listed with their units in Clause 4.

3.1 area of the conduit section

A_x
area of the conduit at section x

3.2 fan inlet area

A_1
surface plane bounded by the upstream extremity of the air-moving device

NOTE Fan inlet area is, by convention, taken as the gross area in the inlet plane inside the casing.

3.3 fan outlet area

A_2
surface plane bounded by the downstream extremity of the air-moving device

NOTE Fan outlet area is, by convention, taken as the gross area in the outlet plane inside the casing.

3.4 temperature

T
air or fluid temperature measured by a temperature sensor

NOTE Temperature is expressed in degrees Celsius.

3.5 absolute temperature

θ
thermodynamic temperature

$$\theta = T + 273,15$$

NOTE In this document, θ represents the absolute temperature in kelvin and T the temperature in degrees Celsius.

3.6 specific gas constant

R
for an ideal dry gas, the equation of state is written

$$\frac{p}{\rho} = R\theta$$

NOTE For dry air, $R = 287 \text{ J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$.

3.7 isentropic exponent

κ
for an ideal gas and an isentropic process

$$\kappa = \gamma = \frac{c_p}{c_v}$$

$$\frac{p}{\rho^\kappa} = \text{constant}$$

NOTE For atmospheric air, $\kappa = 1,4$.

3.8 specific heat capacity at constant pressure

c_p
for an ideal gas

$$c_p = \frac{k}{k-1} R$$

NOTE Specific heat capacity is normally expressed in joules per (kilogram kelvin).

3.9 specific heat capacity at constant volume

c_V
for an ideal gas

$$c_V = \frac{1}{k-1} R$$

NOTE Specific heat capacity is normally expressed in joules per (kilogram kelvin).

3.10 compressibility factor

Z

NOTE 1 For an ideal gas, $Z = 1$.

NOTE 2 For a real gas,

$$Z = \frac{p}{\rho R \theta}$$

where

Z is a function of the ratios p/p_c and θ/θ_c where:

p_c is the critical pressure of the gas;

θ_c is the critical temperature of the gas.

3.11 stagnation temperature at a point

θ_{sg}
absolute temperature which exists at an isentropic stagnation point for ideal gas flow without addition of energy or heat

NOTE 1 The stagnation temperature is constant along an airway and, for an inlet duct, is equal to the absolute ambient temperature in the test enclosure.

NOTE 2 Stagnation temperature is expressed in degrees Celsius.

NOTE 3 For Mach numbers less than 0,122 obtained for standard air with duct velocities less than 40 m/s, the stagnation temperature is virtually the same as the total temperature.

3.12 fluid temperature at a point static temperature at a point

θ
absolute temperature registered by a thermal sensor moving at the fluid velocity

NOTE 1 For real gas flow

$$\Theta = \Theta_{\text{sg}} - \frac{v^2}{2c_p}$$

where v is the fluid velocity, in metres per second, at a point.

NOTE 2 These temperatures are expressed in degrees Celsius.

NOTE 3 In a duct, when the velocity increases, the static temperature decreases.

3.13 dry bulb temperature

T_d

air temperature measured by a dry temperature sensor in the test enclosure, near the fan inlet or airway inlet

NOTE This temperature is expressed in degrees Celsius.

3.14 wet bulb temperature

T_w

air temperature measured by a temperature sensor covered by a water-moistened wick and exposed to air in motion

NOTE 1 When properly measured, it is a close approximation to the temperature of adiabatic saturation.

NOTE 2 This temperature is expressed in degrees Celsius.

3.15 stagnation temperature at a section x

$\Theta_{\text{sg}x}$

mean value, over time, of the stagnation temperature averaged over the area of the specified airway cross-section

NOTE This temperature is expressed in kelvin.

3.16 static or fluid temperature at a section x

Θ_x

mean value, over time, of the static or fluid temperature averaged over the area of the specified airway cross-section

NOTE This temperature is expressed in kelvin.

3.17 absolute pressure at a point absolute pressure

p

pressure, measured with respect to absolute zero pressure, which is exerted at a point at rest relative to the air around it

NOTE This pressure is normally expressed in pascals.

3.18 atmospheric pressure

p_a

absolute pressure of the free atmosphere at the mean altitude of the fan

NOTE This pressure is normally expressed in pascals.

3.19 gauge pressure

p_e

value of the pressure when the datum pressure is the atmospheric pressure at the point of measurement

NOTE 1 Gauge pressure may be negative or positive

$$p_e = p - p_a$$

NOTE 2 This pressure is normally expressed in pascals.

3.20 absolute stagnation pressure at a point

p_{sg}

absolute pressure which would be measured at a point in a flowing gas if it were brought to rest via an isentropic process given by the following equation:

$$p_{sg} = p \left(1 + \frac{\kappa - 1}{2} Ma^2 \right)^{\frac{\kappa}{\kappa - 1}}$$

NOTE 1 Ma is the Mach number at this point (see 3.23).

NOTE 2 This pressure is normally expressed in pascals.

NOTE 3 For Mach numbers less than 0,122 obtained for standard air with duct velocities less than 40 m/s, the stagnation pressure is virtually the same as the total pressure.

3.21 Mach factor

f_{Mx}

correction factor applied to the dynamic pressure at a point, given by the expression

$$f_{Mx} = \frac{p_{sg} - p}{p_d}$$

NOTE The Mach factor may be calculated by:

$$f_{Mx} = 1 + \frac{Ma^2}{4} + \frac{(2 - \kappa) Ma^4}{24} + \frac{(2 - \kappa)(3 - 2\kappa) Ma^6}{192} + \dots$$

3.22 dynamic pressure at a point

p_d

pressure calculated from the velocity and the density ρ of the air at the point given by the following equation:

$$p_d = \rho \frac{v^2}{2}$$

NOTE This pressure is normally expressed in pascals.

3.23**Mach number at a point** Ma

ratio of the gas velocity at a point to the velocity of sound given by the following equation:

$$Ma = \frac{v}{\sqrt{\kappa R_w \Theta}} = \frac{v}{c}$$

where

c is the velocity of sound,

$$c = \sqrt{\kappa R_w \Theta}$$

R_w is the gas constant of humid gas.

3.24**gauge stagnation pressure at a point** p_{esg}

difference between the absolute stagnation pressure, p_{sg} , and the atmospheric pressure, p_a , given by the following equation:

$$p_{\text{esg}} = p_{\text{sg}} - p_a$$

NOTE This pressure is normally expressed in pascals.

3.25**mass flow rate** q_m

mean value, over time, of the mass of air which passes through the specified airway cross-section per unit of time

NOTE 1 The mass flow will be the same at all cross-sections within the fan airway system excepting leakage.

NOTE 2 Mass flow rate is expressed in kilograms per second.

3.26**average gauge pressure at a section x** **mean gauge pressure at a section x** p_{ex}

mean value, over time, of the gauge pressure averaged over the area of the specified airway cross-section

NOTE This pressure is normally expressed in pascals.

3.27**average absolute pressure at a section x** p_x

mean value, over time, of the absolute pressure averaged over the area of the specified airway cross-section given by the following equation:

$$p_x = p_{\text{ex}} + p_a$$

NOTE This pressure is normally expressed in pascals.

3.28**average density at a section x** ρ_x

fluid density calculated from the absolute pressure, p_x , and the static temperature, θ_x

$$\rho_x = \frac{p_x}{R_w \theta_x}$$

where R_w is the gas constant of humid gas

NOTE Density is expressed in kilograms per cubic metre.

3.29**volume flow rate at a section x** q_{Vx}

mass flow rate at the specified airway cross-section divided by the corresponding mean value, over time, of the average density at that section given by the following equation:

$$q_{Vx} = \frac{q_m}{\rho_x}$$

NOTE Volume flow rate is expressed in cubic metres per second.

3.30**average velocity at a section x** v_{mx}

volume flow rate at the specified airway cross-section divided by the cross-sectional area, A_x , given by the following equation:

$$v_{mx} = \frac{q_{Vx}}{A_x}$$

NOTE 1 This is the mean value, over time, of the average component of the gas velocity normal to that section.

NOTE 2 Average velocity is expressed in metres per second.

3.31**conventional dynamic pressure at a section x** p_{dx}

dynamic pressure calculated from the average velocity and the average density at the specified airway cross-section given by the following equation:

$$p_{dx} = \rho_x \frac{v_{mx}^2}{2} = \frac{1}{2\rho_x} \left(\frac{q_m}{A_x} \right)^2$$

NOTE 1 The conventional dynamic pressure will be less than the average of the dynamic pressures across the section.

NOTE 2 Dynamic pressure is expressed in pascals.

3.32**Mach number at a section x** Ma_x

average gas velocity divided by the velocity of sound at the specified airway cross-section given by the following equation:

$$Ma_x = v_{mx} / \sqrt{\kappa R_w \Theta_x}$$

NOTE The Mach number is dimensionless.

3.33**average stagnation pressure at a section x** p_{sgx}

sum of the conventional dynamic pressure p_{dx} corrected by the Mach factor coefficient f_{Mx} at the section and the average absolute pressure p_x given by the following equation:

$$p_{sgx} = p_x + p_{dx} f_{Mx}$$

NOTE 1 The average stagnation pressure may be calculated by the equation:

$$p_{sgx} = p_x \left(1 + \frac{\kappa - 1}{2} Ma_x^2 \right)^{\frac{\kappa}{\kappa - 1}}$$

NOTE 2 Average stagnation pressure is expressed in pascals.

3.34**gauge stagnation pressure at a section x** p_{esgx}

difference between the average stagnation pressure, p_{sgx} , at a section and the atmospheric pressure, p_a , given by the following equation:

$$p_{esgx} = p_{sgx} - p_a$$

NOTE Gauge stagnation pressure is expressed in pascals.

3.35**inlet stagnation temperature** Θ_{sg1}

absolute temperature in the test enclosure near the fan inlet at a section where the gas velocity is less than 25 m/s

NOTE 1 In this case, it is possible to consider the stagnation temperature as equal to the ambient temperature, Θ_a , given by the following equation:

$$\Theta_{sg1} = \Theta_a = T_a + 273,15$$

NOTE 2 Inlet stagnation absolute temperature is expressed in kelvins.

3.36**stagnation density** ρ_{sg1}

density calculated from the inlet stagnation pressure, p_{sg1} , and the inlet stagnation temperature, Θ_{sg1} , given by the following equation:

$$\rho_{sg1} = \frac{p_{sg1}}{R_w \Theta_{sg1}}$$

NOTE Stagnation density is expressed in kilograms per cubic metre.

3.37**inlet stagnation volume flow rate** q_{Vsg1}

mass flow rate divided by the inlet stagnation density given by the formula:

$$q_{Vsg1} = \frac{q_m}{\rho_{sg1}}$$

NOTE Inlet stagnation volume flow rate is expressed in cubic metres per second.

3.38**fan pressure** p_f

difference between the stagnation pressure at the fan outlet and the stagnation pressure at the fan inlet given by the equation:

$$p_f = p_{sg2} - p_{sg1}$$

NOTE 1 When the Mach number is less than 0,15, it is possible to use the relationship:

$$p_f = p_{tf} = p_{t2} - p_{t1}$$

NOTE 2 It is possible to refer the fan pressure to the installation category A, B, C or D.

NOTE 3 Fan pressure is expressed in pascals.

3.39**dynamic pressure at the fan outlet** p_{d2}

conventional dynamic pressure at the fan outlet calculated from the mass flow rate, the average gas density at the outlet and the fan outlet area

$$p_{d2} = \rho_2 \frac{v_{m2}^2}{2} = \frac{1}{2\rho_2} \left(\frac{q_m}{A_2} \right)^2$$

NOTE Fan dynamic pressure is expressed in pascals.

3.40**fan static pressure** p_{sf}

conventional quantity defined as the fan pressure minus the fan dynamic pressure corrected by the Mach factor as given by the following equation:

$$p_{sf} = p_{sg2} - p_{d2} \cdot f_{M2} - p_{sg1} = p_2 - p_{sg1}$$

NOTE 1 It is possible to refer the fan static pressure to the installation category A, B, C or D.

NOTE 2 Fan static pressure is expressed in pascals.

3.41**mean density** ρ_m

arithmetic mean value of inlet and outlet densities

$$\rho_m = \frac{\rho_1 + \rho_2}{2}$$

NOTE Mean density is expressed in kilograms per cubic metre.

3.42 mean stagnation density

ρ_{msg}
arithmetic mean value of inlet and outlet stagnation densities given by the following equation:

$$\rho_{\text{msg}} = \frac{\rho_{\text{sg1}} + \rho_{\text{sg2}}}{2}$$

NOTE Mean stagnation pressure is expressed in pascals.

3.43 fan work per unit mass

W_m
increase in mechanical energy per unit mass of fluid passing through the fan given by the following equation:

$$W_m = \frac{p_2 - p_1}{\rho_m} + \alpha_{A2} \frac{v_{m2}^2}{2} - \alpha_{A1} \frac{v_{m1}^2}{2}$$

NOTE 1 It is possible to calculate W_m as in 3.47, as follows:

$$W_m = \frac{P_u}{q_m}$$

NOTE 2 The value obtained differs by only a few parts per thousand from the value given by the above expression.

NOTE 3 It is possible to refer the fan work per unit mass to the installation category A, B, C or D.

NOTE 4 Fan work is expressed in joules per kilogram.

3.44 fan static work per unit mass

W_{ms}
increase in mechanical energy per unit mass of fluid passing through the fan minus the kinetic energy per unit mass imparted to the fluid, given by the following equation:

$$W_{ms} = \frac{p_2 - p_1}{\rho_m} - \alpha_{A1} \frac{v_{m1}^2}{2}$$

NOTE 1 It is possible to refer the fan static work per unit mass to the installation category A, B, C or D.

NOTE 2 Fan static work is expressed in joules per kilogram.

3.45 fan pressure ratio

r
ratio of the average absolute stagnation pressure at the outlet section of a fan to that at its inlet section as given by the following equation:

$$r = p_{\text{sg2}} / p_{\text{sg1}}$$

NOTE The fan pressure ratio is dimensionless.

3.46**compressibility coefficient** k_p

ratio of the mechanical work done by the fan on the air to the work that would be done on an incompressible fluid with the same mass flow, inlet density and pressure ratio; k_p is given by the equation:

$$k_p = \frac{Z_k \log_{10} r}{\log_{10} [1 + Z_k (r - 1)]}$$

where

$$Z_k = \frac{\kappa - 1}{\kappa} \cdot \frac{\rho_{sg1} P_r}{q_m p_f}$$

NOTE 1 The work done is derived from the impeller power on the assumption of polytropic compression with no heat transfer through the fan casing.

NOTE 2 k_p and ρ_{ms1}/ρ_{msg} differ by less than 2×10^{-3} .

NOTE 3 The compressibility coefficient is dimensionless.

NOTE 4 A second method of calculation is shown in 30.2.3.4.2, section b).

3.47**fan air power** P_u

conventional output power which is the product of the mass flow rate q_m and the fan work per unit mass W_m , or the product of the inlet volume flow rate q_{Vsg1} , the compressibility coefficient k_p and the fan pressure p_f given by the following equation:

$$P_u = q_m W_m = q_{Vsg1} \cdot p_f \cdot k_p$$

NOTE 1 It is possible to refer the fan air power to the installation category A, B, C or D.

NOTE 2 Fan air power is expressed in watts when q_m is in kilograms per second and W_m is in joules per kilogram.

NOTE 3 Fan air power is expressed in watts when q_{Vsg1} is in cubic metres per second and p_f is in pascals.

3.48**fan static air power** P_{us}

conventional output power which is the product of the mass flow rate q_m and the fan static work per unit mass W_{ms} , or the product of the inlet volume flow rate q_{Vsg1} , the compressibility coefficient k_{ps} and the fan static pressure p_{sf} ; k_{ps} is calculated using $r = p_2/p_{sg1}$

$$P_{us} = q_m W_{ms} = q_{Vsg1} \cdot k_{ps} \cdot p_{sf}$$

NOTE 1 It is possible to refer the fan static air power to the installation category A, B, C or D.

NOTE 2 The fan static air power is expressed in watts when q_m is in kilograms per second and W_{ms} is in joules per kilogram.

3.49
impeller power

P_r

mechanical power supplied to the fan impeller

NOTE Impeller power is expressed in watts.

3.50
fan shaft power

P_a

mechanical power supplied to the fan shaft

NOTE Fan shaft power is expressed in watts.

3.51
motor output power

P_o

shaft power output of the motor or other prime mover

NOTE Motor output power is expressed in watts.

3.52
motor input power

P_e

electrical power supplied at the terminals of an electric motor drive

NOTE Motor input power is expressed in watts.

3.53
rotational speed of the impeller

N

number of revolutions of the fan impeller per minute

3.54
rotational frequency of the impeller

n

number of revolutions of the fan impeller per second

3.55
tip speed of the impeller

v_p

peripheral speed of the impeller blade tips

NOTE Tip speed is expressed in metres per second.

3.56
peripheral Mach number

Ma_u

dimensionless parameter equal to the ratio of tip speed to the velocity of sound in the gas at the stagnation conditions of the fan inlet given by the following equation:

$$Ma_u = u / \sqrt{\kappa R_w \theta_{sg1}}$$

3.57**fan impeller efficiency** η_r

fan air power divided by the impeller power P_r as follows:

$$\eta_r = \frac{P_u}{P_r}$$

NOTE 1 It is possible to refer the fan impeller efficiency to the installation category A, B, C or D.

NOTE 2 Fan impeller efficiency may be expressed as a proportion of unity or as a percentage.

3.58**fan impeller static efficiency** η_{sr}

fan static power divided by the impeller power given by the equation:

$$\eta_{sr} = \frac{P_{us}}{P_r}$$

NOTE 1 It is possible to refer the fan impeller static efficiency to the installation category A, B, C or D.

NOTE 2 Fan impeller static efficiency may be expressed as a proportion of unity or as a percentage.

3.59**fan shaft efficiency** η_a

fan air power divided by the fan shaft power given by the equation:

$$\eta_a = \frac{P_u}{P_a}$$

NOTE 1 Fan shaft power includes bearing losses, while fan impeller power does not.

NOTE 2 It is possible to refer the fan shaft efficiency to the installation category A, B, C or D.

NOTE 3 Fan shaft efficiency may be expressed as a proportion of unity or as a percentage.

3.60**fan motor shaft efficiency** η_o

fan air power P_u divided by the motor output power P_o as given by the equation:

$$\eta_o = \frac{P_u}{P_o}$$

NOTE 1 It is possible to refer the fan motor shaft efficiency to the installation category A, B, C or D.

NOTE 2 Fan motor shaft efficiency may be expressed as a proportion of unity or as a percentage.

3.61**overall efficiency** η_e

fan air power divided by the motor input power for the fan and motor combination given by the equation:

$$\eta_e = \frac{P_u}{P_e}$$

NOTE 1 It is possible to refer the overall efficiency to the fan category A, B, C or D.

NOTE 2 Fan overall efficiency is expressed as a proportion of unity or as a percentage.

3.62**ratio of inlet density to mean density** k_ρ

fluid density at the fan inlet divided by the mean fluid density in the fan given by the following equation:

$$k_\rho = \frac{2\rho_1}{\rho_1 + \rho_2}$$

NOTE k_ρ is dimensionless.

3.63**kinetic energy factor at a section x** α_{Ax}

dimensionless coefficient equal to the time-averaged flux of kinetic energy through the considered area, A_x , divided by the kinetic energy corresponding to the mean air velocity through this area and given by the following equation:

$$\alpha_{Ax} = \frac{\iint_{Ax} (\rho v_n v^2) dA_x}{q_m v_{mx}^2}$$

where

v is the local absolute velocity, in metres per second;

v_n is the local velocity, in metres per second, normal to the cross-section.

3.64**kinetic index at a section x** i_{Kx}

dimensionless coefficient equal to the ratio of the kinetic energy per unit mass at the section x and the fan work per unit mass and given by the following equation:

$$i_{Kx} = \frac{v_{mx}^2}{2W_m}$$

3.65**Reynolds number at a section x** Re_{Dx}

dimensionless parameter which defines the state of development of a flow and is used as a scaling parameter

NOTE It is the product of the local velocity, the local density and a relevant scale length (duct diameter, blade chord), divided by the dynamic viscosity as given by the following equation:

$$Re_{Dx} = \frac{v_{mx} D_x}{\nu_x} = \frac{4q_m}{\pi \mu D_x}$$

3.66

friction-loss coefficient

$(\xi_{x-y})_y$

dimensionless coefficient for friction losses between planes x and y of a duct, calculated for the velocity and density at section y; for incompressible flow, the formula is given by:

$$\Delta p_{xy} = \frac{1}{2} \rho_y v_{my}^2 (\xi_{x-y})_y$$

3.67

hydraulic diameter

D_h

hydraulic diameter of a rectangular section of a duct given by the equation:

$$D_h = \frac{4A}{2(b+h)}$$

where

A is the cross-sectional area;

b is the rectangular section width;

h is the rectangular section height.

3.68

flow coefficient

Φ

dimensionless number given by the equation:

$$\Phi = \frac{q_m}{\rho_m D_r^2 u}$$

3.69

pressure coefficient

Ψ

dimensionless number given by the equation:

$$\Psi = \frac{P_f}{\rho_m u^2}$$

3.70

fan power coefficient

λ

dimensionless number given by:

$$\lambda = \frac{\phi \Psi}{\eta}$$

4 Symbols and units

4.1 Symbols

For the purposes of this International Standard, the following symbols and units apply.

Symbol	Represented quantity	Definition ref	SI Unit
A_x	Area of the conduit at section x	3.1	m ²
a	Hole diameter of wall pressure tapings	—	mm
b	Width of the rectangular section of a duct	—	m
C	Discharge coefficient	—	—
c	Velocity of sound	3.23	m/s
c_p	Specific heat capacity at constant pressure	3.8	J/kg/K
c_v	Specific heat capacity at constant volume	3.9	J/kg/K
d	Diameter of orifice or nozzle throat	—	m
d_i	Diameter of stagnation pressure hole in Pitot-static tube	—	mm
D	Internal diameter of a circular conduit upstream of an in-line flowmeter	—	m
D_h	Hydraulic diameter of a rectangular section of a duct	3.67	m
D_x	Internal diameter of a circular conduit in section x	—	m
D_r	Outside diameter of the impeller	—	m
f_{Mx}	Mach factor for correction of dynamic pressure at section x	3.21	—
g	Acceleration due to gravity	—	m/s ²
h	Height of the rectangular section of a duct	—	m
h_u	Relative humidity p_v/p_{sat}	—	—
i_{kx}	Kinetic index at section x	3.64	—
k_c	Resulting coefficient used in the conversion of test results	—	—
k_{cs}	Resulting coefficient used in the conversion of static pressure test results	—	—
k_ρ	Inlet to mean density ratio	3.62	—
k_p	Compressibility coefficient for the calculation of fan air power P_u	3.46	—
k_{ps}	Compressibility coefficient for the calculation of fan static air power	—	—
Ma	Mach number	3.23	—
Ma_x	Mach number at section x	3.32	—
$Ma_{x,\text{ref}}$	Reference Mach number at section x at inlet stagnation conditions	—	—
Ma_u	Peripheral Mach number	3.56	—
m	Area ratio of an orifice plate $(d/D)^2$	—	—
n	Rotational frequency of impeller	—	r/s
N	Rotational speed of impeller	—	r/min
p	Absolute pressure of the fluid	3.17	Pa
p_a	Atmospheric pressure at the mean altitude of the fan	3.18	Pa

p_e	Gauge pressure	3.19	Pa
p_{sg}	Absolute stagnation pressure at a point	3.20	Pa
p_{esg}	Gauge stagnation pressure at a point	3.24	Pa
p_{esgx}	Gauge stagnation pressure at section x	3.34	Pa
p_d	Dynamic pressure at a point	3.22	Pa
p_x	Mean absolute pressure in space and time of the fluid at section x	3.27	Pa
p_{ex}	Mean gauge pressure in space and time at section x	3.26	Pa
p_{sgx}	Mean stagnation pressure at section x	3.33	Pa
p_{dx}	Conventional dynamic pressure at section x	3.31	Pa
p_{sat}	Saturation vapour pressure	12.2	Pa
p_v	Partial pressure of water vapour	12.2	Pa
p_f	Fan pressure	3.38	Pa
p_{sf}	Fan static pressure	3.40	Pa
p_{d2}	Fan outlet dynamic pressure	3.39	Pa
p_u	Mean absolute pressure upstream of an in-line flowmeter	—	Pa
p_{do}	Mean absolute pressure downstream of an in-line flowmeter	—	Pa
P_a	Mechanical power supplied to the fan shaft	3.50	W
P_e	Motor input power	3.52	W
P_o	Motor output power	3.51	W
P_r	Mechanical power supplied to the impeller of the fan	3.49	W
P_u	Fan air power	3.47	W
P_{us}	Fan static air power	3.48	W
q_m	Mass flow rate	3.25	kg/s
q_V	Volume flow rate	—	m ³ /s
q_{Vsg1}	Inlet stagnation volume flow rate	3.37	m ³ /s
q_{Vx}	Volume flow rate at section x	3.29	m ³ /s
r	Fan pressure ratio	3.45	—
r_d	Pressure ratio for a flowmeter $r_d = p_{do}/p_u$	—	—
$r_{\Delta p}$	$\Delta p/p_{do}$ for a flowmeter	—	—
R	Gas constant of dry air or gas	3.6	J/kg/K
R_w	Gas constant of humid air or gas	—	J/kg/K
Re_{Dx}	Reynolds number at section x	3.65	—
T_a	Ambient temperature	—	°C
T_b	Barometer temperature	—	°C
T_d	Dry bulb temperature	3.13	°C
T_w	Wet bulb temperature	3.14	°C
T_x	Static temperature at section x	—	°C
T_{sgx}	Stagnation temperature at section x	—	°C
u_x	Relative uncertainty of x	—	%

U_x	Absolute uncertainty of x	—	same as X
v	Velocity of gas at a point	—	m/s
v_{mx}	Average velocity of the gas at section x	3.30	m/s
v_p	Peripheral velocity, or tip speed, of the impeller	3.55	m/s
W_m	Fan work per unit mass	3.43	J/kg
W_{mS}	Fan static work per unit mass	3.44	J/kg
Z	Compressibility factor in equation of state	3.10	—
Z_k	Coefficient used for the calculation of the compressibility factor k_p (first method)	—	—
Z_p	Coefficient used for the calculation of the compressibility factor k_p (second method)	—	—
z_x	Mean altitude of section x	—	m
α	Flow rate coefficient of an in-line flowmeter	—	—
α_{Ax}	Coefficient of kinetic energy of flow in the section x of area A_x ; α_{Ax} is assumed equal to 1	3.63	—
β	Ratio of the internal diameter of an orifice or nozzle to the upstream diameter of the duct d/D	—	—
β'	Ratio of the internal diameter of an orifice or nozzle to the downstream diameter of the duct	—	—
Δp	Differential pressure	—	Pa
Δz_b	Difference in altitude between the barometer and the mean altitude of the fan	—	m
ε	Expansibility factor	—	—
$(\xi_{x-y})_y$	Conventional friction loss coefficient between planes x and y calculated for section y	3.66	—
η	Efficiency	—	—
η_s	Static efficiency	—	—
η_a	Fan shaft efficiency	3.59	—
η_e	Overall efficiency	3.61	—
η_o	Fan motor shaft efficiency	3.60	—
η_r	Fan impeller efficiency	3.57	—
η_{sr}	Fan impeller static efficiency	3.58	—
θ_{sgx}	Stagnation temperature at section x	3.15	K
θ_x	Static or fluid temperature at section x	3.16	K
θ_a	Ambient temperature	—	K
θ_u	Temperature upstream of an in-line flowmeter	—	K
κ	Isentropic exponent for an ideal gas	3.7	—
Λ	Specific friction-loss coefficient for a length of one diameter of a straight duct	—	—
μ	Dynamic viscosity	—	Pa·s
ρ	Density of gas	—	kg/m ³
ρ_x	Mean density of gas at section x	3.28	kg/m ³

ρ_m	Mean density of gas in the fan	3.41	kg/m ³
Φ	Flow coefficient	3.68	—
Ψ	Pressure coefficient	3.69	—
λ	Fan power coefficient	3.70	—
ω	Angular velocity	—	rad/s
ν	Kinematic viscosity	12.3	m/s

4.2 Subscripts

1	Test fan inlet
2	Test fan outlet
3	Pressure measurement section in an inlet-side airway
4	Pressure measurement section in an outlet-side airway
5	Throat or downstream tapplings for Δp for an inlet-side measurement
6	Upstream tapping for Δp and p_u for an outlet-side measurement
7	Upstream tapping for Δp and p_u for an inlet-side measurement
8	Throat or downstream tapping for Δp for an outlet-side measurement
a	Ambient atmosphere in the test enclosure
b	Barometer
c	Centrepont of the test section
do	Downstream of a flow-measurement device
f	Fan
Gu	Guaranteed relative to the characteristics specified in the contract
n	Reference plane of the fan; $n = 1$ for inlet, $n = 2$ for outlet
s	Static conditions
sat	Saturation conditions
sg	Stagnation conditions
Te	Tested relative to the characteristics specified in the contract
u	Reference air conditions upstream of a flow-measurement device
$x-y$	Airway length from plane x to plane y

5 General

The upper limit of fan work per unit mass is 25 000 J/kg corresponding to an increase in fan pressure approximately equal to 30 000 Pa for a mean density in the fan of 1,2 kg/m³.

The working fluid for test with standardized airways shall be atmospheric air, and the pressure and temperature should be within the normal atmospheric range.

There are four categories of installation:

— category A: free inlet, free outlet;

- category B: free inlet, ducted outlet;
- category C: ducted inlet, free outlet;
- category D: ducted inlet, ducted outlet;

to which correspond four performance characteristics.

Fan performance cannot be considered as invariable. The performance curve of fan pressure versus flow rate may be modified by the upstream fluid flow, e.g. if the velocity profile is distorted or if there is swirl.

Although the downstream flow generally cannot act on the flow through the impeller, the losses in the downstream duct may be modified by the fluid flow at the fan outlet.

Methods of measurement and calculation for the flow rates, fan pressures and fan efficiencies are specified in Clauses 14 to 27 and Annex A. They are established in the case of compressible flow, taking into account Mach number effect and density variation. However, a simplified method is given for reference Mach numbers less than 0,15 and/or fan pressures less than 2 000 Pa.

It is agreed that, for the purposes of this International Standard, calculations are made using absolute pressures and temperatures, but equivalent expressions using gauge pressures are provided.

It is conventionally agreed that:

- for fan installation categories C and D, a common airway section should be provided upstream of the fan inlet to simulate a long, straight inlet duct;
- for fan installation categories B and D, a common airway section (incorporating a standardized flow straightener: an eight-radial-vane straightener, or honeycomb straightener) adjacent to the fan outlet should be provided upstream of the outlet pressure measurement section to simulate a long, straight outlet duct.

When the test installation is intended to simulate an on-site installation corresponding to category C but with a short duct discharging to the atmosphere, the test fan should be equipped with a duct having the same shape as the fan outlet and a length of two equivalent diameters.

For large fans of installation category D (800 mm diameter or larger) it may be difficult to carry out the tests with standardized common airways at the outlet side including straighteners. In this case, by mutual agreement between the parties concerned, the fan performance may be measured using the setup described in 28.2.5 with a duct of length $3D$ on the outlet side. Results obtained in this way may differ to some extent from those obtained by using common airways on both the inlet and outlet side, especially if the fan produces a large swirl.

By convention, the kinetic energy factors α_{A1} , α_{A2} at fan inlet and fan outlet are considered equal to 1.

The test fans shown in the figures for each of the test installations are of one type (e.g. an axial fan). However, a test fan of another type could be used.

6 Instruments for pressure measurement

6.1 Barometers

The atmospheric pressure in the test enclosure shall be determined at the mean altitude between the centre of fan inlet and outlet sections with an uncertainty not exceeding $\pm 0,2$ %. Barometers of the direct-reading mercury column type should be read to the nearest 100 Pa (1 mbar) or to the nearest 1 mmHg. They should be calibrated and corrections applied to the readings for any difference in mercury density from standard, any change in length of the graduated scale due to temperature and for the local value of g .

Correction may be unnecessary if the scale is preset for the regional value of g (within $\pm 0,01 \text{ m/s}^2$) and for room temperature (within $\pm 5 \text{ }^\circ\text{C}$).

Barometers of the aneroid or pressure transducer type may be used provided they have a calibrated accuracy of $\pm 200 \text{ Pa}$ and the calibration is checked at the time of test.

The barometer should be located in the test enclosure at the mean altitude between fan inlet and fan outlet. A correction, $\rho_a g(z_b - z_m)$, in pascals, should be added for any difference in altitude exceeding 10 m,

where

z_b is the altitude at barometer reservoir or at barometer transducer;

z_m is the mean altitude between fan inlet and fan outlet;

g is the local value of the acceleration due to gravity;

ρ_a is the ambient air density.

6.2 Manometers

Manometers for the measurement of pressure difference shall have an uncertainty under conditions of steady pressure, and after applying any calibration corrections (including that for any temperature difference from calibration temperature and for g value), not exceeding $\pm 1 \%$ of the significant pressure or 1,5 Pa, whichever is greater.

The significant pressure should be taken as the fan stagnation pressure at rated duty or the pressure difference when measuring rated volume flow according to the manometer function. Rated duty will normally be near the point of best efficiency on the fan characteristic curve.

The manometers will normally be of the liquid column type, vertical or inclined, but pressure transducers with indicating or recording instrumentation are acceptable, subject to the same accuracy and calibration requirements.

Calibration should be carried out at a series of steady pressures, in both rising and falling sequences to check for any difference.

The reference instrument should be a precision manometer or micromanometer capable of being read to an accuracy of $\pm 0,25 \%$ or 0,5 Pa, whichever is greater.

6.3 Damping of manometers

Rapid fluctuations of manometer readings should be limited by damping so that it is possible to estimate the average reading within $\pm 1 \%$ of the significant pressure. The damping may be in the air connections leading to the manometer or in the liquid circuit of the instrument. It should be linear, and of a type which ensures equal resistance to movement in either direction. The damping should not be so heavy that it prevents the proper indication of slower changes. If these occur, a sufficient number of readings should be taken to determine an average within $\pm 1 \%$ of the significant pressure.

6.4 Checking of manometers

Liquid column manometers should be checked in their test location to confirm their calibration near the significant pressure. Inclined tube instruments should be frequently checked for level and rechecked for calibration if disturbed. The zero reading of all manometers shall be checked before and after each series of readings without disturbing the instrument.

6.5 Position of manometers

The altitude of zero level of manometers or of pressure transducers should be the mean altitude of the section for pressure measurement (see Figure 1).

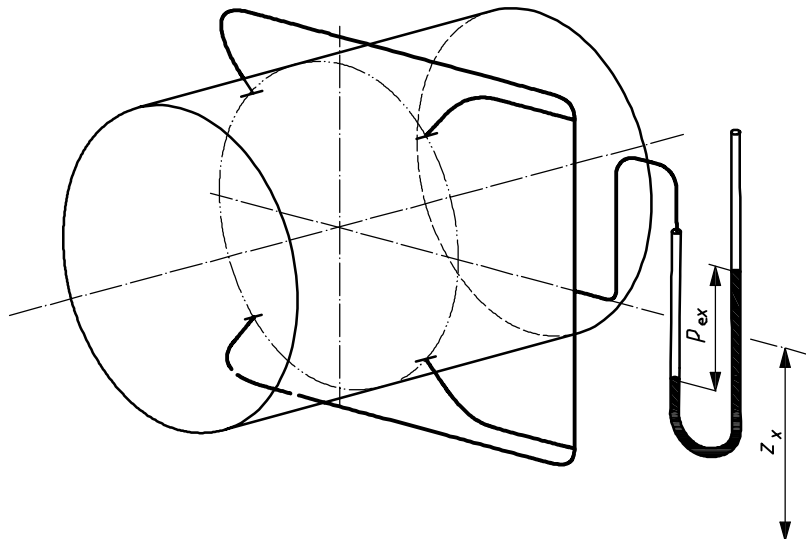


Figure 1 — Tapping connections to obtain average static pressure and altitude of manometer

7 Determination of average pressure in an airway

7.1 Methods of measurement

A differential manometer complying with the specifications of 6.2 to 6.5 shall be used with one side connected either to wall tapplings or to the pressure connections of a set of Pitot-static tubes in the plane of pressure measurement.

To determine the average static pressure in this plane, the other side of the manometer shall be open to the atmospheric pressure in the test enclosure.

To determine the pressure difference between planes of pressure measurement on opposite sides of the fan, either or both sides of the manometer may be connected between sets of four tapping connections arranged as recommended in 7.4.

7.2 Use of wall tapplings

At each of the sections for pressure measurement in the standardized airways specified in Clauses 21 to 25 and in Clauses 30 to 33, the average static pressure shall be taken to be the average of the static pressures at four wall tapplings constructed in accordance with 7.3.

7.3 Construction of tapplings

Each tapping takes the form of a hole through the wall of the airway conforming to the dimensional limits shown in Figure 2. Additional limits are specified in Clauses 22 to 26 for the tapplings used in flow-measurement devices. It is essential that the hole be carefully produced so that the bore is normal to and flush with the inside surface of the airway, and that all internal protrusions are removed. Rounding of the edge of the hole up to a maximum of $0,1a$ is permissible.

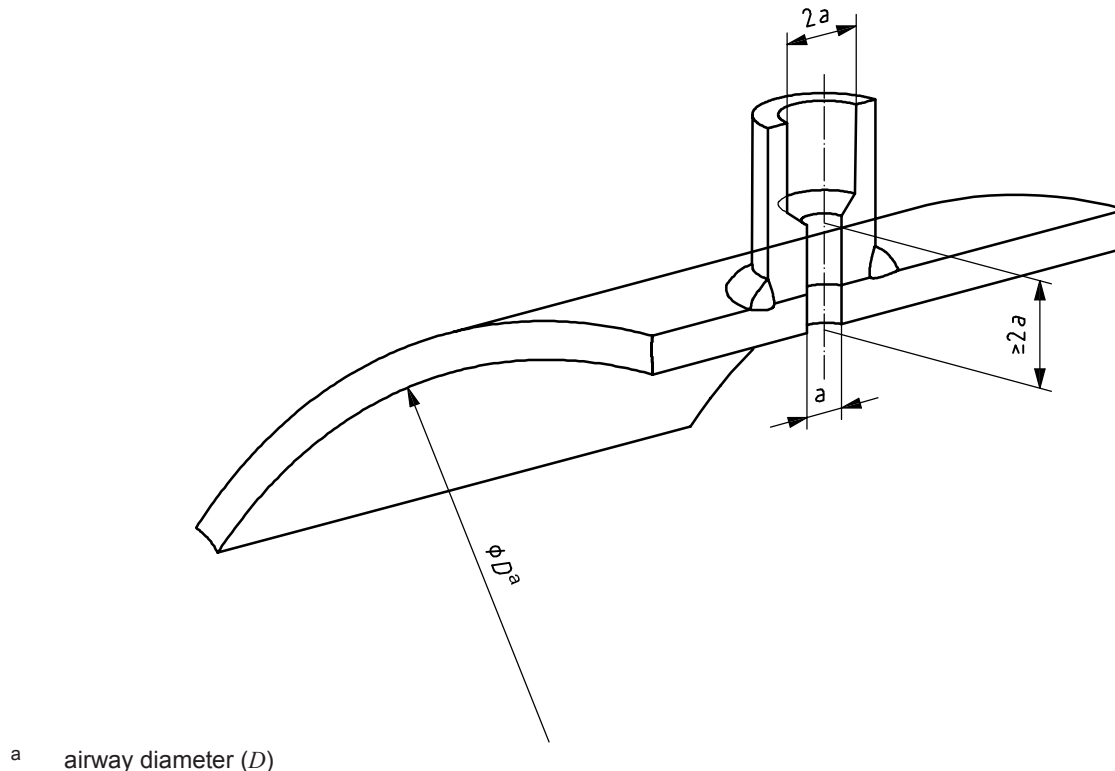


Figure 2 — Construction of wall pressure tapplings

The bore diameter, a , shall be not less than 1,5 mm, not greater than 5 mm and not greater than $0,1D$.

Special care is required when the velocity in the airway is comparable with that at the fan inlet and outlet. In these cases, the tapping should be situated in a section of the airway that is free from joints or other irregularities for a distance of D upstream and $D/2$ downstream, D being the airway diameter. In very large airways, it may not be practicable to meet this condition. In such cases the Pitot-static tube method described in 7.6 may be used.

7.4 Position and connections

In the case of a cylindrical airway, the four tapplings should be equally spaced around the circumference. In the case of a rectangular airway, they should be at the centres of the four sides. Four similar tapplings may be connected to a single manometer. They should be connected as shown in Figure 1.

7.5 Checks for compliance

Care shall be taken to ensure that all tubing and connections are free from blockage and leakage, and are empty of liquid. Before beginning any series of observations, the pressure at the four side tapplings should be individually measured at a flow rate approaching the maximum of the series. If any one of the four readings lies outside a range equal to 5 % for $p_{ex} < 1\,000$ Pa or 2 % for $1\,000$ Pa $< p_{ex} < 30\,000$ Pa, p_{ex} being the mean gauge pressure, the tapplings and manometer connections should be examined for defects. If none are found, eight equally spaced pressure tapplings should be used.

NOTE “Mean gauge pressure” here denotes the pressure across the nozzle or orifice at rated flow in the case of flow measurement, or the rated fan pressure in the case of pressure measurement.

7.6 Use of Pitot-static tube

At the appropriate pressure measurement plane in a circular airway, a minimum of four points should be selected, equally and symmetrically spaced around the axis at approximately one-eighth of the airway diameter from the wall or, in the case of a rectangular airway, one-eighth of the duct width from the centre of

each wall. Under steady flow conditions, a static pressure reading should be taken at each point and the average calculated.

Alternatively, if desired, the static pressure connections of four separate Pitot-static tubes may be connected together to give a single average reading in the manner described in 7.4 and Figure 1.

8 Measurement of temperature

8.1 Thermometers

Instruments for the measurement of temperature shall have an accuracy of $\pm 0,5$ °C after the application of any calibration correction.

8.2 Thermometer location

When a probe is put inside an airway to take temperature measurements, the measurement accuracy is a function of the fluid velocity.

The measured temperature, which is neither the stagnation temperature nor the static temperature, is a value lying between them, usually slightly closer to the stagnation value.

If the air velocity is equal to 25 m/s, the difference between stagnation and static temperatures is 0,31 °C; at 35 m/s, the same difference is 0,61 °C (for a static temperature of 293,15 K).

If the measurement is taken in a section where the air velocity is less than 25 m/s, the measured temperature is assumed equal to both stagnation and static temperatures.

It is therefore recommended that measurement of the stagnation temperature be made upstream of the fan inlet or of the test airway, either in a section where the air velocity lies between 0 m/s and 25 m/s or in the inlet chamber.

In order to measure the mean stagnation temperature, one or several probes shall then be put in the appropriate section, located on a vertical diameter at different altitudes situated symmetrically from the diameter centre. Probes shall be shielded against radiation from heated surfaces.

If it is not possible to meet these requirements, probes can be placed inside an airway on a horizontal diameter, at least 100 mm from the wall or one-third of the airway diameter, whichever is less.

8.3 Humidity

The dry bulb and wet bulb temperatures in the test enclosure should be measured at a point where they can record the condition of the air entering the test airway. The instruments should be shielded against radiation from heated surfaces.

The wet bulb thermometer should be located in an air stream of velocity at least 3 m/s. The sleeving should be clean, in good contact with the bulb, and kept wetted with pure water.

Relative humidity may be measured directly provided the apparatus used has an accuracy of ± 2 %.

9 Measurement of rotational speed

9.1 Fan shaft speed

The fan shaft speed shall be measured at regular intervals throughout the period of test for each test point, so as to ensure the determination of average rotational speed during each such period with an uncertainty not exceeding $\pm 0,5$ %.

No device used should significantly affect the rotational speed of the fan under test or its performance.

9.2 Acceptable instruments

Instruments should have an uncertainty of not more than 0,5 % (i.e. accuracy class index of 0,5 in accordance with IEC 60051-4).

10 Determination of power input

10.1 Measurement accuracy

The power input to the fan over the specified performance range shall be determined by a method, including the averaging of a sufficient number of readings at each test point, which achieves a result with an uncertainty not exceeding ± 2 %.

10.2 Fan shaft power

When the power to be determined is the input to the fan shaft, acceptable methods include the following.

10.2.1 Reaction dynamometer

The torque is measured by means of a cradle or torque-table type dynamometer. The weights shall have certified accuracies of $\pm 0,2$ %. The length of the torque arm shall be determined to an accuracy of $\pm 0,2$ %.

The zero-torque equilibrium (tare) shall be checked before and after each test. The difference shall be within 0,5 % of the maximum value measured during the test.

10.2.2 Torsion meter

The torque is measured by means of a torsion meter having an uncertainty no greater than 2,0 % of the torque to be measured. For the calibration, the weights shall have certified accuracies of $\pm 0,2$ %. The length of the torque arm shall be determined to an accuracy of $\pm 0,2$ %.

The zero-torque equilibrium (tare) and the span of the readout system shall be checked before and after each test. In each case, the difference shall be within 0,5 % of the maximum value measured during the test.

10.3 Determination of fan shaft power by electrical measurement

10.3.1 Summation of losses

The power output of an electric motor for direct drive is deduced from its electrical power input by the summation of losses method specified in IEC 60034-2. For this purpose, measurements of voltage, current, speed and, in the case of alternating current (a.c.) motors, power input and slip of induction motors shall be made for each test point, and the no-load losses of the motor when uncoupled from the fan shall be measured.

10.3.2 Calibrated motor

The power output of an electric motor for direct drive is determined from an efficiency calibration acceptable to both manufacturer and purchaser. The motor should be run on charge for a time sufficient to ensure that it is running at its normal working temperature. The electrical supply should be within the statutory limits, i.e.

- voltage: $\pm 6\%$;
- frequency: $\pm 1\%$.

10.3.3 Electrical meters

The electrical power input to the motor during the fan tests described in 10.3.1 or 10.3.2 shall be measured by one of the following methods:

- a) for a.c. motors, by the two-wattmeter method or by an integrating wattmeter;
- b) for direct current (d.c.) motors, by measurement of the input voltage and current.

The equipment used for standardized airway tests shall be of class index 0,5 in accordance with IEC 60051-2 and IEC 60051-3 to which calibration corrections are applied or, alternatively, of class index 0,2 for which calibration corrections are unnecessary.

10.4 Impeller power

To determine the power input to the fan impeller hub it is necessary, unless the impeller is mounted directly on the motor shaft, to deduct from the fan shaft power an allowance for bearing losses and for the losses in any flexible coupling. This may be determined by running a further test at the same speed with the impeller removed from the shaft and measuring the torque losses due to bearing friction. If considered necessary, the fan impeller may be substituted by an equivalent mass (having negligible aerodynamic loss) to provide similar bearing loadings.

10.5 Transmission systems

For tests with standardized airways, the interposition of a transmission system between the fan and the point of power measurement should be avoided unless it is of a type in which the transmission losses under the specified working conditions can be reliably determined, or the specified power input is required to include those losses.

11 Measurement of dimensions and determination of areas

11.1 Flow-measurement devices

The dimensions of nozzles, orifices and airways used for flow measurement shall conform to the tolerances specified in the appropriate subclauses covering their use.

11.2 Tolerance on dimensions

Specified airway component lengths shall be measured after manufacture and shall conform to the requirements of the test method within a tolerance of $^{+10}_{-1}\%$, except where otherwise stated.

Specified airway component diameters shall be measured after manufacture and shall conform to the requirements of the test method within a tolerance of $\pm 1\%$, except where otherwise stated.

11.3 Determination of cross-sectional area

11.3.1 Dimensional measurements

Sufficient dimensional measurements shall be taken across the reference planes of airways to determine cross-sectional areas within $\pm 0,5 \%$ in standardized airways and other well-defined regular sections.

11.3.2 Circular sections

For circular sections, the mean diameter of the section is taken as being equal to the arithmetic mean of the measured values on at least three diameters of the measuring section. The diameters shall be so positioned that they are at equal angles within the cross-section.

If the difference in linear measurement between two adjacent diameters is more than 1 %, the number of measured diameters shall be doubled. The area of the circular section shall be calculated from the formula:

$$\pi \frac{D^2}{4}$$

where D is the arithmetic mean of the measured diameters.

11.3.3 Rectangular sections

The width and height of a rectangular section shall be measured along five equidistant lines parallel to the width and height. If the difference between two adjacent widths or heights is more than 2 %, then the number of measurements in that direction shall be doubled.

The average width of the section shall be taken as the arithmetic mean of all the widths measured, and the average height of the section shall be taken as the arithmetic mean of all the heights measured. The cross-sectional area of the section shall be taken as being the average width multiplied by the average height.

12 Determination of air density, humid gas constant and viscosity

12.1 Density of air in the test enclosure at section x

The density of the ambient air in the test enclosure is given by the following equation:

$$\rho_a = \frac{p_a - 0,378 p_v}{287 \theta_a}$$

where

θ_a is the absolute ambient temperature, in kelvins, given by

$$\theta_a = T_a + 273,15$$

where $T_a = T_d$ (dry bulb temperature, in degrees Celsius);

p_a is the atmospheric pressure;

p_v is the partial water vapour pressure, in pascals, in the air;

287 is the gas constant for dry air, R , in joules per (kilogram kelvin);

$$0,378 = \frac{R_v - R}{R_v}$$

with $R_v = 461$ which is the gas constant of water vapour.

The gas constant of humid air, R_w , is then given by

$$R_w = \frac{p_a}{\rho_a \Theta_a} = \frac{287}{1 - 0,378 \frac{p_v}{p_a}}$$

NOTE For standard air:

$$\rho_a = 1,2 \text{ kg/m}^3$$

$$\Theta_a = 293,15 \text{ K}$$

$$p_a = 101\,325 \text{ Pa}$$

$$h_u = 0,40$$

$$R_w = 288 \text{ J/(kg} \cdot \text{K)}$$

The average density of the air in an airway section x may be obtained by the following equation:

$$\rho_x = \frac{p_x}{R_w \Theta_x}$$

12.2 Determination of vapour pressure

The partial vapour pressure, p_v , is obtained by the following equation when the air humidity is measured by means of a psychrometer at the fan inlet:

$$p_v = (p_{\text{sat}})_{T_w} - p_a A_w (T_d - T_w) \cdot (1 + 0,001\,15 T_w)$$

where

T_d is the dry bulb temperature, in degrees Celsius;

T_w is the wet bulb temperature, in degrees Celsius;

$A_w = 6,6 \times 10^{-4}/^\circ\text{C}$ when T_w is between 0°C and 150°C ;

$A_w = 5,94 \times 10^{-4}/^\circ\text{C}$ when T_w is less than 0°C ;

$(p_{\text{sat}})_{T_w}$ is the pressure of saturated vapour at the wet bulb temperature T_w .

Table 1 lists values of saturated vapour pressure (p_{sat}) over the temperature range -4°C to $49,5^\circ\text{C}$.

Table 1 — Saturation vapour pressure, p_{sat} , of water as a function of wet bulb temperature, T_w

Wet bulb temperature T_w °C	Saturation vapour pressure, p_{sat} , of water (above water) hPa									
	0,0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9
−4	4,55	4,51	4,48	4,44	4,41	4,37	4,35	4,31	4,28	4,24
−3	4,89	4,87	4,83	4,79	4,76	4,72	4,68	4,65	4,61	4,59
−2	5,28	5,24	5,20	5,16	5,12	5,08	5,04	5,01	4,97	4,93
−1	5,68	5,64	5,60	5,56	5,52	5,47	5,44	5,39	5,36	5,32
−0	6,11	6,07	6,03	5,97	5,93	5,89	5,84	5,80	5,76	5,72
0	6,11	6,16	6,19	6,24	6,29	6,33	6,37	6,43	6,47	6,52
1	6,56	6,61	6,67	6,71	6,76	6,80	6,85	6,91	6,96	7,00
2	7,05	7,11	7,16	7,21	7,25	7,31	7,36	7,41	7,47	7,52
3	7,57	7,63	7,68	7,73	7,79	7,85	7,91	7,96	8,01	8,08
4	8,13	8,19	8,24	8,31	8,36	8,43	8,48	8,53	8,60	8,65
5	8,72	8,79	8,84	8,91	8,96	9,03	9,09	9,16	9,21	9,28
6	9,35	9,41	9,48	9,53	9,61	9,68	9,75	9,81	9,88	9,95
7	10,01	10,08	10,15	10,23	10,29	10,36	10,43	10,51	10,57	10,65
8	10,72	10,80	10,87	10,95	11,01	11,09	11,17	11,24	11,32	11,40
9	11,48	11,55	11,63	11,71	11,79	11,87	11,95	12,03	12,11	12,19
10	12,27	12,36	12,44	12,52	12,61	12,69	12,77	12,87	12,95	13,04
11	13,12	13,21	13,29	13,39	13,47	13,56	13,65	13,75	13,84	13,93
12	14,01	14,11	14,20	14,29	14,39	14,48	14,59	14,68	14,77	14,87
13	14,97	15,07	15,17	15,27	15,36	15,47	15,57	15,67	15,77	15,88
14	15,97	16,08	16,19	16,29	16,40	16,51	16,61	16,72	16,83	16,93
15	17,04	17,16	17,27	17,37	17,49	17,60	17,72	17,83	17,96	18,05
16	18,17	18,29	18,41	18,52	18,64	18,76	18,88	19,00	19,12	19,25
17	19,37	19,49	19,61	19,73	19,87	19,99	20,12	20,24	20,37	20,51
18	20,63	20,76	20,89	21,03	21,16	21,29	21,43	21,56	21,69	21,83
19	21,96	22,11	22,24	22,39	22,52	22,67	22,80	22,95	23,09	23,23
20	23,37	23,52	23,67	23,81	23,96	24,11	24,25	24,41	24,56	24,71
21	24,87	25,01	25,17	25,32	25,48	25,64	25,80	25,95	26,11	26,27
22	26,43	26,60	26,76	26,92	27,08	27,25	27,41	27,59	27,75	27,92
23	28,09	28,25	28,43	28,60	28,77	28,95	29,12	29,31	29,48	29,65
24	29,84	30,01	30,19	30,37	30,56	30,75	30,92	31,11	31,29	31,48
25	31,68	31,87	32,05	32,24	32,44	32,63	32,83	33,01	33,21	33,41
26	33,61	33,81	34,01	34,21	34,41	34,61	34,83	35,03	35,24	35,44
27	35,65	35,87	36,08	36,28	36,49	36,71	36,93	37,15	37,36	37,57
28	37,80	38,03	38,24	38,47	38,69	38,92	39,15	39,37	39,60	39,83
29	40,05	40,29	40,52	40,76	41,00	41,23	41,47	41,71	41,95	42,19
30	42,43	42,68	42,92	43,17	43,41	43,67	43,92	44,17	44,43	44,68
31	44,93	45,19	45,44	45,71	45,96	46,23	46,49	46,75	47,01	47,28
32	47,56	47,83	48,09	48,37	48,64	48,92	49,19	49,47	49,75	50,03
33	50,31	50,60	50,88	51,16	51,45	51,73	52,03	52,32	52,61	52,91
34	53,20	53,51	53,80	54,11	54,40	54,71	55,01	55,32	55,63	55,93
35	56,24	56,55	56,87	57,17	57,49	57,81	58,13	58,45	58,77	59,11
36	59,43	59,76	60,08	60,41	60,75	61,08	61,41	61,75	62,08	62,43
37	62,77	63,11	63,45	63,80	64,15	64,49	64,85	65,20	65,56	65,91

Table 1 (continued)

Wet bulb temperature T_w °C	Saturation vapour pressure, p_{sat} , of water (above water) hPa									
	0,0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9
38	66,27	66,63	66,99	67,35	67,72	68,08	68,45	68,83	69,19	69,56
39	69,95	70,32	70,69	71,07	71,45	71,84	72,23	72,61	73,00	73,39
40	73,79	74,17	74,57	74,97	75,37	75,77	76,17	76,59	76,99	77,40
41	77,81	78,23	78,64	79,05	79,47	79,89	80,32	80,73	81,16	81,59
42	82,03	82,45	82,89	83,32	83,76	84,20	84,64	85,08	85,53	85,97
43	86,43	86,88	87,33	87,79	88,25	88,71	89,17	89,64	90,11	90,57
44	91,04	91,52	91,99	92,47	92,95	93,43	93,91	94,40	94,88	95,37
45	95,87	96,36	96,85	97,35	97,85	98,36	98,85	99,36	99,88	100,39
46	100,89	101,41	101,93	102,45	102,97	103,51	104,04	104,57	105,09	105,63
47	106,17	106,71	107,25	107,79	108,33	108,89	109,44	109,99	110,55	111,11
48	111,67	112,23	112,80	113,37	113,93	114,51	115,08	115,65	116,24	116,83
49	117,41	118,00	118,59	119,17	119,79	120,37	120,99	121,57	122,19	122,80

p_{sat} may be obtained by the following equation, between 0 °C and 30 °C:

$$p_{\text{sat}} = \exp \left(\frac{17,438 T_w}{239,78 + T_w} + 6,414 7 \right)$$

or, between 0 °C and 100 °C:

$$p_{\text{sat}} = 610,8 + 44,442 T_w + 1,413 3 T_w^2 + 0,027 68 T_w^3 + 2,556 67 \times 10^{-4} T_w^4 + 2,891 66 \times 10^{-6} T_w^5$$

The air relative humidity, h_u , can also be directly measured in order to obtain

$$p_v = h_u(p_{\text{sat}})_{T_d}$$

where $(p_{\text{sat}})_{T_d}$ is the saturation vapour pressure at the dry bulb temperature T_d calculated using the above formula with T_d instead of T_w .

12.3 Determination of air viscosity

The following formula can be used in the range –20 °C to +100 °C to obtain the dynamic viscosity, in pascal seconds:

$$\mu = (17,1 + 0,048 T_x) \times 10^{-6}$$

The kinematic viscosity ν is given by the following equation:

$$\nu = \frac{\mu}{\rho}$$

13 Determination of flow rate

13.1 General

The measurement of flow rate may be carried out in accordance with ISO 5167-1 and ISO 3966, and any flow rate measurement obtained in this way conforms to the requirements of this International Standard.

This International Standard specifies different flow-metering methods which are appropriate for fan-testing purposes, and in each case the associated uncertainty of measurement is given.

The flow shall be effectively swirl-free. Provisions to ensure that this condition is met are included in the methods of test.

Two basic flow-metering methods are permissible under these relaxed conditions: i.e. the use of an in-line flowmeter or a traversing method.

13.2 In-line flowmeters (standard primary devices)

13.2.1 The flowmeters which may be used are the multi-Venturi nozzles, the orifice plate, and the conical or bellmouth inlet.

The first two may be used at the inlet to or outlet from an airway as well as between two sections of an airway.

The conical or bellmouth inlet may only be used at the inlet to an airway, drawing air from free space. Multi-nozzles are only used within a test chamber.

The requirements for these instruments and for the simplified installations in which they may be used are given in ISO 5167-1.

13.2.2 The general expression for the mass flow rate through an in-line differential pressure flowmeter is as follows:

$$q_m = \frac{\alpha \varepsilon \pi d^2}{4} \sqrt{2 \rho_u \Delta p}$$

where

q_m is the mass flow rate, in kilograms per second;

d is the throat diameter, in metres;

ρ_u is the upstream density, in kilograms per cubic metre;

Δp is the pressure difference, in pascals;

α is the flow coefficient;

ε is the expansibility factor.

$$\rho_u = \frac{p_u}{R_w \theta_u}$$

Normally, θ_u should be the fluid temperature upstream of the flowmeter.

When the flowmeter is at the inlet side of the fan to be tested

$$\Theta_u = \Theta_{\text{sgu}} - \frac{q_m^2}{2A_u^2 \rho_u^2 c_p} + \frac{P_{\text{rx}} \text{ or } P_{\text{ex}}}{q_m c_p}$$

where

P_{rx} or P_{ex} is the power provided by any auxiliary fan;

A_u is the area of the duct upstream of the flowmeter;

$A_u = \infty$ for an inlet orifice.

When the flowmeter is at the outlet side of the fan to be tested

$$\Theta_u = \Theta_{\text{sgl}} + \frac{P_r \text{ or } P_e}{q_m c_p} - \frac{q_m^2}{2A_u^2 \rho_u^2 c_p}$$

The value of q_m is obtained by an iterative procedure.

For a given device, ε is a function of the pressure ratio and α is a function of the Reynolds number. Values for these coefficients are given in Clauses 22 to 25, Tables 4 and 5, and Figures 19 and 21 to 23.

13.2.3 The pressure difference across an in-line flowmeter shall be measured with an uncertainty not exceeding $\pm 1,4$ % of the observed value.

The values for the uncertainties of the flow coefficient associated with each flow-metering element are given in Clauses 22 to 25. It shall always be possible to reduce the uncertainties associated with any in-line flowmeter installation different from those defined in ISO 5167-1 by calibrating the installation against an improved or calibrated standard device in accordance with ISO 5167-1.

13.2.4 In order to facilitate the selection of type and size of flowmeter, the losses associated with each type are given in Figure 3. Approximate values for the pressure difference (expressed as a multiple of the dynamic pressure in the downstream airway) which will be registered across each device are also shown.

13.2.5 Multi-Venturi nozzles have a relatively low pressure loss and a lower sensitivity to disturbances in the approaching airflow. The orifice plate, in particular, incurs higher pressure losses, and an auxiliary booster fan is required if the fan characteristic is to be extended to maximum volume flow. For tests at one or more preset points on a fan characteristic, an orifice plate can, simultaneously with the flow measurement, control the pressure drop, and this can be a useful property.

13.3 Traverse methods

The local velocity shall be measured at a number of positions across a duct and the individual velocity values combined, using an integration technique, to yield an estimate of the mean velocity in the duct. Measurement of the cross-sectional area of the duct in the traverse plane then allows calculation of the flow rate (see Clauses 11 and 25).

In standardized airways, a Pitot-static tube conforming to the requirements of ISO 3966 (see Figure 24) shall be used.

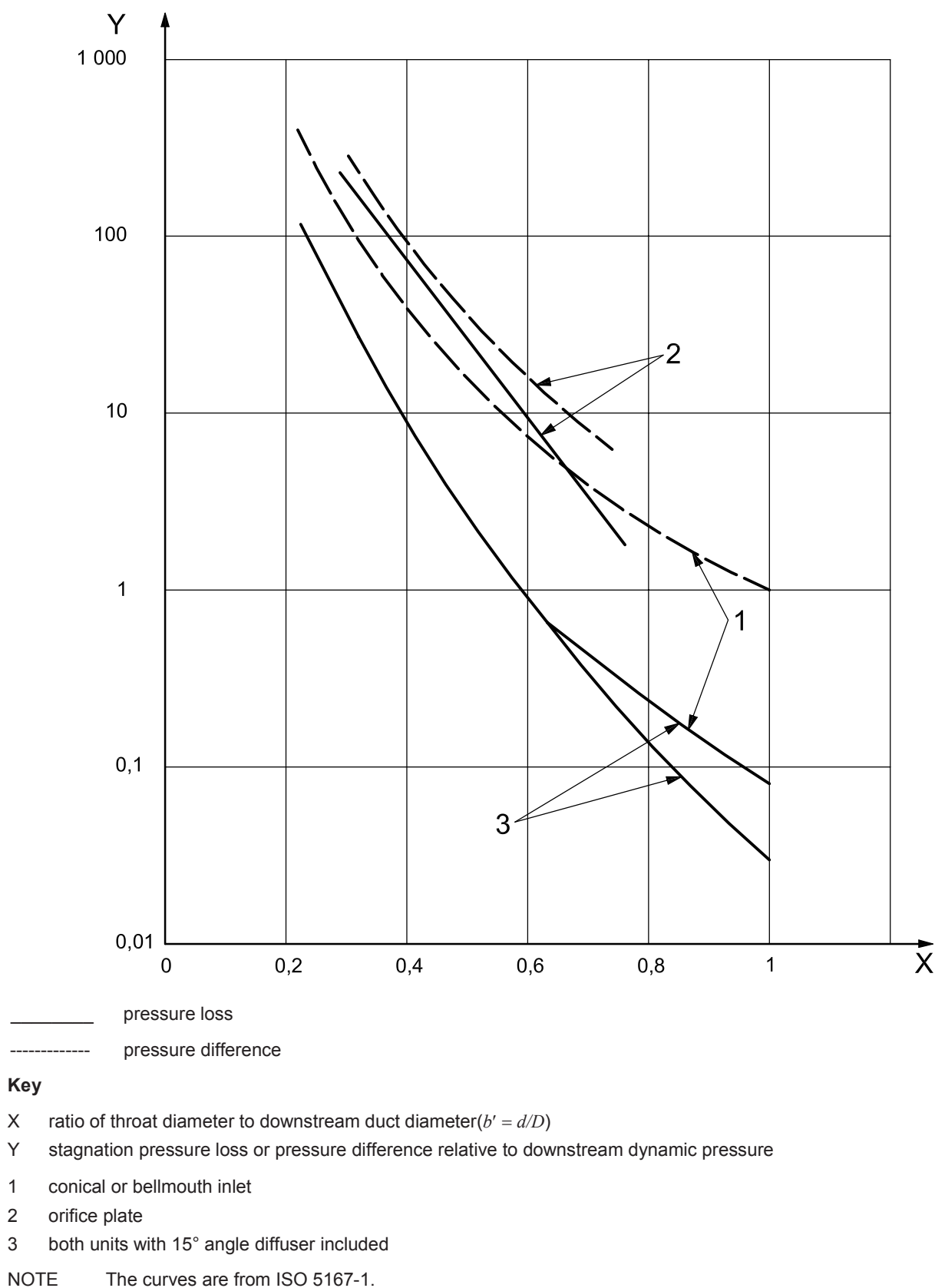


Figure 3 — Pressure loss and pressure difference of standard primary systems

14 Calculation of test results

14.1 General

Specific instructions for the calculation of fan performance from measurements at a single test point are given in Clauses 18 to 33 depending on the test method used.

The method of calculation in the general case of compressible fluid flow is explained in this clause.

14.2 Units

The units throughout these calculations shall be the SI units given in Clause 4. The results will then also be in these units: pressure in pascals; power in watts; and volume flow in cubic metres per second.

14.3 Temperature

14.3.1 In this International Standard, the mean temperature measured at section x is assumed to be the stagnation value, θ_{sgx} , rather than the fluid temperature or static temperature, θ_x , which is slightly lower at high velocities.

The static temperature, θ_x , is determined in accordance with 14.4.3.1 and used in the fluid state equation to calculate the density.

14.3.2 The behaviour of air in the test airways for the provisions of this International Standard is considered as adiabatic, because the air is taken from the atmosphere and because of the absence of heat or mechanical energy increase, except in the test fan. Consequently, the stagnation temperature, θ_{sgx} , in all sections upstream of the fan tested shall be considered constant and equal to the ambient temperature at the test site, θ_a :

$$\theta_{sg1} = \theta_{sg3} = \theta_a$$

except when an auxiliary fan is used upstream of a test chamber or test airway.

14.3.3 The stagnation temperature at the fan outlet, θ_{sg2} , and in the downstream airways is equal to the stagnation temperature at the fan inlet, increased by the temperature rise through the fan which is dependent upon the impeller power, P_r , the mass flow rate, q_m , and the heat capacity of air at constant pressure, c_p .

$$\theta_{sg2} = \theta_{sg1} + \frac{P_r \text{ or } P_e}{q_m c_p} = \theta_{sg4}$$

NOTE In the above equation, c_p can be taken as 1 008 J/(kg·K) as a first approximation for air.

P_r should be replaced by the electric input power P_e when the motor is wholly immersed in the airstream.

14.3.4 When the above conditions do not apply, for instance if the impeller power is not measured, the stagnation temperature shall be measured by a measuring device (e.g. thermometer) inserted into the airway in accordance with 8.2 at a point where the velocity does not exceed 35 m/s provided this is reasonably close to the relevant section.

14.3.5 The fluid temperature at section x , θ_x , is less than the stagnation measured or derived temperature at that section. It is expressed in terms of the Mach number, Ma_x , and of the stagnation temperature, θ_{sgx} , as:

$$\frac{\theta_{sgx}}{\theta_x} = 1 + \frac{\kappa - 1}{2} Ma_x^2$$

The ratio θ_{sgx}/θ_x is plotted in Figure 4 as a function of Ma_x .

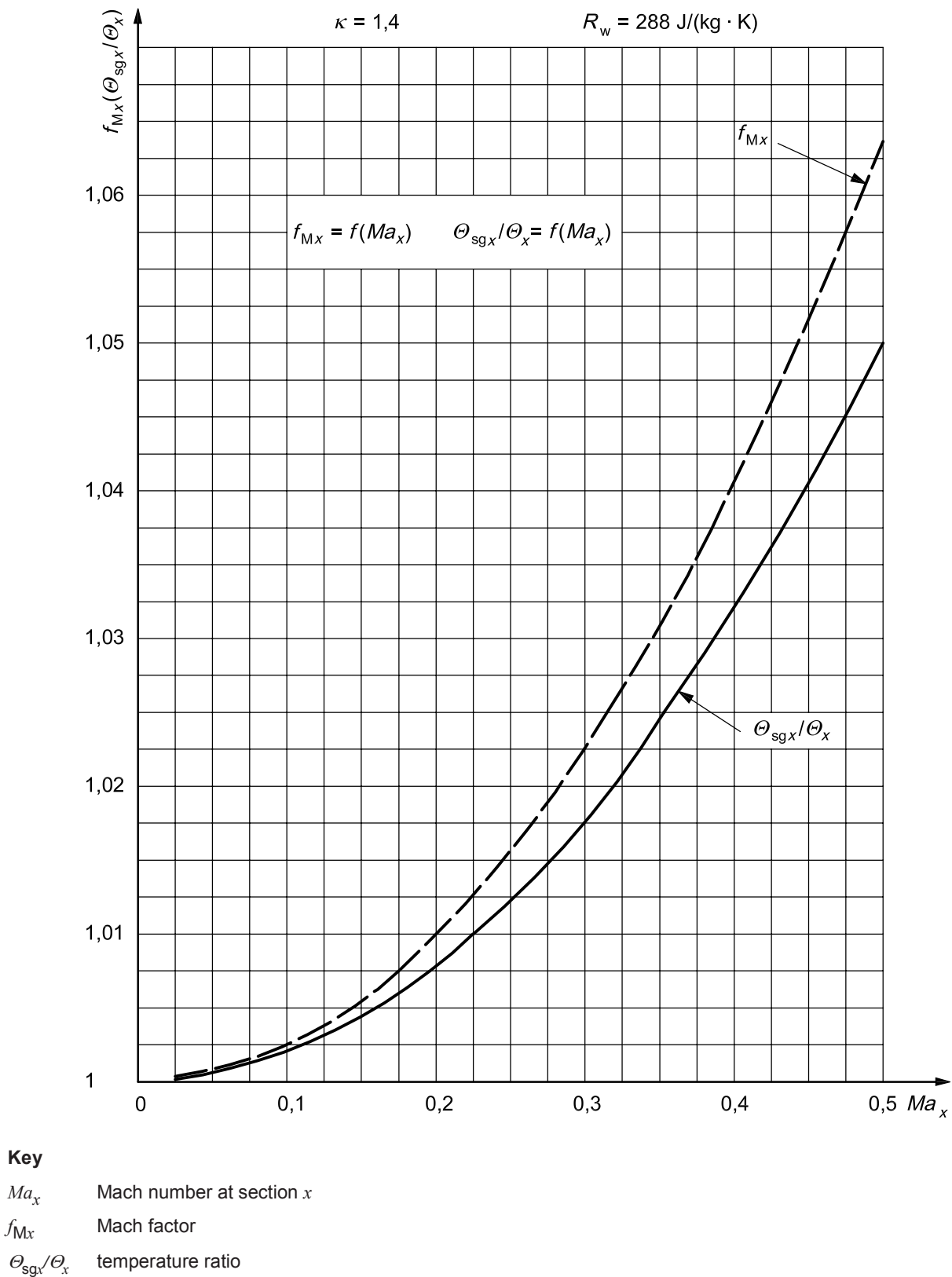


Figure 4 — Changes in f_{Mx} and the ratio Θ_{sgx}/Θ_x as functions of Ma_x

Because Ma_x is usually unknown, Θ_x shall be calculated from

- the mass flow rate, q_m ,
- the stagnation temperature, Θ_{sgx} ,
- the section area, A_x ,
- the pressure, p_x , or the stagnation pressure at section x , p_{sgx} , in accordance with 14.4.3.

14.4 Mach number and reference conditions

14.4.1 General

When carrying out low-pressure fan tests using standardized airways, it is usually agreed that the air velocity is sufficiently low that its influence on parameters such as gas pressure, temperature and density can be neglected. For high- or medium-pressure fans, a distinction shall be made between the stagnation and the static values of pressure, temperature and density, unless the reference Mach number is less than 0,15, corresponding to a velocity of standard air of 51,5 m/s.

The Mach number of 0,15 is considered as the limit above which this distinction shall be made.

14.4.2 Reference Mach number

In order to obtain a rapid evaluation of the limit above which compressibility phenomena due to air velocity shall be taken into account, the reference Mach number, Ma_{2ref} , is defined as:

$$Ma_{2ref} = \frac{V_{m2}}{c_{ref}} = \frac{q_m}{A_2 \rho_a \sqrt{\kappa R_w \Theta_{sga}}} = \frac{q_m}{A_2 \rho_{sg1} \sqrt{\kappa R_w \Theta_{sg1}}}$$

It is assumed that the air reference conditions are those in the test enclosure. The reference Mach number limit above which a distinction between the stagnation and static values of temperature, pressure and density shall be made is regarded as equal to 0,15.

14.4.3 Mach number at a section x , Ma_x

This is defined as the mean velocity at section x , v_{mx} , divided by the velocity of sound c_x at the same section, i.e.

$$Ma_x = \frac{v_{mx}}{c_x} = \frac{q_m}{A_x \rho_x \sqrt{\kappa R_w \Theta_x}}$$

where

$$\rho_x = \frac{p_x}{R_w \Theta_x}$$

$$v_{mx} = \frac{q_m}{A_x \rho_x}$$

14.4.3.1 Calculation of Ma_x and Θ_x when p_x and Θ_{sgx} are known

Assuming that

$$M^2 = \left(\frac{q_m}{A_x} \right)^2 \cdot \frac{\kappa - 1}{2\kappa} \cdot \frac{R_w \Theta_{sgx}}{p_x^2}$$

and

$$\frac{\Theta_{sgx}}{\Theta_x} = \frac{1 + \sqrt{1 + 4M^2}}{2}$$

$$Ma_x = \sqrt{\left(\frac{\Theta_{sgx}}{\Theta_x} - 1 \right) \frac{2}{\kappa - 1}}$$

The ratio Θ_{sgx}/Θ_x and Ma_x are plotted as functions of M^2 in Figure 5.

14.4.3.2 Calculations of Ma_x and Θ_x when p_{sgx} and Θ_{sgx} are known

Assuming that

$$Ma_{sgx}^2 = \frac{q_m^2}{A_x^2 \rho_{sgx}^2 \kappa R_w \Theta_{sgx}} = \frac{q_m^2}{A_x^2 \kappa p_{sgx} \rho_{sgx}}$$

the Mach number Ma_x is given by:

$$Ma_x = Ma_{sgx} \sqrt{\left(1 + 1,217 Ma_{sgx}^2 + 1,369 Ma_{sgx}^4 + 10 Ma_{sgx}^6 \right)}$$

For $\kappa = 1,4$ and $Ma_{sgx} < 0,45$

$$\frac{\Theta_{sgx}}{\Theta_x} = 1 + \frac{\kappa - 1}{2} Ma_x^2$$

Figure 6 shows Ma_x/Ma_{sgx} plotted against Ma_{sgx} .