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Ventilation for buildings — Measurement of air flows on site — Methods

National foreword

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Contents

Page

Foreword 4
1 Scope 5
2 Normative references 5
3 Terms, definitions and symbols 5
3.1 Terms and definitions 5
3.2 Symbols 5
4 Principles and parameters of influence 7
4.1 Hydraulic diameter 7
4.2 Flow disturbances 7
4.3 Air density, ρ 7
4.4 Dynamic pressure, p_d 7
4.5 Corrections for air density, ρ 8
5 Sources of errors 8
5.1 General 8
5.2 Systematic errors 9
5.3 Random errors 10
6 Measurement uncertainty 10
6.1 Overall measurement uncertainty 10
6.2 Standard instrument uncertainty, u_1 11
6.3 Standard method uncertainty, u_2 11
6.4 Standard reading uncertainty, u_3 11
6.5 Expanded measurement uncertainty, U_m 11
7 Measurement requirements 12
7.1 Method requirements and corrections 12
7.2 Measurements using a manometer 12
7.3 Measurements using an anemometer 13
7.4 Measurements using Pitot static tube 13
7.5 Measuring temperature and barometric pressure 13
7.6 Mean value calculation of measurement signal 13
8 Methods for measurement of air flows in ducts – ID (In Duct) methods 13
8.1 Overview of recommended methods 13
8.2 Point velocity measurements using a Pitot static tube (method ID 1) or an anemometer (method ID 2) 14
8.2.1 Method description 14
8.2.2 Preparations to be made at the site of measurement 15
8.2.3 Measurement procedure 18
8.2.4 Corrections of measured values and calculation of air flow 19
8.2.5 Standard method uncertainty 20
8.3 Fixed devices for flow measurement – Method ID 3 20
8.3.1 Method description 20
8.3.2 Preparations of measurements — Equipment 20
8.3.3 Measurement procedure 21
8.3.4 Correction of measured values 21
8.3.5 Standard method uncertainty 21
8.4 Tracer gas measurement – Method ID 4 21
8.4.1 Method description 21
8.4.2 Equipment 22
8.4.3 Calculation of air flow 23
8.4.4 Standard measurement uncertainty 23
8.4.5 Conditions for homogeneous mixing of tracer gas 24

9 Methods for measurement of air flows in Supply ATDs (air terminal devices) – ST (Supply (Air) Terminal (Devices)) methods 25
9.1 Overview of recommended methods 25
9.2 Measurement of reference pressure – Method ST 1 25
9.2.1 Introduction 25
9.2.2 Equipment 26
9.2.3 Correction of measured values 26
9.2.4 Standard method uncertainty 27
9.3 Measurement with tight bag – Method ST 2 27
9.3.1 Method description 27
9.3.2 Limitations 27
9.3.3 Equipment 27
9.3.4 Preparation 28
9.3.5 Measurement 28
9.3.6 Correction of measured values 28
9.3.7 Standard method uncertainty 28
9.4 Measurements with flow hood – Method ST 3 28
9.4.1 Introduction 28
9.4.2 Equipment 29
9.4.3 Measurement 30
9.4.4 Correction of measured values 31
9.4.5 Standard method uncertainty 31

10 Methods for Exhaust ATDs (air terminal devices) – ET (Exhaust (Air) Terminal (Devices)) methods 32
10.1 Overview of recommended methods 32
10.2 Measurement of reference pressure at exhaust ATD – Method ET 1 32
10.2.1 Method description 32
10.2.2 Limitations 33
10.2.3 Equipment 33
10.2.4 Correction of measured values 33
10.2.5 Standard method uncertainty 34
10.3 Measurement using a flow hood – Method ET 2 34
10.3.1 Introduction 34
10.3.2 Equipment 34
10.3.3 Measurement 35
10.3.4 Correction of measured values 36
10.3.5 Standard method uncertainty 36

Annex A (informative) Uncertainties 37
A.1 Examples of calculations 37
A.2 Compound uncertainties 38
A.3 Example of applications 38

Bibliography 39

Foreword

This document (EN 16211:2015) has been prepared 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 January 2016, and conflicting national standards shall be withdrawn at the latest by January 2016.

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.

Measurement methods which are both correct and easy to use are developed and standardized to enable the commissioning and operational monitoring of air processing installations. Interior climate and air quality can often be improved considerably if the heating and ventilation system is managed in a way that ensures good functioning in the long term. It is thus important that the system is designed and constructed to allow measurement and monitoring to be performed using established and approved methods.

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, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

1 Scope

This European Standard specifies simplified methods for the measurement of air flows on site. It provides a description of the air flow methods and how measurements are performed within the margins of stipulated method uncertainties.

One measurement method is to take point velocity measurements across a cross-section of a duct to obtain the air flow. This simplified method is an alternative to the method described in ISO 3966 and EN 12599. This European Standard requests certain measurement conditions (length of straight duct and uniform velocity profile) to be met to achieve the stipulated measurement uncertainties for the simplified method.

2 Normative references

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

EN 12792, *Ventilation for buildings — Symbols, terminology and graphical symbols*

EN 14277, *Ventilation for buildings — Air terminal devices — Method for airflow measurement by calibrated sensors in or close to ATD/plenum boxes*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 12792 apply.

3.2 Symbols

The following symbols are used.

Symbol	Description	SI Unit	Symbol	Description	SI Unit
t	Time	s	O	Perimeter	m
ρ	Density	kg/m^3	p	Pressure	Pa
ρ_s	Standard conditions air density = *1,2*	kg/m^3	p_d	Dynamic pressure	Pa
ρ_r	Real density	kg/m^3	p_s	Static pressure	Pa
$\rho_{\vartheta\ tracer}$	Tracer gas density	kg/m^3	p_t	Total pressure	Pa
$\rho_{\vartheta\ duct}$	Duct air density	kg/m^3	p_u	Measured pressure	Pa
A	Cross-section Area	m^2	Δp	Differential pressure	Pa
a, b, c, etc.	Dimensions of length	mm	Δp_u	Measured differential pressure	Pa
L	Mixing length	mm	q	Air flow	m^3/s, l/s
H	Height of duct	mm	q_k	Corrected air flow	m^3/s, l/s
W	Width of duct	mm	q_s	Tracer gas flow	m^3/s, l/s
B	Barometric pressure	hPa	$q_{s\vartheta duct}$	Tracer gas flow at duct temperature	m^3/s, l/s
C	Contaminant concentration	ppm	$q_{stracer}$	Tracer gas flow at rotameter temperature	m^3/s, l/s
C_i	Initial tracer gas concentration	ppm	q_t	Total air flow	m^3/s, l/s
C_s	Tracer gas concentration in stationary condition	ppm	q_u	Measured air flow	m^3/s, l/s
D	Diameter	mm	ϑ	Temperature	°C
D_h	Hydraulic diameter	mm	ϑ_{duct}	Temperature in duct	°C
k_c	coverage factor	-	ϑ_{tracer}	Temperature of tracer gas	°C
k_1	Correction factor for density	-	V	Volume	m^3
k_2	Correction factor for duct shape	-	v	Air velocity	m/s
k	Flow factor	-	v_s	Standard air velocity	m/s
L_1	Smaller dimension of a rectangular duct	mm	v_r	Real air velocity	m/s
L_2	Larger dimension of a rectangular duct	mm	v_m	Air velocity, mean value	m/s
u_1	Standard Instrument uncertainty	-			
u_2	Standard Method uncertainty	-			
u_3	Standard Reading uncertainty	-			
u_m	Standard measurement uncertainty	-			
U_m	Expanded measurement uncertainty	-			

4 Principles and parameters of influence

4.1 Hydraulic diameter

The hydraulic diameter is the diameter of a circular duct which causes the same pressure drop at equal air velocity and equal friction coefficient, and is defined by the following formula:

$$D_\mathrm{h} = 4 \cdot A/O \quad (1)$$

For a rectangular duct this becomes:

$$D_\mathrm{h} = 2 \cdot L_1 \cdot L_2 \, / \, (L_1 + L_2) \quad (2)$$

where

L_1 and L_2 are the sides of the duct.

For a circular duct this becomes:

$$D_\mathrm{h} = D \quad (3)$$

4.2 Flow disturbances

Flow disturbances in ducts result in irregular velocity profiles.

NOTE Flow seldom has a symmetrical appearance except after long straight sections. The symmetry is often disturbed by varying resistance, for example after a bend, an area decrease or an area increase. The velocity profile also becomes disturbed by a damper and T-piece as well as before and after a fan.

4.3 Air density, ρ

The density of dry air varies with air pressure and temperature in accordance with the following approximating formula:

$$\rho = 1{,}293 \cdot \frac{B}{1013{,}25} \cdot \frac{273{,}15}{273{,}15 + \vartheta} \quad (4)$$

NOTE The relative humidity of the air (RH) has very little influence on the density of air at room temperature. The density of air at 20 °C and 1 013,25 hPa which is saturated with water vapour is only approximately 1 % less than equivalent dry air.

In a low-pressure system it is hardly necessary to consider the influence of static pressure on air density. In a high-pressure system, however, it can be necessary. The calculation is then performed as follows:

$$\rho = 1{,}293 \cdot \frac{B + 0{,}01 \cdot p_s}{1013{,}25} \cdot \frac{273{,}15}{273{,}15 + \vartheta} \quad (5)$$

4.4 Dynamic pressure, p_d

When measuring with a Pitot static tube a dynamic pressure is measured. The dynamic pressure can be used to calculate the air velocity by the use of the following formula:

$$p_\mathrm{d} = \frac{\rho \cdot v^2}{2} \quad (6)$$

4.5 Corrections for air density, ρ

When presenting a measured air flow or velocity, it should be stated if it is the real air flow or the flow converted to standard conditions that is presented. The measurements should correspond to the designed air flow values of the system (real or standard air flow). The methods in this standard present the measurements as real air flow. How to convert between standard and real velocity is described in 4.5. The same conversion is also valid for air flow.

The real flow rate of air is as it is at the present temperature and barometric pressure of the air. Standard air flow is used to present the air flow at standard condition of 1 013,25 hPa and 20 °C. A fan transports approximately the same amount of air independent of air density. The amount of standard flow changes with air density.

The instrument in use can measure real or standard air flow or it could require calibration conditions to display correctly. Compensate accordingly, especially when used for other conditions than calibration condition or standard conditions of 1 013,25 hPa and 20 °C. The barometric pressure will decrease with altitude and also vary with weather.

Convert real flow or velocity to standard flow or velocity by using the following formula:

$$v_s = v_r \cdot \rho_r / \rho_s \quad (7)$$

5 Sources of errors

5.1 General

There are many factors which affect the measurement results which shall be checked in connection with measuring. These factors are for example:

a) calibration equipment, which shall be regularly compared with a traceable norm (calibration unit);

b) calibrated measurement instruments;

c) calibration intervals;

d) examination of instruments’ long term stability;

e) instruments’ temperature or density compensation;

f) random instrument uncertainties;

g) random reading uncertainties;

h) variations in the measured quantity;

i) measurement methods adapted to different installation cases;

j) random uncertainties in measurement methods;

k) measurement methods’ influence on the flow rate;

l) variations in the exterior climate;

m) air flow stability.

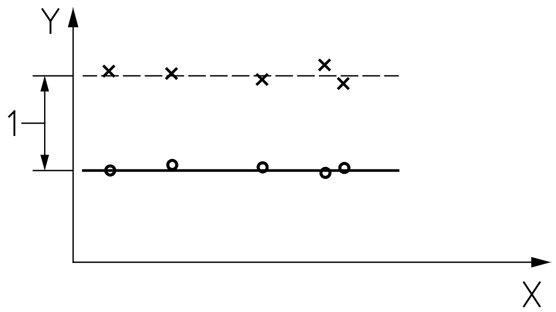
Certain sources of error are difficult to manipulate, others can be reduced or even eliminated. Errors in given data input can be the result of measurements which have been affected by system errors or temporary disturbances. Errors in measurement data can be divided into:

- gross errors, which can happen as a result of the human factor and should be avoided to comply with this standard;
- systematic errors;
- random errors.

5.2 Systematic errors

According to the definition, systematic errors occur if the individual measurement values deviate in the same direction from the "true" value or if they vary in a regular fashion.

The result of measurements where systematic errors occur can appear as in Figure 1.



Key

1 systematic Error

X time

Y value

Figure 1 — Explanation of systematic error

The circles represent measured numbers which lie randomly spread around the true value and which according to the definition are thus free from systematic errors.

The crosses represent results of measurements where the measured numbers lie too high, for example as a result of an uncalibrated measuring instrument being used. This error can easily be rectified by calibrating the instrument and determining a correction.

The following applies to a correction:

Correction = (estimate of true value) – (read value)

or

(Read value) + *(correction) = estimate of true value*

Estimates of true values are also often called measured values. To make corrections it is recommended to add a correction value (positive or negative) instead of multiplying with a correction factor.

Calibration is a part of the determination of the systematic errors of an instrument, which allows the understanding of the calibration uncertainty, to eventually set up the instrument or correct the measurements and by its repetition to assess the drift uncertainty.

An instrument shall always be able to give a correct measured value. This means that calibration shall take place at regular time intervals. It is recommended that electronic instruments used for pressure, flow and velocity measurements are calibrated regularly according to their drift to obtain the uncertainty required. The instrument and other equipment that influence the measurement result (e.g. the bag in the tight bag measuring method) should be calibrated using a method with a (known) low uncertainty, traceable to international calibration standards.

Calibration tables where corrections, or alternatively the real value, are evident should be used.

5.3 Random errors

Even if systematic errors are successfully eliminated, repeated measurements of the same quantity cannot produce identical results despite the measurements being made thoroughly. This type of error is usually defined as a result of chance and is called uncertainty. This means that the size and character of the uncertainty cannot be accounted for in advance. There are several possible sources of random uncertainties, e.g. reading uncertainties, instrument uncertainties, method uncertainties, problem of repeatability due to the operator, variation of the environmental conditions, etc. In general, the random uncertainties can be reduced by increasing the number of measured points or by increasing the time of measurement thanks to instruments with mean value function.

The random uncertainties due to the reading, the instrument and the method are discussed in more detail in Clause 6.

6 Measurement uncertainty

6.1 Overall measurement uncertainty

The overall measurement uncertainty should be presented as expanded measurement uncertainty with a coverage probability of approximately 95 %. See 6.5. and the Example in Annex A. When calculating uncertainty using Formula (8) the uncertainties shall all have the same coverage probability of approximately 68 %.

The measurement standard uncertainty, u_m, is calculated using the following formula:

$$u_\mathrm{m} = (u^2_1 + u^2_2 + u^2_3)^{½} \tag{8}$$

where

u_1, u_2 and u_3	are random standard uncertainties with a coverage probability of approximately 68 %;
u_1	is the standard instrument uncertainty, such as hysteresis, temperature compensation, drift, etc. The instrument uncertainty is normal distributed;
u_2	is the standard method uncertainty, resulting from deviations from the calibration method for the measurement method. In this type are also included deviations from the calibration curve for series-produced measurement devices, dampers or terminals with in-built measurement outlets. The method uncertainty is normal distributed;
u_3	is the standard reading uncertainty. The reading uncertainty is rectangular distributed for digital instruments.

6.2 Standard instrument uncertainty, u_1

Even after correcting a read value or a measured mean value with regards to different influences, there still remain random uncertainties in measurements. Instrument uncertainty includes calibration uncertainty and uncertainty from the instrument itself, such as hysteresis, temperature compensation, drift, etc.

Information on this uncertainty shall be supplied by the instrument manufacturer and it is important to check that the coverage probability of approximately 68 % is used. The user shall make an estimate of the standard instrument uncertainty that also includes hysteresis, drift, environmental influence, etc.

Some instruments have an upper and lower uncertainty value (limit) and the uncertainty can in this case be judged to be rectangular distributed:

$$u_1 = \frac{\text{value}}{\sqrt{3}} \tag{9}$$

Corrections are known errors and not included in the instrument uncertainty. Correct the measurement values by using corrections from the calibration certificate. Even after correcting a read value or a measured mean value with regards to different influences, such as corrections, there still remains random uncertainties in measurements. Instrument uncertainty includes calibration uncertainty and uncertainty from the instrument itself, such as hysteresis, temperature compensation, drift, etc.

6.3 Standard method uncertainty, u_2

When measurements are taken, an accurately specified method should be used. As a result of deviations from the method, e.g. the orientation of a probe, distance between the probe and a grille, etc., certain random uncertainties are produced by the method. For those methods described in Clause 8 to Clause 10, the uncertainty is stated as a standard uncertainty with 68 % coverage probability – one standard deviation for each method. The method uncertainties are normal distributed.

6.4 Standard reading uncertainty, u_3

This type of uncertainty can be attributed to reading uncertainties, so that the resolution can play a large part, especially with analogue instruments.

For digital instruments, reading uncertainty:

$$u_3 = \frac{1}{2\sqrt{3}} \text{ of resolution.} \tag{10}$$

EXAMPLE For an instrument with 0,1 resolution u_3 is 0,03.

In case of digital pulse readout the uncertainty shall be estimated; if this is not possible then an average function over time can be used. For instruments with an analogue display, the standard uncertainty can be estimated as 1/6 of a scale interval.

6.5 Expanded measurement uncertainty, U_m

In order to cover most measurement results it is necessary to present the overall measurement uncertainty with a coverage probability of approximately 95 %. The expanded uncertainty of measurement is stated for a normal distribution as the standard uncertainty of measurement multiplied by the coverage factor $k_c = 2$. That means that the measurement uncertainty covers 95 % of the measurements and that 5 % fall outside the stated uncertainty.

Expanded measurement uncertainty, U_m:

$$U_m = k_c \cdot u_m \quad (11)$$

where

k_c = 2

7 Measurement requirements

7.1 Method requirements and corrections

The measurement methods which are used shall have small method uncertainties. The requirements for method uncertainties shall be to some extent related to the requirement for flow tolerances.

A measurement shall be based on a well-defined method, in which both measurement points as well as the measuring instrument shall be decided. This does not mean that certain selected instruments should be standardized, but that there is a decided procedure with norms for the instrument to be used.

Measurement values are evaluated in a specified way for the method chosen, after which the values are corrected for the method. A correction factor is commonly used at this point, from which:

Correct value = (measured value) · (correction factor for the method)

7.2 Measurements using a manometer

When measuring with a manometer, minimum resolution and maximum uncertainty should apply, in accordance with Table 1.

Table 1 — Resolution for the ranges of manometers

Range Pa	Resolution Pa	Uncertainty
Up to and including 50	0,1	0,5 Pa
Above 50	1	± 0,5 % of reading

The lowest acceptable measured pressure is 3 Pa if the manometer has not lower uncertainty than stated in Table 1.

The manometer should be:

a) zeroed before each measurement; or

b) equipped with a function which automatically zeroes the instrument:

   1) after a certain time period; or

   2) before each measurement; or

   3) compensates the measurement with the offset checked with a following auto zero.

7.3 Measurements using an anemometer

Hot wire anemometers should not be used for measuring velocities less than 0,2 m/s when the air flow shall be determined. At low air velocity the total uncertainty (in %) shall be increased due to the influence of the hot wire uncertainty (standard instrument uncertainty in %).

Mechanical anemometers should not be used when measuring velocities less than 1 m/s. If a vane anemometer is used at lower velocity (in close range of the start threshold of the device), the total uncertainty (in %) shall be increased due to the influence of the vane anemometer uncertainty (in %) at lower air velocity.

The overall diameter of the device obstructing the duct passage area should not exceed 1/10 of the duct diameter.

7.4 Measurements using Pitot static tube

The diameter of the Pitot static tube obstructing the duct passage area should not exceed 1/30 of the duct diameter.

For ducts with a diameter of minimum 100 mm Pitot static pipes of maximum diameter 4 mm are allowed.

Measurement using a Pitot static tube should not be used for velocity measurements of less than 2,5 – 3 m/s

NOTE It is linked to the minimum acceptable pressure measurement (see 7.2).

Any other tube with equivalent or higher accuracy can also be used in conjunction with this standard.

7.5 Measuring temperature and barometric pressure

To make the measurement use, for example, a resistance thermometer or thermo-couples. Instruments shall have a resolution better than 0,1 °C and be calibrated to an accuracy of ± 0,3 °C or better. To take measurements of barometric pressure a barometer with a resolution of 1 hPa and an accuracy of ± 5 hPa or better should be used.

No corrections for air density are required during the proportional balancing of terminals and branch ducts providing that the entire installation is balanced under the same running conditions. For this reason, heaters in terminals and branch ducts, for example, shall be switched off.

Heating or cooling devices in the duct between the fan and the place of measurement shall be switched off while measuring air flow or air velocity.

7.6 Mean value calculation of measurement signal

In order to eliminate reading uncertainties as much as possible, instruments with a mean value calculation function should be used. The instrument shall calculate the mean value from a minimum of 15 readings that are a minimum of 0,1 s apart.

8 Methods for measurement of air flows in ducts – ID (In Duct) methods

8.1 Overview of recommended methods

An overview of recommended methods is given in Table 2.

Table 2 — Methods of measurement of airflows in duct

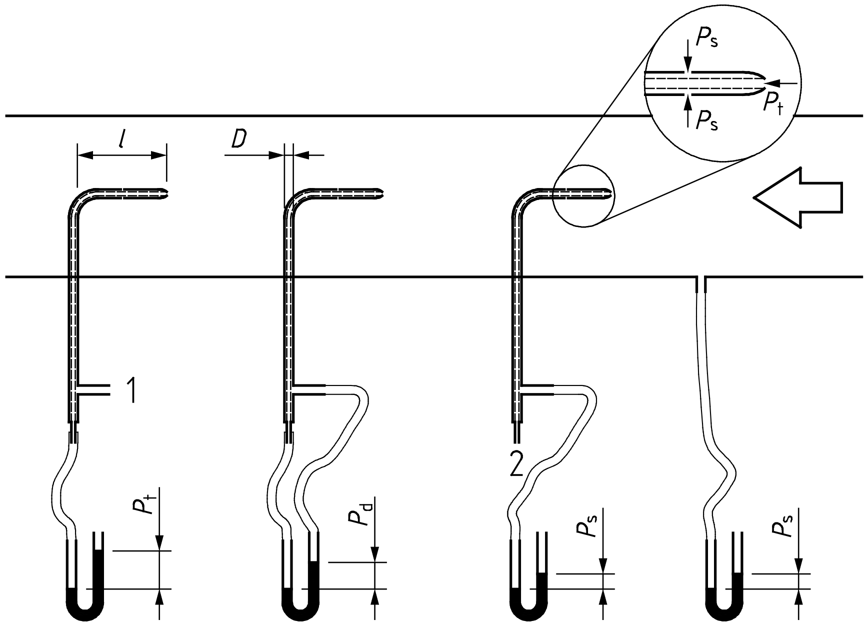
Method	Designation	See Subclause	Standard method uncertainty, u_2
Point measurements using a Pitot static (Prandtl) tube:	ID 1	8.2	
1) Circular cross-section	ID 11		4 % (case A) – 6 % (case B)
2) Rectangular cross-section	ID 12		4 %
Point measurement using hot-wire anemometer or mechanical anemometer:	ID 2	8.2	
1) Circular cross-section	ID 21		4 % (case A) – 6 % (case B)
2) Rectangular cross-section	ID 22		4 %
Fixed flow measurement devices:	ID 3	8.3	5 % (Applies generally using the installation measurements obtained with testing method)
1) Without damper	ID 31		
2) With damper	ID 32		
Tracer gas	ID 4	8.4	5 % or 10 % depending on mixing length

8.2 Point velocity measurements using a Pitot static tube (method ID 1) or an anemometer (method ID 2)

8.2.1 Method description

This method involves the flow being calculated from a series of velocity measurements in the duct cross-section. The determination of velocity is carried out using a Pitot static (Prandtl) tube or anemometer. For the Pitot static tube the velocity is calculated from the differential pressure measurement. Any other tube for air velocity measurement with equivalent or higher accuracy than a Pitot static tube can also be used.

A Pitot static tube measures both total and static pressure. It consists in principle of a tube placed inside another tube. Both the static and the dynamic pressure enter the orifice of the inner tube. In order for the measurement result to be correct, the orifice shall point directly into the axis of flow. The static pressure is measured through holes in the mantle surface of the outer tube. The principles involved in making measurements with a Pitot static tube are illustrated in Figure 2.



Key

1 connection for static pressure

2 connection for total pressure

Figure 2 — Measurements with Pitot static tubes

The following relationship can be established for the pressure conditions at the connections for total and static pressure:

Connection for total pressure:

$$p = p_{\mathrm{s}} + p_{\mathrm{d}} = p_{\mathrm{s}} + \frac{\rho \cdot v^2}{2} \quad (12)$$

Connection for static pressure:

$$p = p_{\mathrm{s}} \quad (13)$$

The differential pressure obtained by connecting both outlets to a manometer is:

$$p_{\mathrm{d}} = \frac{\rho \cdot v^2}{2} \quad (14)$$

The air velocity can be determined from this dynamic pressure:

$$v = \sqrt{\frac{2 \cdot p_{\mathrm{d}}}{\rho}} \quad (15)$$

8.2.2 Preparations to be made at the site of measurement

8.2.2.1 Equipment

For this method a manometer with Pitot static tube for use above 2,5 m/s or anemometer, both with indication of insertion length and a thermometer and barometer are needed.

8.2.2.2 Necessary straight sections before and after the plane of measurement

The flow profile has a distorted appearance after certain disturbances to the flow, e.g. bends or dampers. If measurement takes place directly after a flow disturbance there is a risk of poor accuracy. For this reason it is necessary to have duct sections free from disturbances both before and after the plane of measurement with length *a* as in Table 3. The table states the minimum requirements of straight sections and the selected plane of measurement shall be checked in accordance with 8.2.3.

Table 3 — Necessary straight sections before and after the plane of measurement

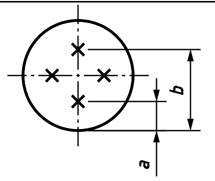
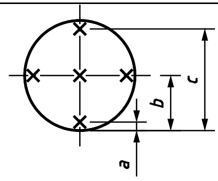
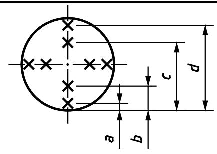
Straight sections	Circular duct	Rectangular duct
Before plane of measurement	$a \geq 5 \cdot D$	$a \geq 6 \cdot D_h$
After plane of measurement	$a \geq 2 \cdot D$	$a \geq 2 \cdot D_h$

8.2.2.3 Preparation procedure and selection of measuring planes

1) Select the location of the plane of measurement according to Table 3, taking into consideration the required straight sections. After certain types of disturbances, throttling dampers among others, considerably longer straight sections can be required. In the case of circular ducts, the plane of measurement should be located at least 150 mm upstream of any duct joints. For rectangular ducts, the plane of measurement should be located at least 50 mm upstream of any C-clip joint. Rectangular ducts with a dimension exceeding 600 mm are normally cross-profiled in order to be more stable with regard to pressure changes. If possible, measurements should be made from a non-profiled side.

2) Remove the external insulation at the point of measurement. Great care should be taken at measurements in internally insulated ducts since it is difficult to exactly determine the location of the point of measurement. If measurements are made in internally insulated ducts the diameter or rectangular dimensions together with the measurement points locations shall be recalculated, taking into consideration the thickness of the insulation according to Table 4 or alternatively Tables 5 to 7.

Table 4 — Measurement points for circular ducts

Nominal Diameter [a] D mm	Position of measurement points	a mm	b mm	c mm	d mm	Figure
100 125 160	$a = 0,29 \cdot D$ $b = 0,71 \cdot D$	29 36 46	71 89 114			
200 250 315 400	$a = 0,10 \cdot D$ $b = 0,50 \cdot D$ $c = 0,90 \cdot D$	20 25 32 40	100 125 158 200	180 225 283 360		
500 630 800 1 000 1 250	$a = 0,043 \cdot D$ $b = 0,290 \cdot D$ $c = 0,710 \cdot D$ $d = 0,957 \cdot D$	22 27 34 43 54	145 185 230 290 360	355 445 570 710 890	478 603 766 957 1 196	

[a] According to duct standard.

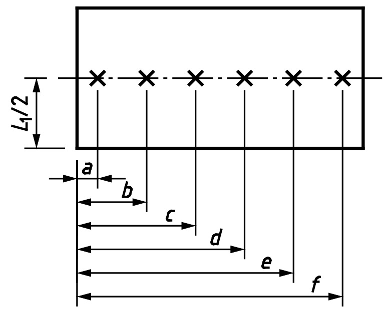
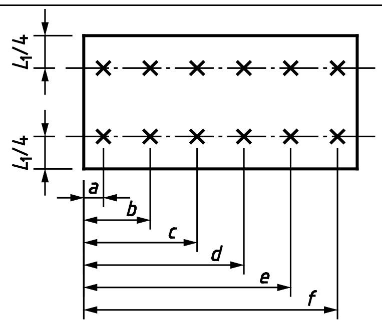
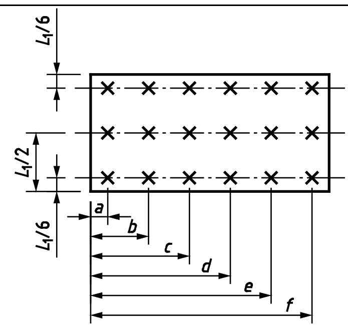
Table 5 — Measurement points for rectangular ducts related to the longer dimension: L_2

$150 \le L_2 \le 300$ mm		$300 < L_2 \le 2\,000$ mm		
$a = 0,08 \cdot L_2$	$b = 0,43 \cdot L_2$	$a = 0,06 \cdot L_2$	$b = 0,235 \cdot L_2$	$c = 0,43 \cdot L_2$
$c = 0,57 \cdot L_2$	$d = 0,92 \cdot L_2$	$d = 0,57 \cdot L_2$	$e = 0,765 \cdot L_2$	$f = 0,94 \cdot L_2$

Table 6 — Measurements points for rectangular ducts related to the longer dimension — Values recalculated in accordance with L_2

L_2	**150**	**200**	**250**	**300**	**400**	**500**	**600**	**800**	**1 000**	**1 200**	**1 400**	**1 600**	**1 800**	**2 000**
a	13	16	20	25	25	30	35	50	60	70	85	95	110	120
b	65	85	110	130	95	120	140	190	235	280	330	375	420	470
c	85	115	140	170	170	215	260	345	430	515	600	690	775	860
d	137	184	230	275	230	285	340	455	570	685	800	910	1 025	1 140
e	-	-	-	-	305	380	460	610	765	920	1 070	1 225	1 380	1 530
f	-	-	-	-	380	470	565	750	940	1 130	1 315	1 505	1 690	1 880

Table 7 — Measurements points for rectangular ducts on the height, L_1

100 ≤ L_1 ≤ 400	400 < L_1 ≤ 800	800 < L_1 ≤ 2 000
		

3) Ensure that the lighting is good at the place of measurement.

4) Drill holes in the duct so that measurements can be made along lines in a cross-section. The cross-section shall be perpendicular to the axis of the duct. For circular ducts: The two lines shall be perpendicular to each other. In case A, one of the lines of points is placed in the same plane as the axis of the duct and the centre of the bent upstream the duct. If this is impossible (e.g. access restriction) use two other perpendicular lines in the cross-section case B. Note that the uncertainty is higher in case B. The reasons for the increase of uncertainty in case B is that the flow profile is different from case A and that the location of the probe is more difficult in comparison with case A. In Figure 3, cases A and B are shown for a horizontal duct with horizontal and/or vertical ducts upstream.

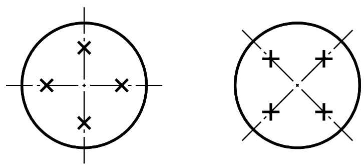


Figure 3 — Cases A and B — Cross-section of a horizontal duct — A bent upstream is in a horizontal or vertical plane

8.2.3 Measurement procedure

It is important that the Pitot static tube is kept parallel to the direction of flow (if oblique to the flow, this results in either too low or too high readings) and at the correct point of measurement. First determine the velocity distribution as described:

Measure the dynamic pressure in the centre of the cross-section.

Search for the position of highest dynamic pressure and note both its value and location.

If this maximum pressure is located further from the duct wall than 0,1 D (0,1 D_h) and the maximum dynamic pressure is less than two times the dynamic pressure in the centre (anemometer: the maximum velocity is less than 1,4 × the velocity in the centre), and if no backflow is detected in the cross-section, the plane of measurement is approved. Measurement points are selected as in Table 4 for circular ducts and as in Tables 5 to 7 for rectangular ducts and the measurement is made.

If these three criteria are not met, a new plane of measurement is selected.

If no plane of measurement is found that meets these three criteria, measurements should not be made according to this method (ID 2) whether by means of a Pitot static tube or by means of an anemometer.

Barometric pressure, air flow temperature, outside air temperature, duct dimension and distance to obstacles of flow are measured and noted. In addition, any velocity pulsation is noted.

After all measurements are completed, the holes are sealed in a sustainable way (for example by mean of a plastic plug).

8.2.4 Corrections of measured values and calculation of air flow

When measuring air velocity, correction is made for:

1) instrument error (systematic error): compensate by applying calibration corrections in accordance with the calibration certificate and/or calibration instruction for the instrument;

2) air temperature and barometric pressure.

There are manometers and anemometers that are programmed to compensate for density and displays real velocity directly by the use of the measured or selected values of temperature and barometric pressure. See the instrument manual. In the case of static over-pressure or under-pressure of more than 2000 Pa, the static pressure change caused by the fan shall be added to the barometric pressure.

A temperature compensated thermal anemometer should be used, otherwise it should be calibrated at the same temperature as that of the duct. Even in the case of the use of a temperature compensated thermal anemometer, generally, the indicated velocity is not the real velocity but a velocity which could occur at standard conditions of pressure, temperature and humidity for some manufacturers. These standard conditions differ from one manufacturer to another. Refer to the manual or the manufacturer directly to know what are his specific standard conditions. See 4.5 to convert standard velocity to real velocity.

A manometer or anemometer that displays the air velocity by using the standard density of ρ = 1,2 kg/m^3 needs to be corrected by the density according to Figure 4 to display the real velocity. Multiply measured velocity with (k_1) to obtain corrected velocity according to Figure 4. Alternatively use Formula (16) to obtain (k_1):

$$k_1 = \sqrt{\frac{1\,013,25 \cdot (273,15 + \vartheta)}{B \cdot 293,15}} \tag{16}$$

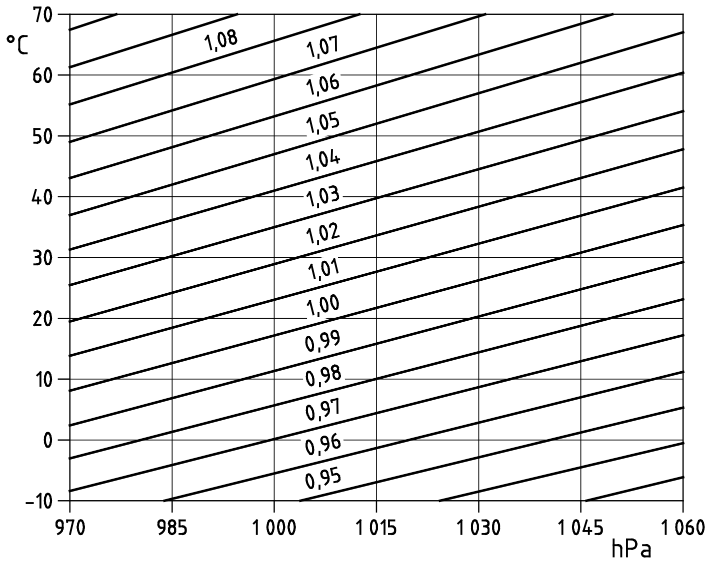


Figure 4 — Correction factor k_1 for density

a) The air flow is calculated by multiplying the average air velocity with the duct area in accordance with the formula: $q = v_{m.} \cdot A$

b) Duct shape (measurement points used). This correction (k_2) is made in accordance with Table 8 and 9 Multiply calculated flow with (k_2) to obtain corrected flow. Note some instruments do this automatically. The manufacturer of the hot wire anemometer can also recommend other k_2-factors.

Table 8 — Correction for duct shape k_2 for circular ducts

Diameter D (mm)	k_2
$D \leq 160$	0,89
$160 < D \leq 400$	0,95
$400 < D \leq 1\ 250$	0,98

Table 9 — Correction for duct shape k_2 for rectangular ducts

Width W and height H	k_2
Standing duct $H > W$	0,94
Laying duct $H < W$	0,98
Square cross-section or vertical duct	0,96

8.2.5 Standard method uncertainty

Random method uncertainties can arise, e.g. as a result of oblique velocity profile in the measurement cross-section and oblique setting of the probe. The standard method uncertainty with a coverage probability of approximately 68 % in case A is approximately 4 %. In case B measurements, the standard method uncertainty with a coverage probability of approximately 68 % increases to approximately 6 %.

If the manometer is used below 2 m/s the uncertainty of instrument (see 6.2) shall be recalculated and increased. The method uncertainty is given for velocities above 2,5 m/s and in cases where the velocity is lower, the method uncertainty shall be recalculated and increased.

8.3 Fixed devices for flow measurement – Method ID 3

8.3.1 Method description

There are a number of products on the market designed for measuring flows in ducts.

From the test method of EN 14277, a common factor for all products within this category is that the air flow is obtained with the aid of the following formula:

$$q = k \cdot (\Delta p_u)^{e} \qquad (17)$$

where

e = the device's exponent; many manufacturers use 0,5 but other exponents can be used.

8.3.2 Preparations of measurements — Equipment

For this method a manometer, thermometer and barometer are needed.

8.3.3 Measurement procedure

There are different policies regarding the development of products based on this type of measurement principle. It is important to consider the following:

- The measurement pressure shall be kept relatively high for the accuracy of measurement to be good.
- Pressure losses in the system shall be as small as possible.
- Sound generated shall be as small as possible.

These above conditions are difficult to combine however. Certain devices are built on the principle of measuring a dynamic pressure. Their advantage is that they do not create any extra pressure drop. The majority of fixed measurement devices are based on a pressure drop being created. These provide better accuracy of measurement at the cost of increased losses (see 7.2).

NOTE The fixed measurement devices that are combined with a damper, to facilitate commissioning normally have a larger method uncertainty than those devices which are only used for measurement. This is caused by disturbances and in some cases hysteresis in the damper function.

8.3.4 Correction of measured values

When measuring flow, correction is made for:

1) instrument error (systematic error): compensate by applying calibration corrections in accordance with the calibration certificate and/or calibration instruction for the instrument;

2) air temperature and barometric pressure.

A manometer that displays the air flow by using the standard density of ρ = 1,2 kg/m^3 needs to be corrected by the correct density by multiplying measured value with k_1 – see 8.2.4, Formula (16). Note there are instruments that do this automatically.

8.3.5 Standard method uncertainty

The manufacturer of the fixed measurement device shall have tested and rated the air fixed measurement device in accordance with EN 14277. The required length of straight duct to obtain an expanded method uncertainty of maximum 5 % with a coverage probability of approximately 68 %, is determined by the manufacturer in accordance with EN 14277.

8.4 Tracer gas measurement – Method ID 4

8.4.1 Method description

One of the difficulties involved in flow measurements in ventilation ducts is that there are often not sufficient straight sections before and after the plane of measurement. This applies to both measurements using a fixed measuring device and measurements with a Pitot static tube or anemometer.

When using tracer gas for flow measurements it is however a benefit if there are many disturbances to the flow in the form of dampers, bends, etc, for the mixing of gases to be adequate. The tracer gas method can only be used if a homogeneous mixture of tracer gas and air can be obtained. The method is based on injecting a known tracer gas (nitrous oxide (N_2O), helium (He), etc.), into the ventilation ducts. When the tracer gas has mixed well with the ventilation air downstream in the duct, the gas concentration can be determined and hence the air flow. A diagrammatic illustration of the measurement set-up is shown in Figure 5.

The method assumes a continuous known flow of the tracer gas, q_s, and that the tracer gas is well mixed with the air transported in the duct, q.

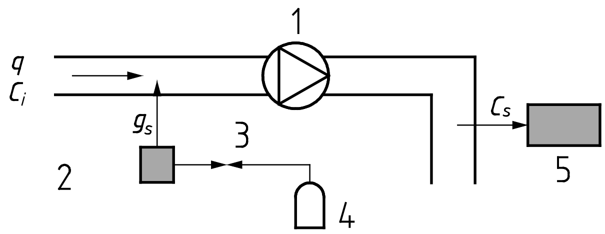
If the tracer gas concentration in the sampling cross-section is designated C_s, the following relationship is obtained:

$$q = (q_s / C_s)\ 10^6 \quad (18)$$

If the air contains a known initial concentration, C_i, of the tracer gas the relationship shall be as follows:

$$q = (q_s / (C_s - C_i))\ 10^6 \quad (19)$$

8.4.2 Equipment



Key

1 fan

2 flow meter (Rotameter)

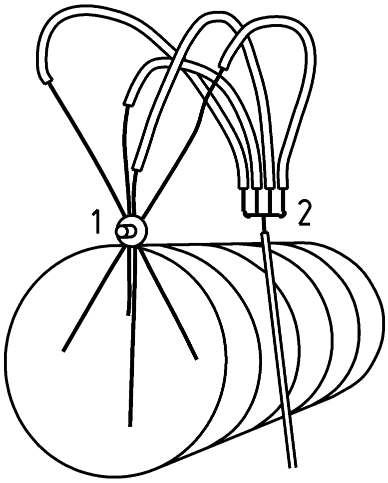
3 adjustment valve

4 gas tube (for example N2O)

5 gas analyser

Figure 5 — Tracer gas measurement equipment

The nozzle device for injecting tracer gas should be constructed so that the tracer gas is spread over four points at a diameter of approximately 63 % of the internal duct diameter. After the nozzle device has been inserted into the duct, two of the four injection tubes are angled outwards and all four tubes adjusted so that they are in the correct location in the duct, see Figure 6. The nozzle device is prepared in an analogue fashion for sampling.



Key

1 nozzle with four metal tubes (two vertical and two angled inserted at 63 % of duct diameter)

2 connector that connects one plastic hose to four plastic hoses

Figure 6 — Nozzle device for injecting tracer gas

8.4.3 Calculation of air flow

The air flow is calculated in accordance with Formula (18) and Formula (19).

If a rotameter is used for measuring the flow of tracer gas, this shall be calibrated for the tracer gas used. It is not possible to use one single factor for recalculating the calibration curve of the rotameter from air to tracer gas.

The tracer gas flow q_s shall be recalculated so that it applies at the temperature in the ventilation duct, $\vartheta_{duct.}$ The temperature of the tracer gas, ϑ_{tracer}, as it passes through the rotameter shall therefore be measured:

$$q_{s\vartheta duct} = q_{s\vartheta tracer} \sqrt{\frac{\rho_{\vartheta tracer}}{\rho_{\vartheta duct}}} \quad (20)$$

Table 10 — Example of density of N_2O

ϑ °C	ρ_ϑ N_2O kg/m³
5	1,93
20	1,83
35	1,73

The air flow, q, in the duct is obtained by Formula (21):

$$q = (q_s / (C_s - C_i))\ 10^6 \quad (21)$$

8.4.4 Standard measurement uncertainty

The standard measurement uncertainty, u_m, consists of:

— instrument uncertainty, u_1; and

— method uncertainty, u_2; and

— reading uncertainty, u_3;

partly for the determination of tracer gas flow and partly tracer gas concentration.

If the flow of tracer gas, q_s, can be determined with a measurement uncertainty of u_f % and the tracer gas concentration, C_s, can be determined with a standard measurement uncertainty of u_k %, the standard measurement uncertainty u_q in q is:

$$u_q = (u^2_f + u^2_k)^{½} \tag{22}$$

If a homogeneous tracer gas mixture is obtained, the method uncertainty is as a rule negligible and only depends on leakage in the duct between the point of injection of tracer gas and the sampling cross-section.

8.4.5 Conditions for homogeneous mixing of tracer gas

The distance required for the tracer gas to mix thoroughly with air in the ventilation duct is called the mixing length and is defined as the shortest distance at which the largest variation in C_s is less than a pre-defined value.

The mixing length is thus not a fixed value but varies depending on the variation in concentration allowed.

To achieve the best accuracy in flow measurements, it is first necessary to ensure the smallest possible variation in measurement cross-section. In practice however, larger variations shall be accepted since there are often not sufficiently long duct sections available. If tracer gas is injected uniformly through a number of holes in the cross-section (at least four) and if sampling takes place at more than one point, a considerable decrease of the mixing length is acceptable. Additionally, the mixing length can be reduced substantially if tracer gas is injected upstream of a fan. Choose the place of injection of tracer gas according to Table 11 to achieve at least the required mixing length.

Table 11 — Mixing length (L) required for standard method uncertainty to fall below 5 % and 10 %

Conditions	u_2 **= 5 %**	u_2 **= 10 %**
Straight duct without disturbances. Injection in centre. Sampling in centre.	$L = 80 \cdot D_h$	$L = 60 \cdot D_h$
Straight duct without disturbances. Injection via circle of diameter 63 % of internal duct diameter (four holes in circle)		
Sampling in centre	$L = 25 \cdot D_h$	$L = 20 \cdot D_h$
Sampling at four points (same positions as for injection)	$L = 15 \cdot D_h$	$L = 10 \cdot D_h$
Duct with two 90° bends. Injection before these via circle of diameter 63 % of internal duct diameter (four holes in circle)		
Sampling in centre	$L = 20 \cdot D_h$	$L = 15 \cdot D_h$
Sampling at four points (same positions as for injection)	$L = 10 \cdot D_h$	$L = 5 \cdot D_h$
Injection before and sampling after a fan. Injection via circle of diameter 63 % of internal duct diameter (four holes in circle)	$L = 10 \cdot D_h$	$L = 5 \cdot D_h$

9 Methods for measurement of air flows in Supply ATDs (air terminal devices) – ST (Supply (Air) Terminal (Devices)) methods

9.1 Overview of recommended methods

An overview of recommended methods is given in Table 12.

Table 12 — Methods of measurement of supply airflows at ATD

Method	Designation	See Subclause	Standard method uncertainty, u_2
Measurement of reference pressure:	ST 1	9.2	5 %
In intake to connection box	ST 11		(With straight section requirements obtained by calibration method)
Inside the connection box	ST 12		
with one pressure nozzle	ST 121		
with two pressure nozzles	ST 122		
Measurement with tight bag	ST 2	9.3	3 %
Measurement with flow hood:	ST 3	9.4	5 %
Direct method	ST 31		≤ 5 %
Indirect method			≥ 5 %
zero pressure differential	ST 32		
pressure increase	ST 33		

9.2 Measurement of reference pressure – Method ST 1

9.2.1 Introduction

Some supply air terminals are equipped with a pressure nozzle to enable flow measurements. For supply air terminals which are connected to the duct system via a connection box (plenum box), this can be used for the measuring function.

A common factor for all products within this category is that the air flow is obtained with the aid of the following formula:

$$q = k \cdot (\Delta p_u)^{e} \quad (23)$$

where

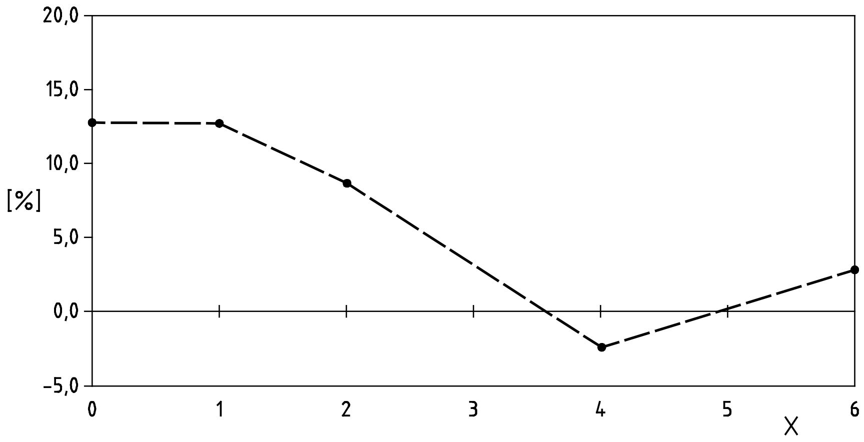
e = the device's exponent; many manufacturers use 0,5 but other exponents can be used.

Two different measurement principles can be distinguished:

1) Method ST 11: measurement in the intake of the connection box.

2) Method ST 12: measurement of the pressure/pressure difference inside the connection box.

For both of these methods the manufacturer of the air terminal device shall have tested and rated the air terminal device in accordance with EN 14277. Some practical problems arise when taking measurements at the intake of the connection box. The straight sections required are in practice difficult to achieve as there is seldom sufficient space. Great caution shall be exercised when terminals equipped with pressure nozzles are used with this method. Figure 7 illustrates examples of measured uncertainties for the *k*-factor stated by the manufacturer as a function of the connection length.



Key

X number of diameters

NOTE The uncertainty is shown as a function of distance (in diameters) from the disturbance to the connection with the terminal.

Figure 7 — Example: Effects of disturbance from a 90° bend for terminal with pressure nozzles in the intake

When measuring pressure inside the connection box, measurements may be based on two different variables depending on the construction of the terminal:

— Method ST 121: measurement of a reference pressure. This method can be used when the terminal has a fixed setting or when changes in the spread pattern do not affect the reference pressure in the connection box.

— Method ST 122: measurement of a pressure differential. This method shall be used if the terminal setting affects its pressure drop.

9.2.2 Equipment

For this method a manometer, thermometer and barometer are needed.

9.2.3 Correction of measured values

When measuring flow, correction is made for:

1) instrument error (systematic error): compensate by applying calibration corrections in accordance with the calibration certificate and/or calibration instruction for the instrument;

2) air temperature and barometric pressure.

A manometer that displays the air flow by using the standard density of ρ = 1,2 kg/m^3 needs to be corrected by the correct density by multiplying measured value with k_1 – see 8.2.4, Formula (16). Note there are instruments that do this automatically.

9.2.4 Standard method uncertainty

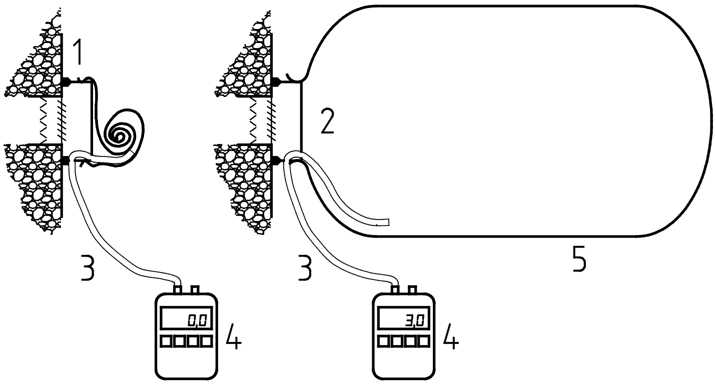
The standard method uncertainty with a coverage probability of approximately 68 % is 5 % with the requirements for straight sections obtained from the calibration method.

9.3 Measurement with tight bag – Method ST 2

9.3.1 Method description

The method illustrated in Figure 8 uses a rolled up measurement bag with a defined known volume attached to a frame which is placed over the terminal, completely covering it. The time taken to fill the measurement bag with air to a certain over-pressure is measured. The flow is then obtained from the formula:

$$q = V / t \tag{24}$$



Key

1 seal

2 frame fixed to tight bag

3 measurement tube connected to manometer

4 manometer

5 bag

Figure 8 — The principles of the measurement bag method

9.3.2 Limitations

The lower limit for terminal pressure drop is for measurements made on ceiling mounted terminals approximately 10 Pa and for wall-mounted terminals approximately 50 Pa. In the case of wall-mounted terminals the measurement bag shall be lifted during inflation in order to reduce the pressure in the bag.

9.3.3 Equipment

For this method the following items are needed:

- measurement bags of different volumes;
- frames with suitable inner dimensions;
- stop-watch;
- manometer, barometer and thermometer;

- the material in the measurement bags shall be any flexible tight material (i.e. plastic) with a recommended thickness of (0,02 – 0,04) mm.

9.3.4 Preparation

The volume of the bag should be selected so that it does not fill in less than 10 s. The bag is fixed to the frame and the manometer tube placed inside the bag.

9.3.5 Measurement

The frame with the rolled up (empty of air) bag is placed over the terminal and the stop-watch started at the same time. The time taken to fill the bag to an over-pressure of 3 Pa is measured. If the filling time is less than 10 s, the measurement is repeated using a bag with a larger volume.

9.3.6 Correction of measured values

When measuring flow, correction is made for:

1) instrument error (systematic error): compensate by applying calibration corrections in accordance with the calibration certificate and/or calibration instruction for the bag, stop watch and manometer;

2) air temperature and barometric pressure.

The bag method shows the real flow rate directly.

9.3.7 Standard method uncertainty

Measuring instrument uncertainty depends on the accuracy of calibration of the bags' volume.

Method uncertainty can occur through poor synchronizing with the stop-watch and poor attachment of frame over the terminal resulting in leakage. Laboratory measurements have shown the standard method uncertainty with a coverage probability of approximately 68 % can be set at 3 %.

Reading uncertainty of the stop-watch is estimated to be ± 0,1 s.

9.4 Measurements with flow hood – Method ST 3

9.4.1 Introduction

Flow hoods can, in some cases, be used for measuring the air flow from a supply air terminal. Caution shall be exercised when using this measurement method. The reasons for this are:

- a need to equalize the flow pattern;

- the influence of flow hood pressure drop;

- leakage of flow.

This leads to three different measurement methods applied depending on how these measurement problems are handled:

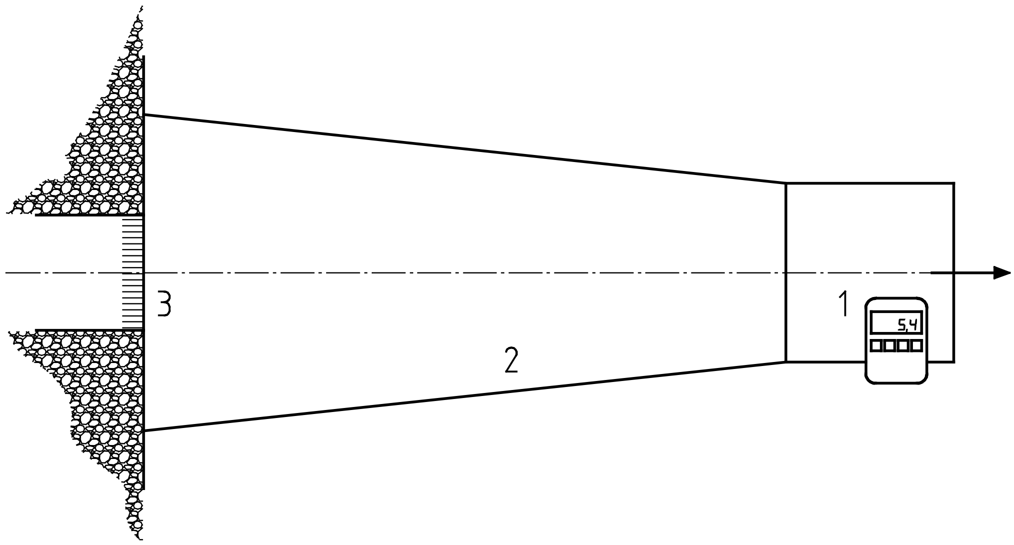
- ST 31: measurement with flow hood with no pressure drop compensation (see Figure 9);

- ST 32: measurement with flow hood and auxiliary fan (zero pressure differential). The pressure drop which exists in the measuring device can be compensated for by using an auxiliary fan. The fan's speed is adjusted until the static pressure in the flow hood is equivalent to the pressure in the room, i.e. there is no over or under-pressure. The flow through the terminal is then unaffected by the measuring device;

- ST 33: measurement with flow hood in two steps. The pressure drop which exists in the measurement device is known and it can be changed into two different levels. The flow rate is measured for the two levels of pressure drop and the correct flow rate can then be calculated. Instruments with different performance are available and the manufacturer shall give a description of the measurement technique and method uncertainty.

9.4.2 Equipment

Examples of equipment for methods ST 31 and ST 32 are given in Figure 9 and Figure 10. Method ST 33 has a similar arrangement as Figure 9 including in addition some constriction device.



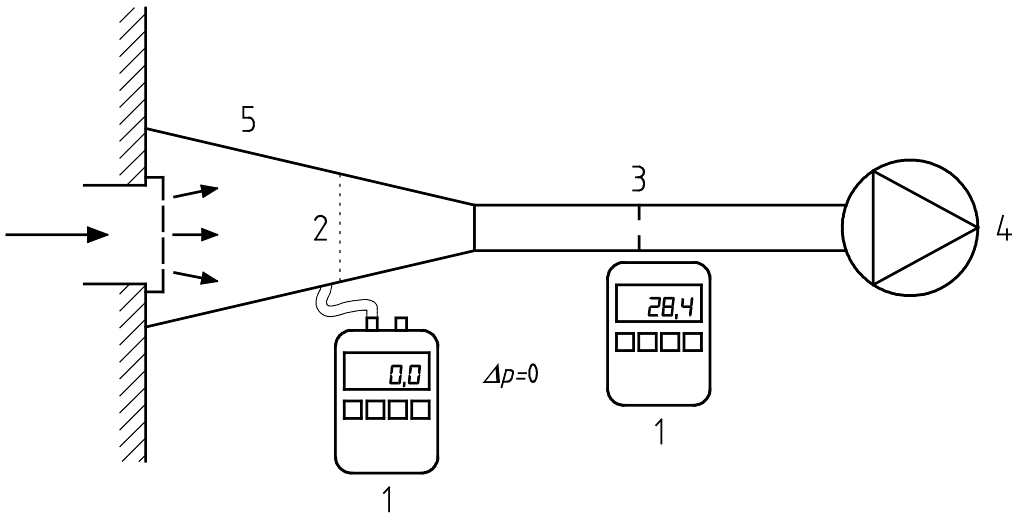
Key

1 measuring instrument

2 flow hood

3 grille (ATD)

Figure 9 — Example of measurement using method ST 31



Key

1 manometer and flow-meter

2 possible perforated sheet for even air distribution

3 measurement section

4 adjustable speed fan

5 flow hood

Figure 10 — Flow hood with auxiliary fan (ST 32)

9.4.3 Measurement

The flow hood shall be applied tightly around the ATD, checking there is no leakage of airflow created.

9.4.4 Correction of measured values

When measuring flow, this is corrected for:

1) instrument error (systematic error): compensate by applying calibration corrections in accordance with the calibration certificate and/or calibration instruction for the instrument;

2) air temperature and barometric pressure.

An instrument that displays the standard air flow needs to be corrected to real air flow – 4.5 Formula (7). Note there are instruments that do this automatically.

9.4.5 Standard method uncertainty

Three conditions have an important impact on method uncertainty:

1) Equalized flow: For method ST 31 and ST 33 it is assumed that if the flow hood has a length of at least three times that of the flow hood's largest hydraulic diameter, the flow is equalized. If this requirement cannot be fulfilled due to the size of the ATD, the flow hood may still be used but the user should check that the flow is stabilized by comparing it with other measurement methods. The air flow direction should be uniform in the flow hood and swirl should be avoided. This also depends on the ATD type and spread which is measured. To correctly assess the impact of these conditions, the instrument should be calibrated in combination with the relevant terminal type and spread pattern unless it has been showed by previous lab tests that the flow pattern is equalized.

2) In Method ST 31, pressure drop of the flow hood shall be low compared to available pressure in duct. This can be checked by covering a part of the flow hood and noting if the airflow changes. If so, other methods (with compensation – ST 32 and 33) should be used.

3) There shall be no leakage taking place, e.g. the inner ceiling framework shall be tight. Note there could be other leakages than inner ceiling leakage.

These three conditions shall be achieved. In the case of no pressure drop influence and no leakage the standard method uncertainty with a coverage probability of approximately 68 % is 5 %.

If these three conditions are not observed, their influence can result in much higher uncertainty levels (i.e. up to 100 % of measured value).

NOTE For method ST 32, the method uncertainty is dependent on the accuracy of the determined zero pressure differential.

10 Methods for Exhaust ATDs (air terminal devices) – ET (Exhaust (Air) Terminal (Devices)) methods

10.1 Overview of recommended methods

An overview of recommended methods is given in Table 13.

Table 13 — Methods of measurement of exhaust airflows at ATD

Method	Designation	See Subclause	Standard method uncertainty, u_2
Measurement of reference pressure	ET 1	10.2	
Using probe	ET 11		5 %
Using fixed measurement outlet	ET 12		5 %
Measurement with flow hood	ET 2	10.3	
Direct method			
Indirect method			5 %
a) zero pressure differential	ET 21		
b) pressure increase	ET 22		

10.2 Measurement of reference pressure at exhaust ATD – Method ET 1

10.2.1 Method description

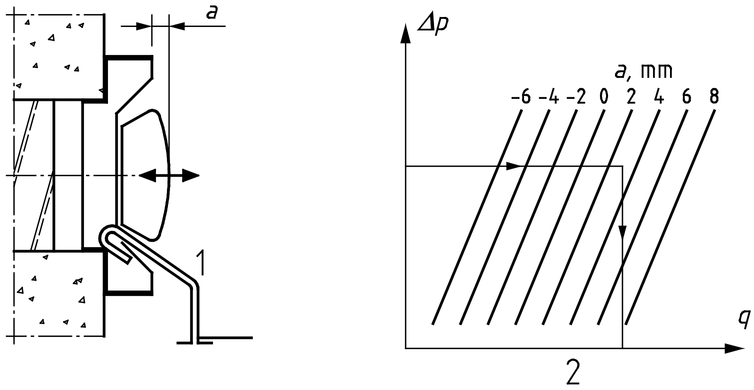
This method is mainly applicable for traditional exhaust air terminals (control valves). A measurement probe is placed at a specific location behind the terminal where a pressure (p_u) is measured. The principle is illustrated in Figure 11. With information on the terminal's settings, the air flow can subsequently be determined either by means of a graph or a flow factor (k-factor).

The following formula is used when the principle of flow factors is applied:

$$q = k \cdot (\Delta p_u)^{e} \quad (25)$$

k is obtained as a function of the terminal's setting.

^{e}: many manufacturers use 0,5 but other exponents can be used.



Key

1 measurement probe connected to the manometer

2 An example of a graph showing air flow as a function of measured pressure with a conical opening as a parameter

Figure 11 — Example of measurement using Method ET 1

10.2.2 Limitations

Due to the pressure conditions downstream from an exhaust air terminal, the following points shall be fulfilled for the method to be used:

- the manufacturer/supplier of the terminal gives instructions about exactly where the pressure measurement should be made and how the measurement probe should be shaped or supply a special measurement probe;
- the manufacturer/supplier of the terminal gives instructions about the *k*-factor as a function of the terminal's setting or provides a diagram of the flow as a function of characteristic pressure differential.

10.2.3 Equipment

For this method a measurement probe, constructed in accordance with the manufacturer's instructions, manometer, thermometer and barometer are needed.

10.2.4 Correction of measured values

When measuring flow, this is corrected for:

1) Instrument error (systematic error). Compensate by applying calibration corrections in accordance with the calibration certificate and/or calibration instruction for the instrument.

2) Air temperature and barometric pressure. A manometer that displays the air flow by using the standard density of ρ = 1,2 kg/m^3 needs to be corrected by the correct density by multiplying measured value with k_1 – see 8.2.4. Note there are instruments that do this automatically.

10.2.5 Standard method uncertainty

It is important to be aware of the fact that a formula with the exponent set to 0,5 is only approximate. There is a built-in error due to the use of the square root in the characteristic pressure. The reason for this is that the flow through this type of terminal (control valves) does not have fully developed turbulence within the whole of the terminal's working area. This means that the exponent is not 0,5 (square root) but probably is between 0,52 and 0,56.

A better accuracy can be achieved by using pressure/flow graphs or any representing formula, which manufacturers provide. Note there are instruments that allow for adjusting an exponent other than 0,5 by following automatic evaluation._If these better graphs or formulas are used, standard method uncertainties can be decreased to 5 %. Using the *k*-factor method (with square root formula) the standard method uncertainties with a coverage probability of approximately 68 % will be 10 %.

10.3 Measurement using a flow hood – Method ET 2

10.3.1 Introduction

Even in exhaust conditions, caution should be exercised when using this measurement method due to the influence of flow hood pressure drop.

This leads to three different measurement methods applied depending on how pressure drop is handled:

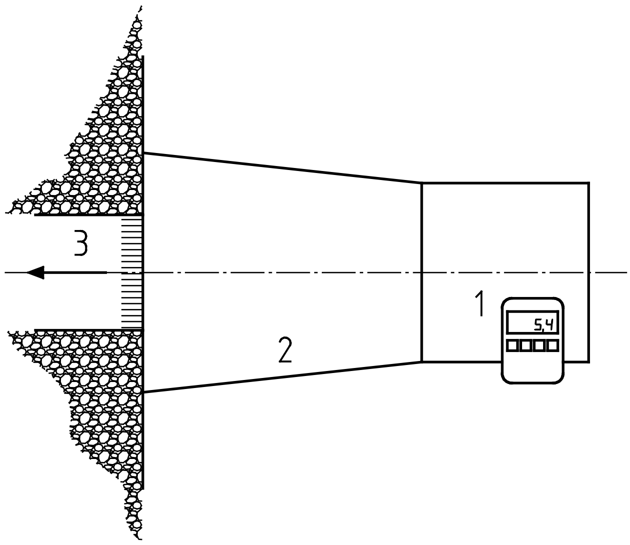
1) ET 21: measurement with flow hood with no pressure drop compensation (see Figure 12).

2) ET 22: measurement with flow hood and auxiliary fan (zero pressure differential). The pressure drop which exists in the measuring device can be compensated for by using an auxiliary fan. The fan's speed is adjusted until the static pressure in the flow hood is equivalent to the atmospheric pressure, i.e. there is no over or under-pressure. The flow through the terminal is then unaffected by the measuring device.

3) ET 23: measurement with flow hood in two steps. The pressure drop which exists in the measurement device is known and it can be changed into two different levels. The flow rate is measured for the two levels of pressure drop and the correct flow rate can then be calculated. Instruments with different performance are available and the manufacturer shall give a description of the measurement technique and method uncertainty.

10.3.2 Equipment

Examples of equipment for methods ET 21 and ET 22 are given in Figure 12 and Figure 13. Method ET 23 has similar arrangement as Figure 12 including in addition some constriction device.



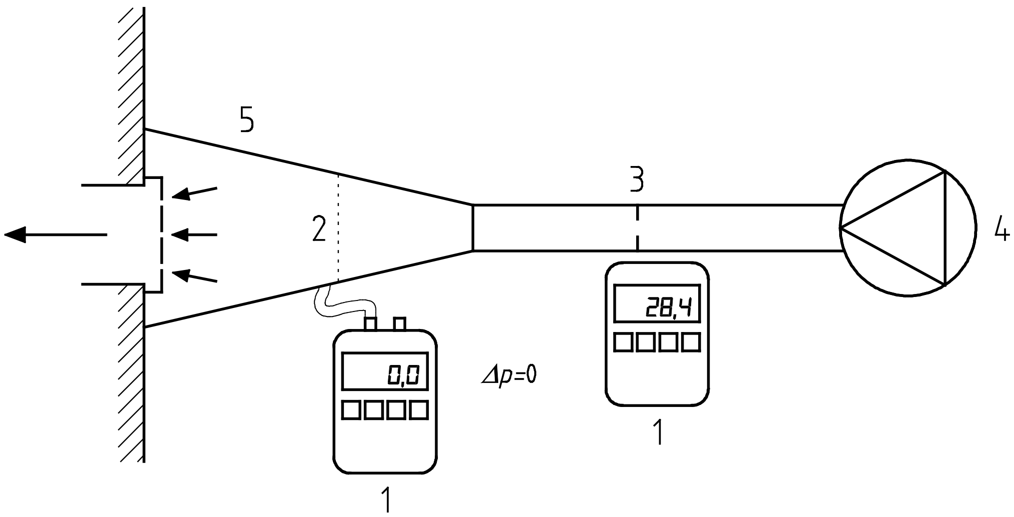
Key

1 measuring instrument

2 flow hood

3 grille (ATP)

Figure 12 — Example of measurement using method ET 21



Key

1 manometer and flow-meter

2 possible perforated sheet for even air distribution

3 measurement section

4 adjustable speed fan

5 flow hood

Figure 13 — Example of measurement using method ET 22

10.3.3 Measurement

The flow hood shall be applied tightly around the ATD, checking there is no leakage of airflow created.

10.3.4 Correction of measured values

When measuring flow, this is corrected for:

1) instrument error (systematic error): compensate by applying calibration corrections in accordance with the calibration certificate and/or calibration instruction for the instrument;

2) air temperature and barometric pressure.

An instrument that displays the standard air flow needs to be corrected to real air flow, see 4.5, Formula (7). Note there are instruments that do this automatically.

10.3.5 Standard method uncertainty

In method ET 21, pressure drop of the flow hood shall be low compared to available pressure in the duct. This can be checked by covering a part of the flow hood and noting if the airflow changes. If so, other methods (with compensation – ET 22 and 23) should be used.

There shall be no leakage taking place e.g. the inner ceiling framework shall be tight. These conditions shall be achieved. In this case the standard method uncertainty with a coverage probability of approximately 68 % is 5 %.

If these conditions are not observed, their influence can result in much higher uncertainty levels.

NOTE For method ET 22, the method uncertainty is dependent on the accuracy of the determined zero pressure differential.

Annex A
(informative)

Uncertainties

A.1 Examples of calculations

Here is an example of how to use Clause 6:

Suppose that the air flow shall be measured in a duct using method ID 21 as in 8.2. The measuring instrument is a hot wire anemometer. First calculate u_m, with a coverage probability of approximately 68 %.

u_1

Hot wire anemometers can often, at velocities over approximately 1 m/s, show random uncertainties of around 3 %. Instruments which are calibrated show uncertainties due to shortcomings in the calibration method. If in this case the hot wire instrument is calibrated with equipment with a 2 % uncertainty, the probable uncertainty level is:

$$u_1 = (3^2 + 2^2)^{½} = 3,6\ \%$$

u_2

For measurement method ID 21 it is clear that the method uncertainty u_2 = 4-6 %, is in this case 5 %. See 6.3 for further information.

u_3

For digital instruments the uncertainty is $\frac{1}{2\sqrt{3}}$ of the resolution (Formula (10)). If the resolution is 0,1 m/s on a value read at 3,5 m/s, then u_3 = 0,029 m/s or approximately 1 %.

For analogue instruments the reading uncertainty depends on, amongst other things, the scale divisions. Logarithmic or other nonlinear scales can in some velocity ranges give a reading uncertainty of 3 % or more.

u_m

If Formula (8) is applied, the probable measurement uncertainty, u_m, using the selected measurement method and a hot wire anemometer is as follows:

$$u_m = (3,6^2 + 5^2 + 1^2)^{½} = 6,3\ \%$$

i.e. $u_m \cong 7$ % (whole numbers are usually used in these calculations)

U_m

To cover most measurement results it is recommended that the coverage probability of approximately 95 % is used for presenting the final measurement uncertainty. Use Formula (11).

$U_m = k_c \cdot u_m$, where k_c = 2, in this case 2 × 6,38 % $\cong$ 13 %

A.2 Compound uncertainties

In many cases the quantity desired cannot be measured directly but can be calculated indirectly by expressing it in other variables which can be measured.

For example:

If measurement of the total air flow cannot be carried out, it can be determined by addition of the component air flows. The uncertainty in the different component flows, $q_1, \ldots, q_n$ (m^3/s) has been determined as in Clause 6 to be $u_{q1}, \ldots, u_{qn}$ %

$$q_t = q_1 + q_2 + \ldots + q_n \text{ m}^3/\text{s} \tag{A.1}$$

where

q_t = total air flow, m^3/s

The probable uncertainty in q_t is u_{qt} m^3/s:

$$u_{qt} = \left[\left(\frac{q_1 \cdot u_{q1}}{100} \right)^2 + \left(\frac{q_2 \cdot u_{q2}}{100} \right)^2 + \ldots + \left(\frac{q_n \cdot u_{qn}}{100} \right)^2 \right]^{1/2} \text{ m}^3/\text{s} \tag{A.2}$$

where

u_{qn} = probable uncertainty in the flow q_n %

When adding and subtracting (Formula (A.2)), the absolute uncertainties in part flow measurements can be used when calculating the probable uncertainty in the total flow.

A.3 Example of applications

Determine the probable uncertainty, u_{qt}, on adding the following three-part flow measurements:

q_1 = 26 l/s, measured with a standard uncertainty u_{q1} = 6 %;

q_2 = 31 l/s, measured with a standard uncertainty u_{q2} = 7 %;

q_3 = 35 l/s, measured with a standard uncertainty u_{q3} = 8 %.

Using Formula (A.2) gives:

$u_{qt} = ((0{,}06 \cdot 26)^2 + (0{,}07 \cdot 31)^2 + (0{,}08 \cdot 35)^2)^{1/2}$ l/s;

u_{qt} = 3,9 l/s (≅ 4 l/s), U_{qt} = 7,8 l/s, with a coverage probability of approximately 95 %;

i.e. 92 ± 8 l/s or 92 l/s ± 8 % of measured value.

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1) ISO 5221 was withdrawn in November 2009 and has not been replaced.

2) ISO 4053-1 was withdrawn in March 2003 and has not been replaced.

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