PUBLISHED DOCUMENT

PD CR 14378:2002
CR 14378:2002
Incorporating Corrigendum No. 1

Ventilation for buildings — Experimental determination of mechanical energy loss coefficients of air handling components

ICS 91.140.30

British Standards

National foreword

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This Published Document, having been prepared under the direction of the Engineering Sector Policy and Strategy Committee, was published under the authority of the Standards Policy and Strategy Committee on 6 May 2002

Summary of pages

This document comprises a front cover, an inside front cover, the CR title page, pages 2 to 24, an inside back cover and a back cover.

The BSI copyright date displayed in this document indicates when the document was last issued.

Amendments issued since publication

Amd. No.	Date	Comments
14069 Corrigendum No. 1	15 January 2003	Replacement of Figure A.4, Figure A.5, and Figure A.6

ISBN 0 580 39422 0

CEN REPORT

RAPPORT CEN

CEN BERICHT

CR 14378

January 2002

Incorporating corrigendum July 2002

ICS

English version

Ventilation for buildings - Experimental determination of mechanical energy loss coefficients of air handling components

This CEN Report was approved by CEN on 10 November 2001. It has been drawn up by the Technical Committee CEN/TC 156.

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

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Ref. No. CR 14378:2002 E

CONTENTS

Foreword

This Technical Report has been prepared by Technical Committee CEN/TC 156, 'Ventilation for buildings', the secretariat of which is held by BSI.

This report should be considered with a series of standards for ductwork used for ventilation and air conditioning of buildings for human occupancy.

The position of this report in the field of mechanical building services is shown in Figure 1.

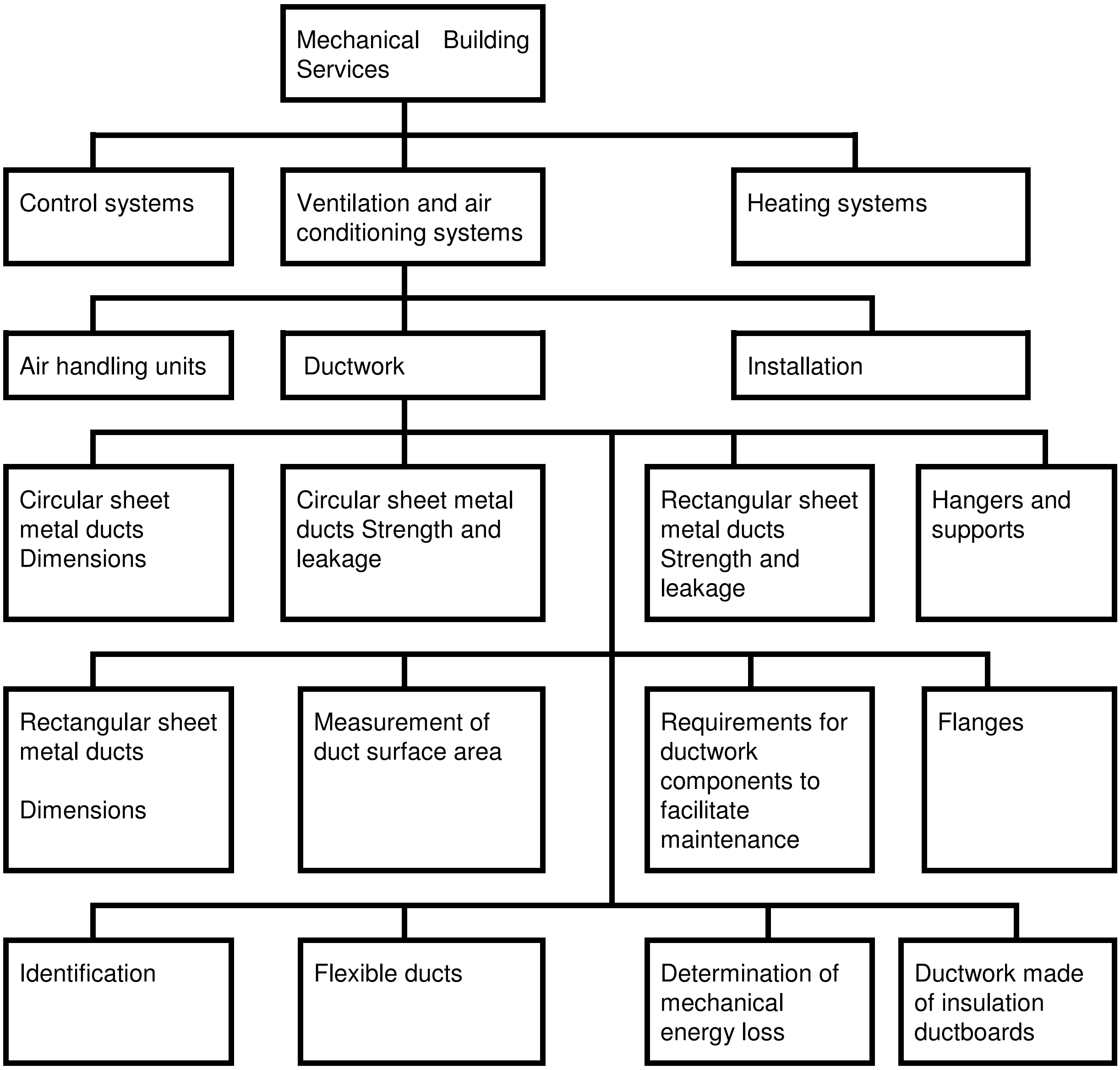


Figure 1 - Position of CR 14378 in the field of mechanical building services

1 Scope

This Technical Report specifies unified test procedures and conditions for the experimental determination of mechanical energy loss coefficients for ductwork components such as ducts, bends, diffusors, converging junctions and diverging junctions.

2 Normative references

This Technical Report incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references the subsequent amendments to or revisions of any of these publications apply to this Technical Report only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

CR 12792 Ventilation for buildings . Symbols, units and terminology

ISO 5221 Air flow measurement in an air handling duct.

3 Terms and definitions

For the purposes of this report, the terms and definitions and symbols are principally in accordance with CEN Technical Report CR 12792.

4 Test method

4.1 Principle

In principle it is possible to give a definition of energy loss produced by a component of air distribution systems.

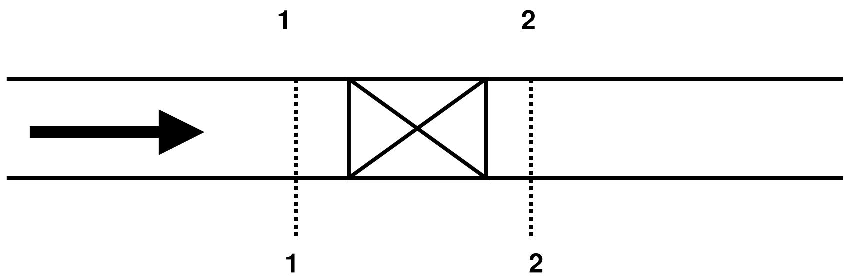


Figure 2 - Diagrammatic representation of energy flow

The mechanical energy loss in the flow within a typical component, as represented in Figure 2, is equal to the difference between the energy entering the component through section I and the energy leaving the component through section 2.

By applying the generalized Bernoulli formula which takes into account the fact that the air is compressible, therefore its density varies through the component, and that it is a real fluid, the velocity distribution in a section being non-uniform, the energy loss per unit mass (J/kg) is expressed by:

$$[\Delta y]_1^2 = \frac{p_1 - p_2}{\rho_{12}} + \alpha_{A1}\frac{v_{m1}^2}{2} - \alpha_{A12}\frac{v_{m2}^2}{2} + g(Z_1 - Z_2) \quad (1)$$

where

Δy is the energy loss per unit mass

p is the absolute pressure

V_m is the mean flow velocity

Z is the altitude

ρ_{12} is the fluid density

g is the free fall acceleration

α_A is the kinetic energy factor

The kinetic energy factor α_A can be determined by Pitot-tube exploration in the cross section under consideration. The density ρ_{12} depends on the flow variation through the component.

In practice the presence of an air handling component in a duct system modifies the flow structure upstream and downstream of the component. For this reason the practical determination of the mechanical energy losses is generally made on the test installation as shown in Figure 3.

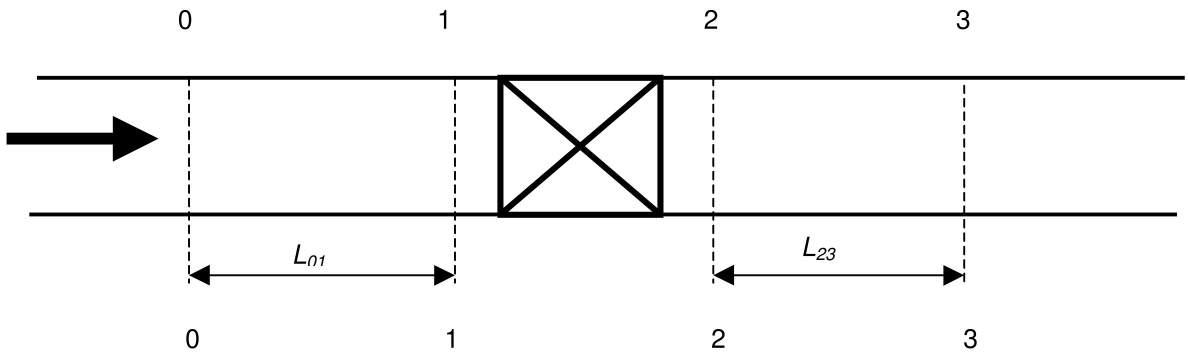


Figure 3 - Diagrammatic representation of the test installation

A straight duct of the length L_{01} is installed upstream of the component and a straight duct of the length L_{23} downstream. The measurement sections (0 upstream and 3 downstream) are consequently distant from the component. From the test values obtained in these sections the characteristics of flow are calculated for the sections I and 2 and then used in the generalized Bernoulli formula to obtain the mechanical energy loss.

The choice of lengths L_{01} and L_{23} and the assumptions concerning the flow through these duct sections can cause differences in the final results. Therefore an agreement on the choice of lengths shall be established before the start of the experimental work.

There is no intrinsic value of energy loss coefficient for an air handling component. For each upstream flow condition a different value will be found. Consequently the use of a long straight duct upstream of the component is just one of many possible conditions. However the different lengths of this duct and different entry conditions can produce variations in the flow pattern.

Therefore, it is important to specify in detail all characteristics of the installation upstream of the component. The upstream straight duct shall have a length equal to 200 and a specified perforated plate at the entrance. The measuring section shall be located at a distance 5D from the component.

The downstream flow pattern is dependent on the component under test. Usually a very long straight duct is used and the measuring section is a distance away in order to allow for the correct measurement. The energy loss of the ducting shall be taken into account in the calculation of the energy loss coefficient of the component under test. For the same length of straight duct this energy loss may be very different depending on the flow pattern (essentially in the presence or in the absence of swirl).

As the actual loss is not known the conventional energy loss corresponding to the fully established flow without swirl is normally used.

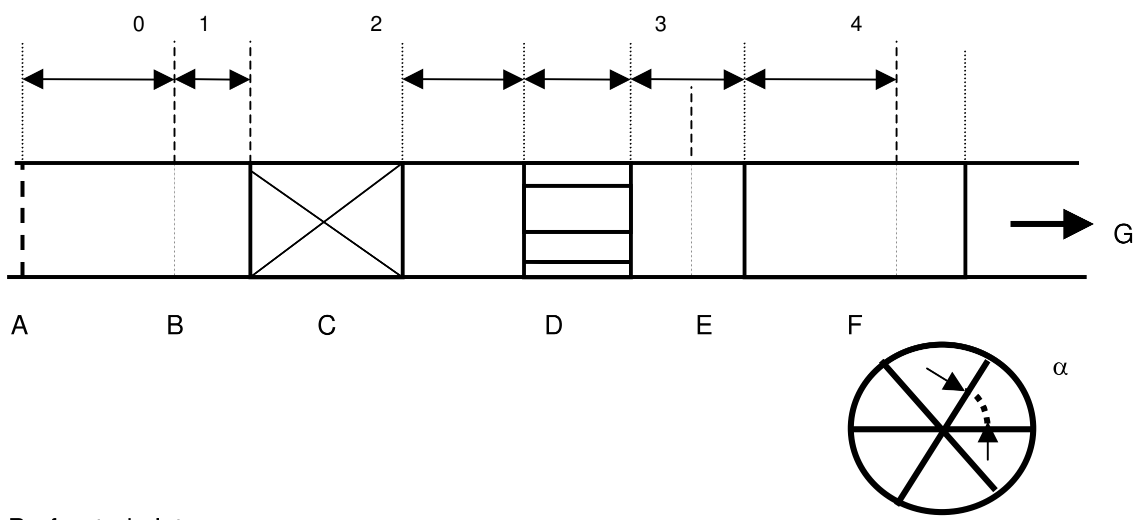
A specified flow straightener (as used for fan performance testing specified in ISO 5221) instead of a very long duct, (it can be as long as 40*D)* shall be installed immediately downstream of the component under test. The correct measurement of the pressure is then possible where the loss in the straightener and associated ducting is taken into account conventionally.

An important advantage of this method is the elimination of the necessity to measure the kinetic energy factor α_A in the upstream section as well as in the downstream section. It is assumed that α_A is equal to one. If a particular component produces a very strong swirling flow with an irregular velocity distribution, the energy loss in the straightener will be far greater than the conventional value used for the calculation. The energy loss coefficient of the component under test will appear higher.

These characteristics are presented in this way because in practice the rotational energy in fluid flow will be lost anyway and this loss is produced by the component (though not jn the component itself). It will be noted that in the usual method (a long straight duct downstream) this assumption is also applied but the measurement is more difficult and the scatter of results obtained in different laboratories can be important.

4.2 Test installation

The standard test installation is shown in Figure 4.



A Perforated plate
B Upstream measuring section
C Component under test
D Flow straightener “ETOILE’
E Downstream measuring section
F Complementary measuring
G Flow rate control and measurement

Figure 4 - Standard test installation

The following specification shall be used:

a) Duct diameter: Equal to the diameter of the component under test

b) Perforated plate at the inlet:

- diameter of holes: 5 mm
- distance between axes : 7,5 mm
- free area/total area: 0,40

c) Duct roughness: Smooth metal duct

d) Flow straightener "ETOILE" in accordance with the drawing

- Length: 20 (tolerance 1%)
- Thickness: < 0,0070
- Angle: $\alpha = 45° \pm 5°$

4.3 Rectangular and other non-circular ducts and components

For ducts and components with non-circular cross sections (essentially rectangular and oval) the notion of a hydraulic diameter shall be introduced. The hydraulic diameter is calculated as four times the cross section divided by the perimeter.

For a rectangular cross section with sides *a* and *b*, therefore, the hydraulic diameter D_h is given by:

$$D_h = \frac{4ab}{2(a+b)} = \frac{2ab}{(a+b)} \qquad (2)$$

The standard test installation shall be made with upstream and downstream ducts of the same cross section as the component under test; using D_h instead of D for the circular duct, all calculations will use the same formulae.

As an alternative solution a test installation with circular ducts may be used. The component under test shall be connected to the upstream and downstream ducts using a transition with the following specification:

- the cross section area of the circular duct shall be equal to the cross section area of the component with a tolerance of ± 10 %,
- The length of the transition shall be equal to one diameter of the circular duct,
- For the calculation of the energy loss coefficient under test, the energy loss in the transition shall be considered equal to the loss in a straight duct having the same length.

4.4 Measurements

The following quantities shall be measured:

a) Atmospheric pressure p_a, Pa

b) Air temperature θ °C, [$T = 273{,}15 + \theta$ K]

c) Air humidity from both dry and wet bulb or dew point temperature

d) Static pressure in the section 0 (mean value of four individual readings), p_{s0} Pa

e) Static pressure in the section 3 (mean value of four individual readings), p_{s3} Pa

f) Differential pressure between the section 0 and 3, p_{s03} Pa

g) Static pressure in the section 4 (mean value of four individual readings), p_{s4} Pa

h) Mass flow rate (by an appropriate standardized method as given in Annex B), q_m kg/s

4.5 Calculation method

4.5.1 The calculation method is given in 4.5.2 to 4.5.9

4.5.2 The absolute pressures are calculated for the sections 0 and 3 as follows:

$$p_0 = p_a - p_{s0} \quad (3)$$

$$p_3 = p_a - p_{s3} \quad (4)$$

4.5.3 The mean air density (which is assumed to be constant throughout the test installation) is calculated from:

$$\rho = \frac{p_m}{287T} \bullet f \quad (5)$$

where

$$p_m = \frac{p_0 + p_3}{2} \quad (6)$$

and the humidity factor f is given by:

$$f = 1 - 0{,}378 \bullet \frac{p_v}{p_m} \quad (7)$$

where p_v is the partial vapour pressure

4.5.4 The Reynolds number is calculated from:

$$\mathrm{Re} = \frac{4q_m}{\pi \mu D} \quad (8)$$

where the dynamic viscosity μ is given by:

$$\mu = (17{,}1 + 0{,}048 \cdot \theta)10^{-6} \quad (9)$$

4.5.5 The mean air velocity is calculated from the following:

$$v = \frac{4q_m}{\rho D^2 \pi} \quad (10)$$

4.5.6 The pressures in sections I and 2 are calculated from the following:

$$p_1 = p_0 - \zeta_{01} \bullet \frac{\rho v^2}{2} \quad (11)$$

$$p_2 = p_3 - \zeta_{23} \bullet \frac{\rho v^2}{2} \quad (12)$$

where

$$\zeta_{01} = 5\left(0{,}005 + 0{,}42\ \mathrm{Re}^{-0{,}30}\right) \quad (13)$$

and

$$\zeta_{23} = 0{,}95\ \mathrm{Re}^{-0{,}12} + 3\left(0{,}005 + 0{,}42\ \mathrm{Re}^{-0{,}30}\right) \quad (14)$$

Values of ζ_{01} and ζ_{23} for some Reynolds numbers are given in Table 1.

Table1 — Values of ζ_{01} and ζ_{23} for some Reynolds numbers

Re	ζ_{01}	ζ_{23}
50000	0,11	0,32
100 000	0,09	0,29
200 000	0,08	0,27
400000	0,07	0,24

4.5.7 The differential pressure between sections I and 2 shall then be calculated as follows:

$$p_1 - p_2 = \Delta p_{03} - (\zeta_{01} + \zeta_{23}) \bullet \rho \frac{v^2}{2} \quad (15)$$

4.5.8 The mechanical energy loss per unit mass is given by:

$$[\Delta y]_1^2 = \frac{p_1 - p_2}{2} \quad (16)$$

4.5.9 The energy loss coefficient for the component tested is then given by:

$$\zeta = \frac{p_1 - p_2}{\frac{\rho v^2}{2}} \quad (17)$$

4.6 Calculation of uncertainties

The uncertainties of the test results are determined by consideration of the formula used for calculating the energy loss coefficient of a component:

$$\zeta = \frac{p_1 - p_2}{\rho \frac{v^2}{2}} \quad (18)$$

In practice the value of p_1-p_2 is not measured directly and is calculated from the measured differential pressure Δp_{03} by:

$$p_1 - p_2 = \Delta p_{03} - (\zeta_{01} + \zeta_{23}) \bullet \rho \frac{v^2}{2} \quad (19)$$

The energy loss coefficient is therefore given by:

$$\zeta = \frac{\Delta p_{03}}{\rho \frac{v^2}{2}} - (\zeta_{01} + \zeta_{23}) \qquad (20)$$

The term $(\zeta_{01}+\zeta_{23})$ represents a calculated conventional value of the correction to be applied. It varies only slightly with Reynolds number; for example, for a Reynolds number variation of 100 % (for instance from 10^5 to 2×10^5) this coefficient varies only 8 %. As the Reynolds number can be readily known with an uncertainty of less than 2 ***%,*** it is clear that the uncertainty on $(\zeta_{01}+\zeta_{23})$ is very small.

Therefore, the uncertainty on ζ will be closely related to the uncertainty of the term:

$$\frac{\Delta p_{03}}{\rho \frac{v^2}{2}} \qquad (21)$$

In fact the absolute uncertainty of ζ will be very close to the absolute uncertainty of this term.

The term $\frac{\Delta p_{03}}{\rho \frac{v^2}{2}}$ can be developed as follows:

$$\frac{\Delta p_{03}}{\rho \frac{v^2}{2}} = \frac{\Delta p_{03}}{\frac{\rho}{2}\left[\frac{4 \cdot q_m}{\rho \cdot D^2 \cdot \pi}\right]^2} = \frac{\Delta p_{03} \cdot D^4 \cdot \pi^2}{8 \cdot q_m{}^2} \qquad (22)$$

In order to determine the overall uncertainty, the following expression shall be used:

$$\zeta = \frac{\Delta p_{03} \cdot D^4 \cdot \pi^2}{8 \cdot q_m{}^2} - (\zeta_{01} + \zeta_{23}) \qquad (23)$$

We can substitute $\zeta = X - Y$

where $X = \frac{\Delta p_{03} \cdot D^4 \cdot \pi^2}{8 \cdot q_m{}^2}$ (24)

and $Y = (\zeta_{01} + \zeta_{23})$ (25)

The absolute, and not the relative, values of the uncertainties for each of these terms shall be used to find the uncertainty associated with ζ, because ζ is calculated as a difference between, and not a product of, the two terms.

Where the absolute uncertainties of X and Y are ΔX and ΔY respectively, the absolute uncertainty of ζ will be given by:

$$\Delta\zeta = \sqrt{\Delta X^2 + \Delta Y^2} \qquad (26)$$

Because these are <u>absolute</u> uncertainties it is not possible to produce a general statement for all possible situations, and the relative magnitude of X and Y is very important

EXAMPLE

Consider the results obtained for a given component as follows:

Re = 100 000 with X = 0,73 and Y = 0,38 the loss coefficient is $\zeta = X - Y = 0{,}35$

If X is obtained with a relative uncertainty of 3 % and Y with a relative uncertainty of 0,3 % these values should be transformed into absolute uncertainties.

Therefore ΔX= 0,0219 and ΔY= 0,00114.

The absolute uncertainty $\Delta\zeta$ on ζ may then be estimated as follows:

$$\Delta\zeta = \sqrt{\Delta X^2 + \Delta Y^2}$$

The relative uncertainty on ζ is therefore 6,2 %.

With the same relative uncertainties on *X* and *Y*, but with a different relative magnitude of *X* and *Y*, the relative uncertainties on ζ will be different.

If *X* has about twice value of *Y* for component A and about three times value of *Y* for component B, the uncertainty on ζ will be about twice the uncertainty on *X* for component A and about 1,5 times the uncertainty on *X* for component B.

On examination of the term *X* it is apparent that four quantities shall be measured:

- pressure Δp_{03}
- duct diameter *D*
- density ρ
- flow rate q_m

It is clear that the flow rate should be measured with a very high accuracy. An error of 2 % in q_m will give 4 % for the term *X* and 8 % for the term ζ for component A used in the above example.

The second important quantity is Δp_{03} where an error of 2 % will give 2 % for X and 4 % for ζ for component A.

Highly sensitive micromanometers shall be used as there is no generally recognized National or International standard, but it is not possible to correctly evaluate the uncertainty associated with pressure measurement. Only a direct comparison between the pressure measuring instruments can allow this evaluation.

4.7 Number of test points

The mechanical energy loss coefficient of air handling components usually varies with Reynolds number. This variation is significant for low Reynolds numbers and generally the coefficient decreases when the Reynolds number increases. For Reynolds numbers higher that 150 000, however, the variation in the coefficient can be considered negligible.

Therefore, in order to decide the number of test points, the useful range of Reynolds numbers shall first be defined. A minimum of three tests shall be carried out as follows:

- at the minimum required Re
- at the maximum required Re
- at an intermediate Re

If the minimum required Reynolds number is above 150 000 a single test for one Reynolds number shall be sufficient.

4.8 Presentation of data

The test report shall include the following:

- a clear definition of the component tested
- the energy loss coefficient at corresponding Reynolds numbers

Annex A

Particular test arrangements

A.1 Components with inlet different from outlet (diverging or converging)

Where the inlet diameter of a component is different from its outlet diameter, the test installation shall be built according to the general principles using the inlet diameter *D*1 for the installation upstream of the component and the outlet diameter *D*2 for the installation downstream of the component. The upstream mean velocity v_1 and Reynolds number Re_1 shall be calculated using the measured mass flow rate and corresponding upstream cross section; the same calculation shall be applied for the downstream part of the test installation in order to calculate the downstream mean velocity v_2 and Reynolds number Re_2,

The differential pressure between Sections I and 2 shall be calculated from:

$$p_1 - p_3 = \Delta p_{03} - \zeta_{01} \frac{\rho v_1^2}{2} - \zeta_{23} \frac{\rho v_2^2}{2}$$

where

$$\zeta_{01} = 5\left(0{,}005 + 0{,}42\ \mathrm{Re}_1^{-0{,}30}\right)$$

and

$$\zeta_{23} = 0{,}95\ \mathrm{Re}_2^{-0{,}12} + 3\left(0{,}005 + 0{,}42\ \mathrm{Re}_2^{-0{,}30}\right)$$

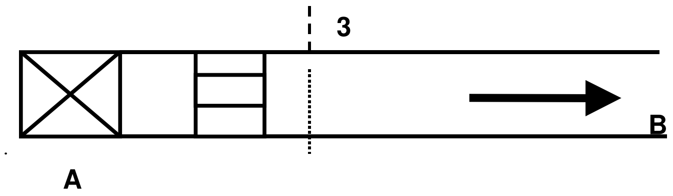
The energy loss coefficient of the component is given by:

$$\zeta = \frac{p_1 - p_2}{\rho \frac{v_1^2}{2}}$$

A.2 Components with free inlets

Components intended to be used at the inlet of air handling installations shall be tested in the condition corresponding to their normal use. Only the downstream part of the general test installation as shown in Figure A.I shall be used. The calculations shall be the same assuming that the differential pressure used to calculate the energy loss coefficient is given by:

$$p_1 - p_2 = p_3 - \zeta_{23} \frac{\rho v_2^2}{2}$$



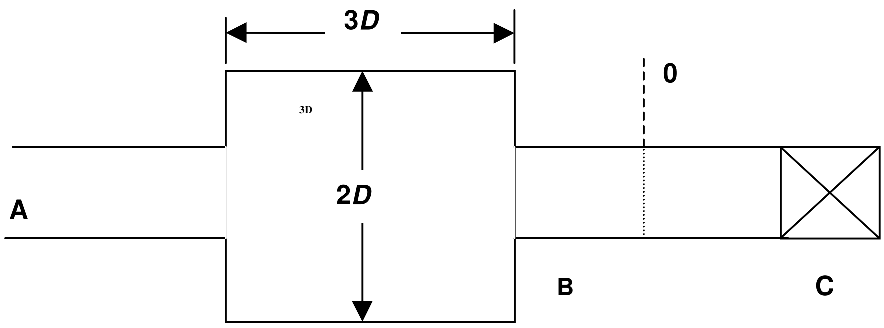
A Component under test

B Flow rate control and measurement

Figure A.1 —Testing components with free inlet

A.3 Components with free outlets

Components intended to be used at the outlet of air handling installations shall be tested in the conditions corresponding to their normal use. Only the inlet part of the general test installation shall be used. In order to allow the flow-rate control and measurement without changing test conditions, an inlet chamber shall be used as shown in Figure A.2. The flow measuring and control system shall be installed upstream of the component under test.



A Flow rate control and measurement

B Perforated plate

C Component under test

Figure A.2 — Testing components with free outlet

A.4 Components with two inlets (converging junctions)

By convention the inlet branches shall be designated as Branch A and Branch B, and the common section with the total flow as C.

The upstream test installation of both Branches A and B shall be built in accordance with the test installation for the general test method (i.e. perforated plate at the inlet, 20*D* long straight duct, pressure taps at 5*D* upstream of the component under test). The downstream test installation (common section C) shall be built in accordance with the test installation for the general test method (straight duct of 17*D* minimum length, straightener and pressure taps at 5*D* downstream of the components under test).

The test installation is shown in Figure A.3.

a) For each component two energy loss coefficients shall be defined, one for each branch. The procedure in accordance with clause 4 shall be applied with following specifications:

b) The energy loss coefficient for each branch shall be defined with respect to the dynamic pressure in the common Section C with total flow.

c) When correcting for the energy loss in the straight duct or in the straightener care shall be taken to apply the correct dynamic pressure and Reynolds number.

d) The number of test points shall be defined in accordance with the specification given in 4.5. However, for each total flow rate, tests shall be carried out for at least five flow rate ratios between branches (corresponding approximately to the ratio between the flow rate in one branch and the total flow rate equal to: 0, 0,3, 0,5, 0,7 and 1,0).

e) As there are three different flow rates for each case, at least two of them shall be measured. The use of the calibrated inlet perforated plate is recommended and the static pressure at section 0 can be used. An example of calibration is given in Figure A.4.

f) In order to change the flow rate ratio between branches it will be necessary to modify the flow resistance of the branches. For this purpose an inlet chamber in accordance with the drawing shown in Figure A.5 shall be used. This chamber shall have a diameter at least two times larger than the test duct diameter and a length equal to 3D. An orifice plate at the inlet shall be used in order to modify the flow rate. It is considered that the velocity distribution immediately upstream of the component under test will not be modified when such a chamber is used.

   In order to cover the complete range of flow rates the chamber shall be used successively on both inlet branches.

g) An example of the calculation is shown in Table A.1 referring to Figure A.3

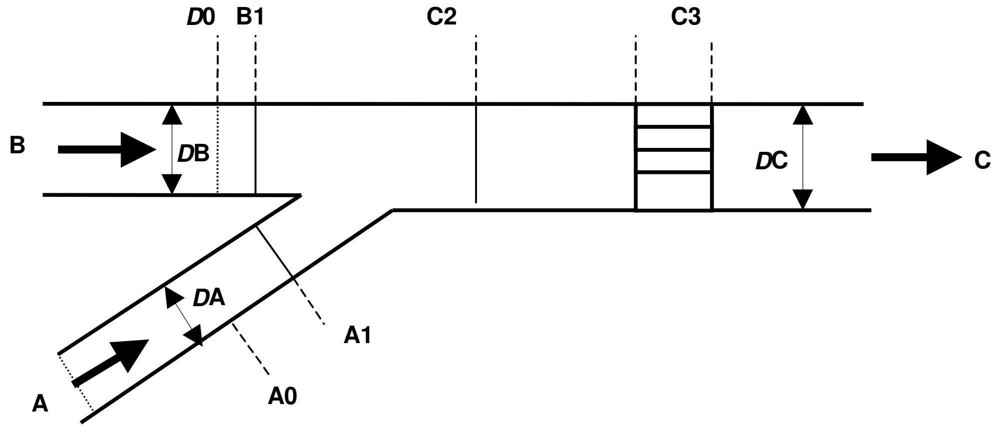


Figure A.3 — Converging junctions

Table A.1 — Example of calculation for converging junction

	BRANCH A (or BRANCH B)	**BRANCH C**
Mass flow-rate	q_{mA}	q_{mC}
Reynolds number	$Re_A = \frac{4q_{mA}}{\pi \mu D_A}$	$Re_C = \frac{4q_{mC}}{\pi \mu D_C}$
Mean velocity	$v_A = \frac{4q_{mA}}{\rho \pi D_A^2}$	$v_C = \frac{4q_{mC}}{\rho \pi D_C^2}$
Measured pressure differential	$\Delta p_{AC} = p_{A0} - p_{C3}$	
Calculated pressure differential	$p_{A1} - p_{C2} = \Delta p_{AC} - K$	
Correction term	$K = \zeta A_{01} \frac{\rho v_A^2}{2} - \zeta C_{23} \frac{\rho v_C^2}{2}$ where $\zeta A_{01} = 5 \left(0{,}005 + 0{,}42\ Re_A^{-0{,}30}\right)$ and $\zeta C_{23} = 0{,}95\ Re_C^{-0{,}12} + 3\left(0{,}005 + 0{,}42\ Re_C^{-0{,}30}\right)$	
Loss coefficient	$\zeta_{AC} = \frac{p_{A1} - p_{C2}}{\frac{\rho v_C^2}{2}}$	

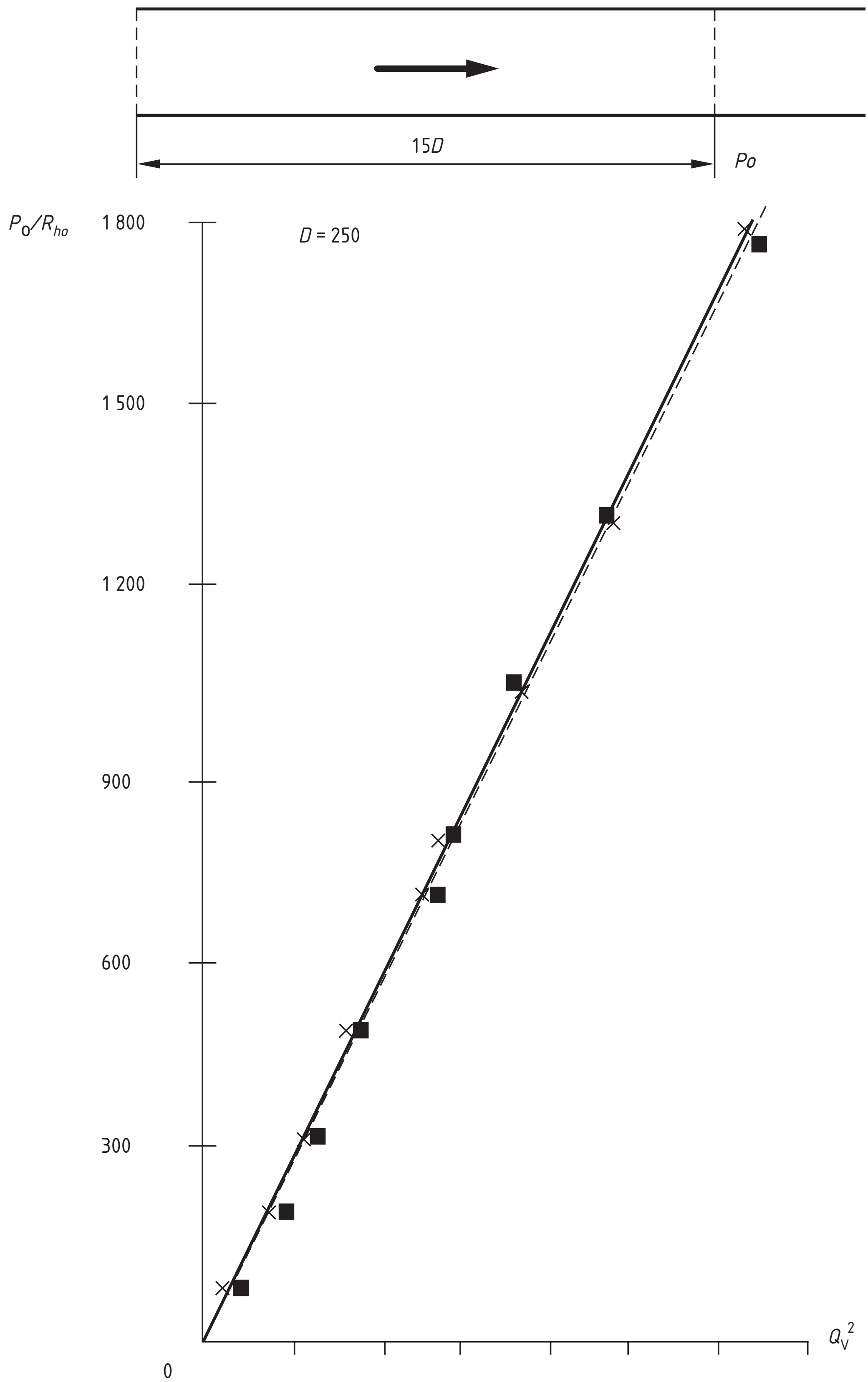
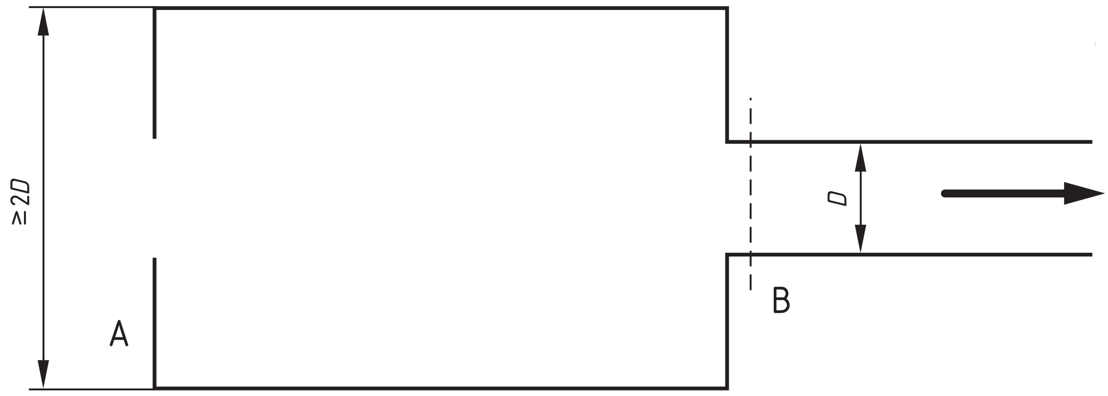


Figure A.4 — Calibrated perforated plate



Key

A Orifice plate
B Perforated plate

Figure A.5 — Inlet chamber for flow regulation

A.5 Components with two outlets (diverging junctions)

By convention the outlet branches shall be designated as Branch A and Branch B and the common inlet section with total flow as C.

The upstream test installation of the common Section C shall be built in accordance with the general test method (perforated plate at the inlet, 20*D* long straight duct, pressure taps at 5*D* upstream of the component under test). The downstream installation of both branches A and B shall be built in accordance with the general test method (straight duct of 17*D* minimum length, straightener and pressure taps at 5*D* downstream of the component under test). Each Branch A and B shall have its fan, flow rate measuring and controlling system.

The test installation is shown in Figure A.6 with an example of the calculation given in Table A.2.

For each component two energy loss coefficients shall be defined, one for each branch. The same procedure as in the general test method (Clause 4) shall be applied with following specifications:

a) The energy loss coefficient for each branch shall be defined with respect to the dynamic pressure in the common Section C with total flow.

b) When correcting for the energy loss in the straight duct or in the straightener the care shall be taken to apply the correct dynamic pressure and Reynolds number.

c) The number of test points shall be defined in accordance with the specification given in 4.7.

However, for each total flow rate, tests shall be carried out for at least five flow rate ratios between branches (corresponding approximately to the ratio between the flow rate in one branch and the total flow rate equal to: 0, 0,3, 0,5, 0,7 and 1,0).

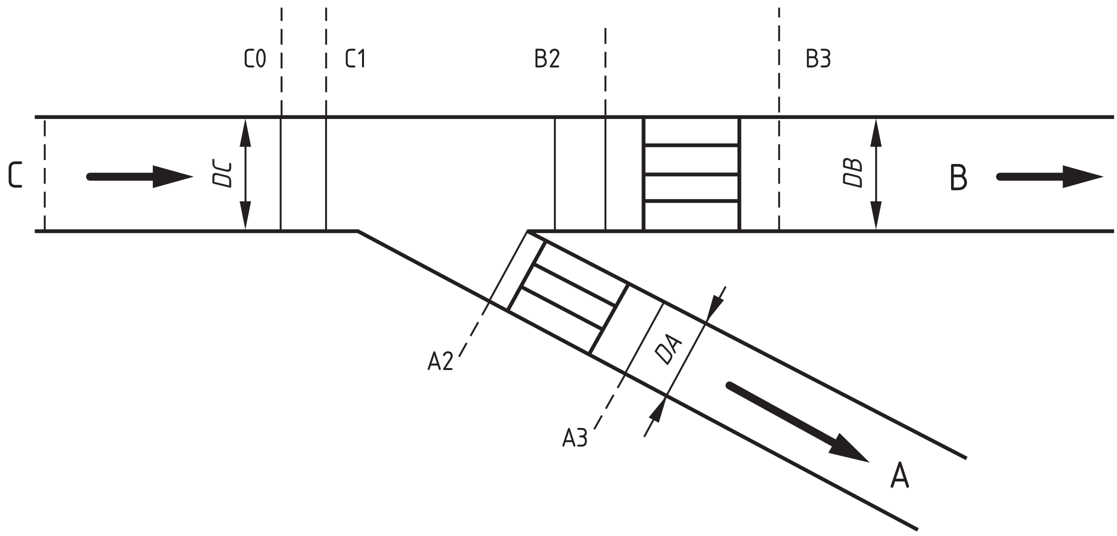


Figure A.6 — Diverging junctions

Table A.2 — Example of calculation for diverging junction

	BRANCH C (or BRANCH B)	BRANCH A
Mass flow-rate	q_{mC}	q_{mA}
Reynolds number	$Re_C = \frac{4q_{mC}}{\pi \mu D_C}$	$Re_A = \frac{4q_{mA}}{\pi \mu D_A}$
Mean velocity	$v_C = \frac{4q_{mC}}{\rho \pi D_C^2}$	$v_A = \frac{4q_{mA}}{\rho \pi D_A^2}$
Measured pressure differential	$\Delta p_{CA} = p_{C0} - p_{A3}$	
Calculated pressure differential	$p_{C1} - p_{A2} = \Delta p_{CA} - K$	
Correction term	$K = \zeta C_{01} \frac{\rho v_C^2}{2} - \zeta A_{23} \frac{\rho v_A^2}{2}$ where $\zeta C_{01} = 5\left(0{,}005 + 0{,}42\ Re_A^{-0{,}30}\right)$ and $\zeta A_{23} = 0{,}95\ Re_A^{-0{,}12} + 3\left(0{,}005 + 0{,}42\ Re_A^{-0{,}30}\right)$	
Loss coefficient	$\zeta_{CA} = \frac{p_{C1} - p_{A2}}{\frac{\rho v_C^2}{2}}$	

A.6 Components without swirl

When testing components with which it may be reasonably expected that swirl cannot be generated (such as straight ducts) the upstream part of the general test installation shall be used, as it is necessary to assure the standardized inlet flow conditions. However, as there is no possibility to generate a swirl in the flow the downstream installation shall be built in accordance with Figure A.7.

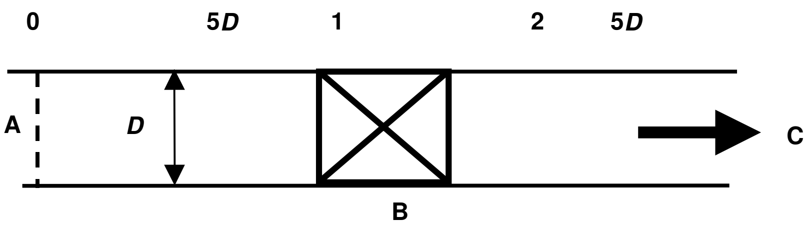


Figure A.7 —Testing of components without swirl

A Perforated plate

B Component under test

C Flow rate control and measurement

The differential pressure used to calculate the energy loss coefficient shall be:

$$p_1 - p_2 = p_0 - p_3 - (\zeta_{01} + \zeta_{23}) \frac{\rho v^2}{2} = \Delta p_{03} - (\zeta_{01} + \zeta_{23}) \frac{\rho v^2}{2}$$

$$\text{where } \zeta_{01} + \zeta_{23} = 10 \left(0{,}005 + 0{,}42 \text{ Re}^{-0{,}30}\right) \frac{\rho v^2}{2}$$

Annex B

Measuring techniques

B.1 Flow rate measurement

For the purposes of this Technical Report, the flow rate measurement shall be carried out using one of the fourteen methods described in ISO 5221.

The following shall be considered:

a) The fluid is air, its temperature and pressure being almost those at ambient conditions.

b) Because the flow rates are sometimes relatively small, the Reynolds numbers to be considered can sometimes correspond to relatively small values (for instance, some thousands)

c) The widest possible freedom of choice is provided in order to have methods which can be applied either to laboratory testing or to site testing

d) The methods of measuring air flow rates in a duct have reached a higher degree of accuracy than is sometimes necessary for the requirements of air distribution and air diffusion.

The values indicated for the uncertainty of the coefficients given shall be increased for the uncertainty of the air flow rate itself when inappropriate manometers are used.

Finally, it should not be forgotten that the values which are mentioned throughout this Technical Report would be seriously in error if the flow approaching the measuring devices herein do not offer any guarantee on this point without the addition of a suitable accessory.

In cases where low Reynolds numbers occur and where reduced requirements concerning accuracy are acceptable, special information is given in an Annex to ISO 5221.

One of the following devices shall be used:

1) Orifice plate with corner taps

2) Orifice plate with flange taps

3) Orifice plate with *D* and *D*/2 tappings

4) ISA 1932 nozzle

5) "Long radius" nozzle

6) Classical venturi tube

7) Venturi nozzle

8) Orifice plate with conical entrance

9) "Quarter circle" orifice plate

10) Orifice plate located at the inlet end of the system

11) "Quarter circle" nozzle located at the inlet end of the system

12) Inlet cone

13) Venturi nozzle with sonic throat (critical flow nozzle)

14) Pitot-static tube

B.2 Pressure measurement

B.2.1 Atmospheric pressure

The atmospheric pressure in the test enclosure shall be determined at the mean altitude between the inlet and outlet sections with an uncertainty not exceeding ± 0,2 %. Barometers of the direct reading mercury column type shall be read to the nearest 100 Pa (1 millibar), or to the nearest 1 mm of mercury. They shall 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 the gravitational acceleration [*g*].

NOTE 1 Correction can be unnecessary if the scale is preset for the regional value of of the gravitational acceleration [*g*] (within ± 0,01 $m \cdot s^{-2}$) and for room temperature (within ± 5 °C).

NOTE 2 Barometers of the aneroid or pressure transducer type can be used provided they have a calibrated accuracy of ± 200 Pa and the calibration is checked at the time of test.

B.2.2 Pressure difference

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 ± l % of the significant pressure or 1,5 Pa whichever is the greater.

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

Calibration shall be at a series of steady pressures, taken in both rising and falling sequence to check for any difference.

The reference instrument shall be a precision manometer or micro-manometer capable of being read to an accuracy of ± 0,25 %, or 0,5 Pa whichever is the greater.

Liquid column manometers shall be checked in their test location to confirm their calibration near the significant pressure. Inclined tube manometers shall be checked frequently 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.

B.2.3 Use of wall tappings

At each of the sections for pressure measurement in the standardized airways specified in Section 2, the average static pressure shall be taken to be the average of the static pressure at four wall tappings.

Each tapping takes the form of a hole through the wall of the airway conforming to the dimensional limits shown in Figure B.1. 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 0,1 times the diameter of the smaller hole [a] is permissible.

In the case of a cylindrical airway, the four tappings shall be equally spaced around the circumference. In the case of a rectangular airway they shall be at the centres of the four sides. Four similar tappings can be connected to a single manometer, but to avoid an averaging error it is recommended that they should be connected in pairs by two equal lengths of tubing as shown in Figure B.2. The mid points of these should be connected by a third tube and the manometer connected at the mid-point of this in accordance with 5.5.

NOTE The bore diameter should not be less than 1,5 mm and not greater than 5 mm or 0,1 *D*. Care shall be taken to ensure that all tubing and connections are free from blockage and leakage and contain no liquid. Before the commencement of any series of observations the pressure at the four side tappings shall be individually measured at a flow rate towards the maximum of the series. If any one of the four readings lies outside a range equal to 2 % of the significant pressure, the tappings and manometer connections shall be examined for defects, and if none are found the flow shall be examined for uniformity.

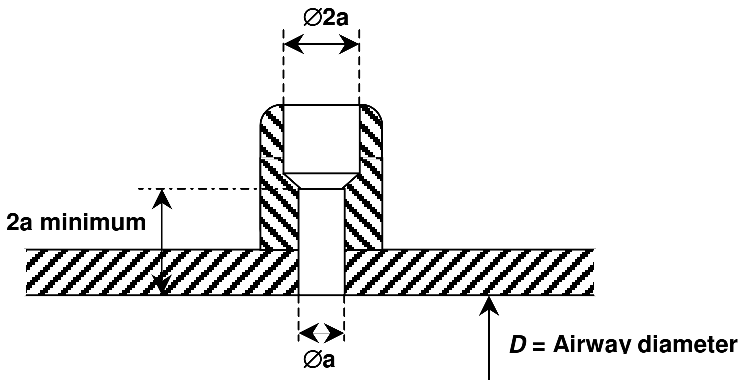


Figure B.1 —Construction of wall pressure tappings

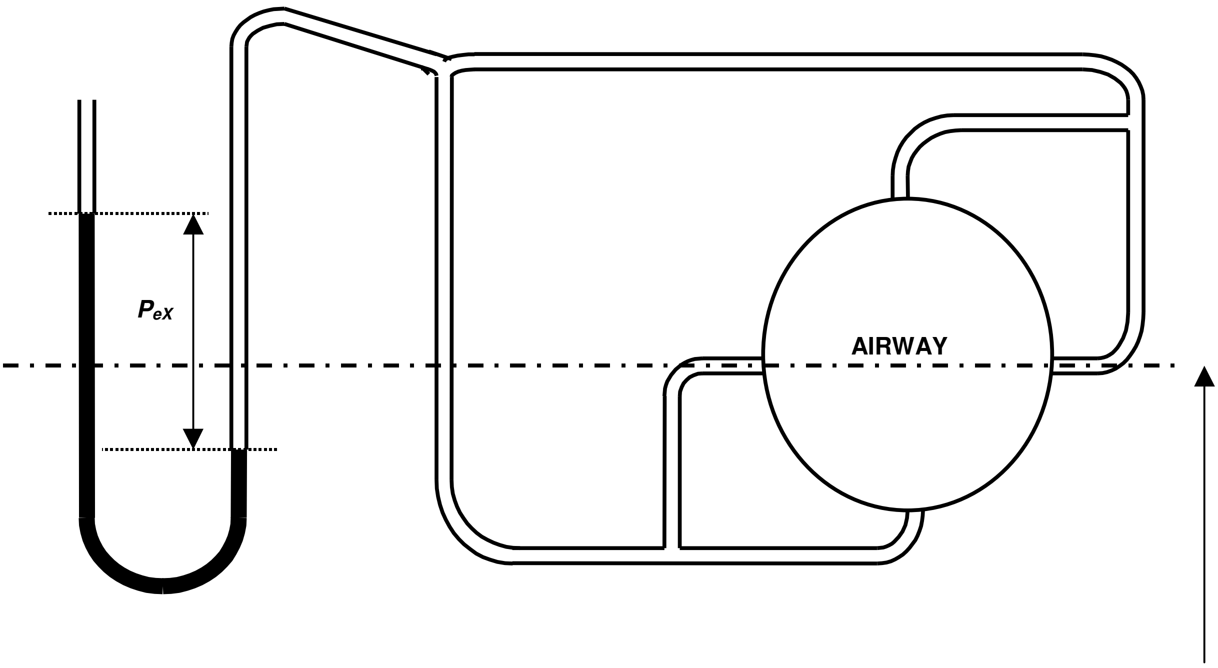


Figure B.2 — Tapping connections to obtain average static pressure and altitude of manometer

B.3 Temperature measurement

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

B.4 Humidity measurement

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

The wet-bulb thermometer shall be located in an air stream of velocity of at least 3 $m \cdot s^{-1}$. The sleeving shall be clean, in good contact with the bulb, and kept wet with pure water.

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

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