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Methods for measurement of airflow rates in ventilation systems

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FOREWORD

The problem of measuring airflow rate and air velocity has been subjected to a great deal of attention in various quarters. This is because of the great difficulties associated with such measurements, especially in field conditions, as well as the impact of the ventilation plant on indoor climate and running costs.

The measuring methods presented in this publication have been assembled by the Nordic Ventilation Group. The publication is a direct translation of Report T32:1982 issued by the Swedish Council for Building Research, which in its turn is a revised version of the earlier Report B4:1977, 'Metoder för mätning av luftflöden i ventilationsinstallationer' (Methods for the measurement of airflow rates in ventilation systems).

A special attempt has been made to make the methods as uncomplicated as possible. Of course they can gradually be improved and simplified still further.

The idea behind this work has been to formulate identical codes within the Nordic countries for the inspection and adjustment of ventilation systems. The publication should be regarded as a stage report of proposals for methods for testing and rating ventilation systems under field conditions.

The measuring methods are divided into two groups; recommended methods where the size of the method error is less than 10%, and other methods for which the size of the error cannot be calculated.

As required, these methods are taken up for revision by the Nordic Ventilation Group.

With future revision in mind, the experience gained and points of view that rise to the surface in the utilization of the methods will be received with gratitude.

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INTRODUCTION

If the adjustment and inspection of a completed plant, whilst it is in operation, are to be carried out correctly, methods and instruments must be developed and standardized. Frequently large savings in energy can be made if the heating and ventilation system is looked after correctly. It is therefore important to spend time on developing methods for field measurements and to collaborate in their standardization.

The present work, part of a more extensive Nordic collaboration project being pursued by the Nordic Ventilation Group, is a translation of Report T32:1982 from the Swedish Council for Building Research and constitutes the third revised edition of Report R51:1974 'Methods for the measurement of airflow rates in ventilation systems'. In determining the present material for field use it has been our ambition to use the least complicated methods. However, every attempt must be made to further improve and simplify the measuring technique.

The aim in the present work has been that the technician carrying out the measurements, assisted by descriptions of methods with their associated reports and tables for the registration of values both measured and calculated, shall be able to carry out and document the measurements within the limits of the stated method error.

The descriptions contain information about:

- equipment required
- necessary preparations for measuring
- executing the measurement (measuring points, time, etc)
- necessary corrections of the measured values
- measurement errors
- evaluation of results.

The report are arranged so that:

- measuring points, and the values read and corrected are shown
- the calculation methods for obtaining average values, etc, are shown
- calculation of probable error (noting and calculation of variation range, instrument errors, method errors, reading errors and also probable measurement errors) can be carried out according to a definite system.

Further, the descriptions and reports contain tables and conversion scales to simplify both fieldwork and the work of evaluation.

The different measuring methods are divided into two groups, methods recommended and other methods. The recommended methods (*R-methods*) are methods for which the method error is stated and where the method error is less than 10%. Thus it is these methods that shall be used in the measurement of the absolute values of airflow rates.

Methods in the other group are those whose uncertainty is unknown but high. These methods may in no circumstances be used when determining the absolute values of flow rates. But in certain circumstances they may be used when only relative measurements need to be done - see Chapter 3.

1. THE METHODS' RANGE OF APPLICATION

The methods presented here as R-methods can be used in agreements concerning the adjustment and inspection of ventilation systems - see references /1/ and /2/.

2. GENERAL REQUIREMENTS

2.1 Calibration

Instruments shall be calibrated with a method that gives a (known) low error. Calibration curves for which the correction - alternatively the actual value - is stated shall be used.

Calibrated value = value indicated + correction for the instrument.

Thus the correction should be stated as an absolute value and not as a factor, in view of the fact that the correction shall be done in the field. The calibration rules of the Nordic Ventilation Group shall be followed - see references /3/ and /4/.

2.2 Measurement

A measurement shall be based on a well-defined method, where both the measuring points and the measuring instruments must be established. This does not mean that an instrument standard shall be established, but that a definite and standard procedure should be utilized for the instruments used.

Measurement values are evaluated in a specific manner for the method, and then corrected with reference to that method. Usually here a correction factor must be used where:

Correct value = measured value x correction factor for method.

Regarding the correction factor for different methods see Chapters 5-9.

2.3 Measurement errors

The probable measurement error, $\bar{m}$, shall be calculated in accordance with the following:

$$\bar{m} = \sqrt{m_1^2 + m_2^2 + m_3^2}\ \% \qquad (1)$$

where:

m_1 = error of measuring instrument, %

m_2 = error of measuring method, %, because of the nonagreement to the calibration method for the measuring method. Included in this type of error are also deviations from the calibration curve for mass-produced measuring devices, dampers or air terminal devices with built-in measurement outlets (i.e. pressure nozzles)

m_3 = reading error, %

Random error m_1

Even when a value read or a measured average value has been corrected with reference to the different factors there still remain random errors in a measurement. These depend, among other things, on the effects of hysteresis, for which correction cannot be made. These errors are discovered as deviations in the measurement values at repeated measurements of the same quantity and therefore appear for example in the preparation of a calibration curve when a band is obtained instead of a curve.

Random error m_2

When measurements are carried out a carefully specified method should be used. Because of deviations from the method, for example the direction of the probe and the distance between the probe and inlet-register, etc, even measuring methods will produce certain random errors. The measuring methods available nowadays have different degrees of accuracy.

Random error m_3

Such errors can for example be referred to reading errors, so that scale graduation is of great importance.

Example of error calculation

The airflow rate is assumed to be measured through an air inlet register using method B1 in accordance with Chapter 6.1 (the inlet register is included in the group of exhaust air terminal devices). Measuring device: hot-wire anemometer.

m_1 Hot-wire anemometers at velocities exceeding approximately 1 m/s can often show random errors of about ±2%. The instrument being calibrated quite naturally shows errors because of defects in the calibration method. If in such a case the hot-wire instrument is calibrated against equipment with an error of ±1% the probable error becomes:

$$m_1 = \sqrt{2^2 + 1^2} = \pm 2.2\%$$

Empirical values of m_1 are obtained from reference /3/.

m_2 For measuring method B1 is shown that within accuracy range 1 the error $m_2 = \pm 5\%$ (excluding reading and instrument errors).

m_3 The reading of instruments occurs with a varying degree of accuracy, one of the reasons being the graduation of the instrument concerned. Logarithmic or other nonlinear scales may within certain zones produce reading errors of ±3% or more. If the reading error is 0.1 m/s at a value read of 3.5 m/s then $m_3 = \pm 3\%$.

$\bar{m}$ The probable error, $\bar{m}$, with the selected measuring method and the selected hot-wire anemometer becomes:

$$\bar{m} = \sqrt{2.2^2 + 5^2 + 3^2} \qquad \text{i.e. } \bar{m} \cong \pm 6\%$$

In measurement of the airflow rate in this example the deviation from the prescribed flow may thus be maximally about 9% so that the deviation may be kept within the maximum of 15% permitted by VVS AMA 72 (General material- and work specifications from HVAC-installations. Publisher: Svensk Byggtjänst AB, Stockholm, Sweden).

2.4 Composite errors

It is frequently impossible to measure a certain quantity of interest. Then it has to be calculated in a roundabout manner by being expressed in other variables that can be measured.

Example:

a)

If measurement of the total airflow rate cannot be carried out it must be determined by summing the partial airflow rates. The error in the different partial airflow rates $q_1, \ldots, q_n$ (m^3/s) has been determined in conformity with point 2.3 above to $\bar{m}_{q_1}, \ldots, \bar{m}_{q_n}$ %.

$$q_{tot} = \sum_{i=1}^{n} q_i$$

where

q_{tot} = total airflow rate, m^3/s

Probable error in $q_{tot} = \bar{m}_{q_{tot}}$ m^3/s

$$\bar{m}_{q_{tot}} = \sqrt{\sum_{i=1}^{n} \left(\frac{\bar{m}_{q_i}}{100} \times q_i\right)^2} \; m^3/s \qquad (2)$$

where

$\bar{m}_{q_i}$ = probable error in the airflow rate q_i, %

In equation (2) has been utilized a rule (rule 1) which says that *in the addition and subtraction of partial values the absolute errors in the partial values shall be utilized in calculation of the probable error* of the total value.

b)

If the determination of a fan's total power requirement (P) shall be made with known values of the airflow rate (q m^3/s), the total pressure rise given by the fan (Δp_t Pa) and the efficiency (η%), a rule shall be used (rule 2) which says that *in multiplication and division of factors the relative (or percentual) errors of the factors shall be used in calculation of the probable error* of the resulting value.

$$P = \frac{q \times \Delta p}{1000 \times \eta} \text{ kW}$$

where

P = power requirement, kW

Probable error in P = $\bar{m}_P$ %

$$\bar{m}_p = \sqrt{\bar{m}_q^2 + \bar{m}_{\Delta p}^2 + \bar{m}_\eta^2}\ \% \qquad (3)$$

where

$\bar{m}_q$ = probable error in q expressed in %

$\bar{m}_{\Delta p}$ = probable error in Δp expressed in %

$\bar{m}_\eta$ = probable error in η expressed in %

Examples of applications

1. Determine the probable error, $\bar{m}_{q_{tot}}$ in the summation of the following three partial airflow measurements:

   q_1 = 26 l/s with probable measurement error $\bar{m}_{q_1}$ = 6%

   q_2 = 31 l/s " " " " $\bar{m}_{q_2}$ = 7%

   q_3 = 35 l/s " " " " $\bar{m}_{q_3}$ = 8%

   Utilization of equation (2) gives:

   $$\bar{m}_{q_{tot}} = \sqrt{(0.06x26)^2+(0.07x31)^2+(0.08x35)^2}\ \text{l/s}$$

   $$\bar{m}_{q_{tot}} = 3.87\ \text{l/s}$$

i.e. q_{tot} = 92 ±4 l/s or

q_{tot} = 92 l/s ±4%

2. Determine the probable error, $\bar{m}_p$, in determination of a fan's power requirement with the help of the following data:

   The airflow rate (q) has been determined with the probable measurement error $\bar{m}_q$ = 6%. The pressure increase Δp across the fan has been determined with the probable measurement error $\bar{m}_{\Delta p}$ = 9%. The efficiency η has been determined with a probable error of $\bar{m}_\eta$ = 8%. Application of equation (3) gives:

   $$\bar{m}_p = \sqrt{6^2 + 9^2 + 8^2} = 13.5\%$$

2.5 Measurement reports

The forms for the different methods shown in Chapters 5-9 can be used for presentation of the measurement results obtained.

3. COMPARATIVE MEASUREMENTS

3.1 The relative method

At certain times, for example in the balancing of installations by the so-called proportional balancing method, it is sometimes necessary to determine a relative airflow rate, that is to say the airflow rate through one device in relation to that of another device. For devices of the same type and size the airflow rates can then be estimated from information on the total airflow rate and average velocities across the device.

This applies on condition that the average velocity is measured in a reproducible manner - see section 3.2 'Determination of a characteristic average velocity'. If the devices are of different size the average velocities measured must be multiplied by the gross area of the device so that a comparison of the airflow rates shall be possible.

For each type of device the same type of measuring instruments shall be used when carrying out measurements. The measuring instrument shall be used in a reproducible manner and the instrument shall be calibrated.

Description of the method

The relative method can be used for all types of supply and exhaust air terminal devices if it is possible to determine a characteristic velocity across the device. The basis of the method is that for every type of device a measurement is carried out of the airflow rate in a duct that supplies one or more devices of the same type with air. A characteristic average velocity is measured for every device and the airflow rate is then determined by apportioning the absolute airflow measured in proportion to the average velocities measured.

The method implies that for every type of fitting an effective area, A_k, or a conversion factor, k, must be determined which can be used in the measurement of devices situated elsewhere in the system.

Application 1, devices of the same size

In measuring devices of the same size the measurements are carried out by determination of the device's effective area, A_k. This can be determined from the airflow rate, q, in the supply duct of the device and a characteristic average velocity, v_m, across the device in accordance with the following relationship:

$$A_k = \frac{q}{v_m}$$

Example 1. The airflow rate to a device is determined to 0.13 m^3/s through measurement with a Pitot (Prandtl) tube. The average velocity across the device is measured with a rotating vane anemometer to 4.0 m/s. (See FIGURE 1a). The effective area then becomes:

$$A_k = \frac{0.13}{4.0} = 0.032 \text{ m}^2$$

If total airflow measurement is carried out in a duct that supplies a number of devices of equal size of the same type, the effective area can be determined from the equation:

$$A_k = \frac{q_{tot}}{\Sigma v_m}$$

The airflows through the individual devices are then determined by the relation:

$$q = A_k \times v_m$$

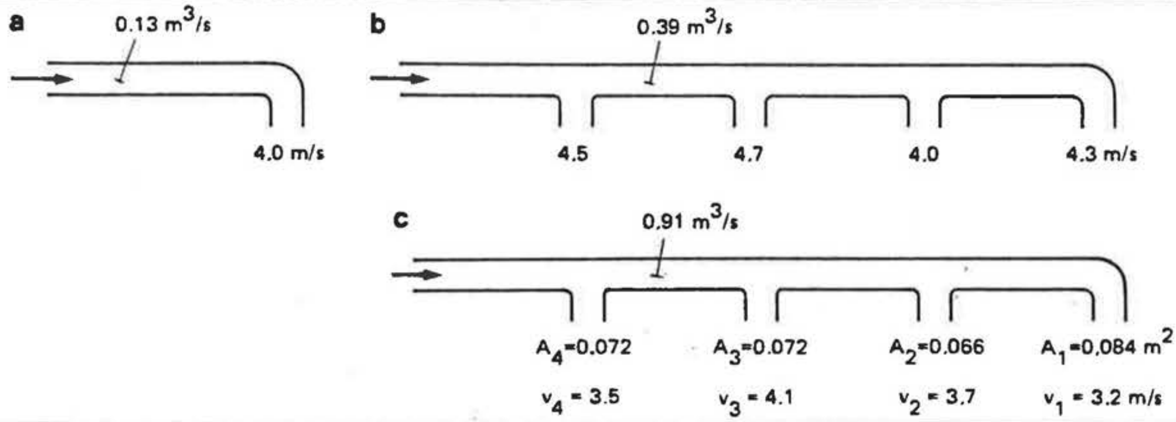

FIGURE 1. Determination of airflow rates by relative measurements.

Example 2. The average velocity across four uniform devices is measured with a rotating vane anemometer to values given in FIGURE 1b. The total airflow rate for the three downstream devices is measured by traversing with a Pitot tube to 0.39 m^3/s.

The effective area for these devices becomes:

$$A_k = \frac{0.39}{4.7 + 4.0 + 4.3} = 0.030 \text{ m}^2$$

For the individual device the airflow rate is determined by

$$q = A_k \times v_m$$

that is

$q_1 = 0.030 \times 4.5 = 0.135 \text{ m}^3/\text{s}$

$q_2 = 0.030 \times 4.7 = 0.141 \text{ m}^3/\text{s}$

$q_3 = 0.030 \times 4.0 = 0.120 \text{ m}^3/\text{s}$

$q_4 = 0.030 \times 4.3 = 0.129 \text{ m}^3/\text{s}$

Application 2, devices of different size

When measuring on devices of different size the measurements are carried out by determination of the conversion factor k for the device concerned. The airflow is now divided both on the basis of the average velicity measured and on the characteristic area for each size of device. The characteristic area may for example be the gross area of the device.

The method is based on the assumption that the conversion factor is constant and independent of device size. In fact however the factor varies somewhat with the size of the device. Therefore the method should only be used when difference in size of the devices is limited.

If total airflow rate measurement is undertaken in a duct to a single device with the area A (m^2) and a characteristic average velocity v_m (m/s), then k is determined by:

$$k = \frac{q}{A \times v_m}$$

where

q = the airflow rate measured in the duct (m^3/s).

If the duct supplies n devices with airflows $q_1, q_2, \ldots, q_n$ and if the average velocities across the devices are $v_1, v_2, \ldots, v_n$ and the areas $A_1, A_2, \ldots, A_n$, then k is determined by

$$k = \frac{q}{A_1 v_1 + A_2 v_2 + \ldots A_n v_n}$$

The airflow rate through the individual devices of the same type is determined by:

$$q_i = k \times A_i \times v_i$$

Example 3. The average velocity across four devices is measured to values in accordance with FIGURE 1c. The stated areas are presumed to be gross areas. The total airflow rate for the three downstream devices is found to be 0.91 m^3/s by measurement in the duct.

$$k = \frac{0.91}{0.084 \times 3.2 + 0.066 \times 3.7 + 0.072 \times 4.1} = 1.126$$

The airflow rate through each individual device becomes:

q_1 = 1.126 x 0.084 x 3.2 = 0.303 m^3/s

q_2 = 1.126 x 0.066 x 3.7 = 0.275 m^3/s

q_3 = 1.126 x 0.072 x 4.1 = 0.032 m^3/s

q_4 = 1.126 x 0.072 x 3.5 = 0.284 m^3/s

Sources of error

The relative method is based on an absolute measurement of the airflow rate in a duct and it is therefore necessary that the measurement is carried out with the greatest possible accuracy. It must be ensured that there is no unreasonable leakage between this measuring point and the devices. Attention should also be given to possible leaks where the devices join the duct.

In the above example leakage of the duct system has been disregarded. If the leakage is evenly distributed over the system, the total airflow rate measured should be reduced by the measured or calculated airflow leakage prior to calculation of the conversion factor or the effective area.

Method error

The method error when the relative method is used is not known in detail. In the *best case*, when devices of the same type and size are used and when the installation conditions are similar, the probable error in estimation of the airflow rate through the individual devices is approximately 10%.

3.2 Determination of a characteristic average velocity

Measurement of airflow rates through supply or exhaust air terminal devices, when using a conversion factor or an effective area, is based on the measurement of a characteristic average velocity across the device. In order to obtain a reproducible value this measurement of velocity must be carried out by a specified method. Only exceptionally have device manufacturers supplied such measuring methods. In most cases therefore it is necessary to decide oneself on a method for determination of the characteristic average velocity. Below are given some rules that should be followed in the selection of measuring points and instruments.

Grilles

Measurement of grilles can be achieved by traversing with a rotating vane anemometer. Traversing technique is described in Chapter 6.6. If the anemometer is equipped with a stopwatch, the measurement time is selected so that the anemometer cuts out when measurement in the last section is completed.

Velocity measurements can also be done with other types of anemometers, for example a hot-wire anemometer. The velocity is then measured between the fins at a number of points evenly distributed over the grille. Every measurement value is corrected with reference to the calibration curve and then the average velocity is determined as the arithmetic average, or mean, of the values measured.

Measurement with these instruments, because of the usually quite large variations in velocity across the grille area, is often more uncertain than measurement with the rotating vane anemometer. With regard to accuracy of measurement the velocity ratio between the maximum and minimum velocities should not exceed 1.5.

Slot air terminal devices

Measurements on slot air terminal devices are carried out using the same principles as for grilles.

Air diffusers

Measurements on air diffusers can be carried out with a Pitot tube velometer or hot-wire anemometer. The measurement as done at four points on two diameters right-angled to each other in the middle ring-shaped slot (slot R2 in FIGURE 4) at the distance $y/b = 0.8$. See FIGURES 2, 3 and 4.

In the case of circular air diffusers the points should be positioned on diameters that are turned 45° in relation to the direction of the flow in the horizontal main duct. The average velocity is determined as the arithmetic average of the values measured.

It is important that the probe of the anemometer is placed in the same position and at the same angle for the different measurements. FIGURE 3 gives examples of the probe positioning with differing types of instruments. Every instrument and every position has its particular conversion factor.

All air diffusers included in the measurement shall be set at the same position to make it possible for the same conversion factor to be used. It must be borne in mind that an alteration in setting may cause greater or lesser changes in the airflow depending on the type of air diffuser.

Like slot air terminal devices, in the case of air diffusers the velocity ratio between the maximum and minimum velocity should not exceed 1.5. Generally the situation is that measurements on air diffusers often suffer from great uncertainty. Frequently the measurements can be carried out by using method C3 (see page 72), which can also be used for relative measurements.

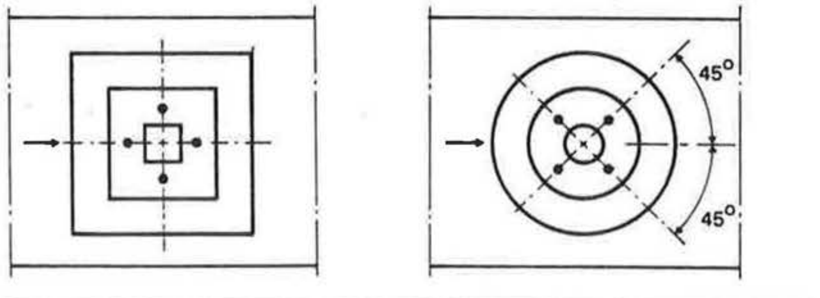

FIGURE 2. Positions of measuring points in measurements of air diffusers. In the measurement of circular air diffusers the measuring points should be positioned on two diameters right-angled to each other, forming av 45° angle to the direction of flow in the main duct.

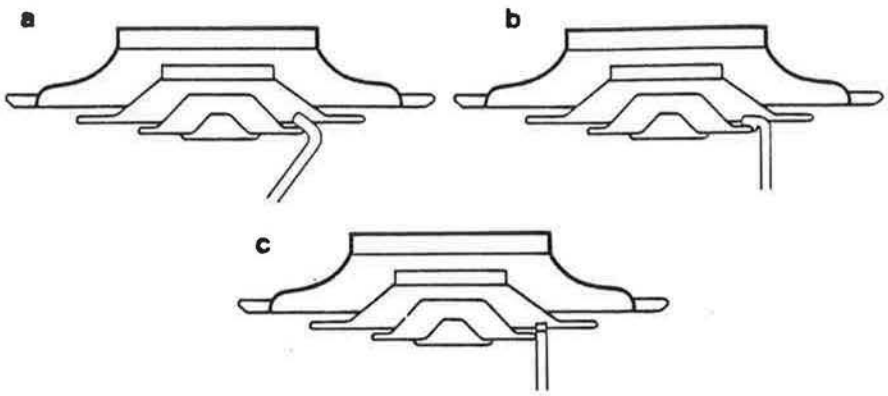

FIGURE 3. Examples of positioning of probes in the measurement of air diffusers.
a) Pitot tube b) velometer c) hot-wire anemometer

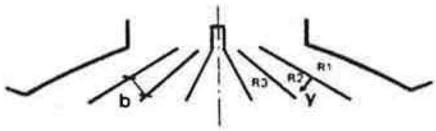

FIGURE 4. Cross section of ceiling air diffusers showing designations y and b.

Exhaust air terminal devices

Measurement on exhaust air terminal devices can be carried out using the same principles as for air diffusers, that is through the determination of a characteristic average velocity from measurement at four points. In most cases, however, measurement can be done both faster and more reliably using method B3 (see page 59), with which the exhaust airflow is measured directly.

Nozzles

Measurement in high pressure systems, on for example induction units, with nozzles, is carried out by measuring the pressure drop across the nozzles. The square root of the pressure drop is proportional to the airflow rate.

Other devices or openings

When perforated sheet-metal panels are used over a greater surface as supply or exhaust devices or if specially designed openings are used it is impossible to determine a characteristic average velocity with sufficient accuracy. In such cases the airflow must be determined by means of an absolute measurement in the air duct.

4. BASES OF CALCULATIONS

In this chapter an account is given of the most frequent quantities and conversion formulae in the determination of airflow rates.

Hydraulic diameter d_h

$$d_h = \frac{4 \times A}{O} \quad \text{m} \qquad (1)$$

where

A = cross section area of duct m^2

O = circumference of duct m

For a rectangular duct this becomes:

$$d_h = \frac{2 \times a \times b}{a + b} \quad \text{m} \qquad (2)$$

where

a and b are the duct's sides in m.

For a circular duct this becomes:

$$d_h = d \quad \text{m}$$

where

d = the duct's diameter m

Density of the air ρ

$$\rho = 1.293 \times \frac{B}{760} \times \frac{273}{273 + t} \ \text{kg/m}^3 \qquad (3)$$

where

B = barometric pressure in mm Hg

t = air temperature in ^{o}C

If B is stated in mbar then the following is obtained instead:

$$\rho = 1.293 \times \frac{B}{1013} \times \frac{273}{273 + t} \ \text{kg/m}^3 \qquad (4)$$

In low pressure systems it is not necessary to consider the effect of static pressure on the density.

However, in high pressure systems this may be actual. Calculations are then made in accordance with the following:

$$\rho = 1.293 \frac{B + p_s \times 0.0075}{760} \times \frac{273}{273 + t} \text{ kg/m}^3 \quad (5)$$

where

B = stated in mm Hg

p_s = static overpressure in the duct in Pa

If B is stated in mbar then:

$$\rho = 1.293 \frac{B + 0{,}01\, p_s}{1013} \times \frac{273}{273 + t} \text{ kg/m}^3 \quad (6)$$

Dynamic pressure p_d

$$p_d = \frac{\rho \times v^2}{2} \quad \text{Pa} \quad (7)$$

where

v = air velocity in m/s

If p_d is required in mm WG then:

$$p_d = \frac{\rho v^2}{2g} \text{ mm WG} \quad (8)$$

where

g = 9.81 m/s^2

Air velocity v

$$v = \sqrt{\frac{2p_d}{\rho}} \quad \text{m/s} \quad (9a)$$

where

P_d is stated in Pa.

For ρ = 1.2 kg/m^3 becomes:

$$v = 1.29 \sqrt{p_d} \quad (9b)$$

Alternatively equation (9a) may be written:

$$v = 1.29 \sqrt{p_d \frac{1.2}{\rho}} \quad \text{m/s} \quad (9c)$$

If p_d is given in mm WG then:

$$v = \sqrt{\frac{2gp_d}{\rho}} \text{ m/s} \quad (10a)$$

For ρ = 1.2 kg/m^3 then:

$$v = 4.04 \sqrt{p_d} \quad \text{m/s} \quad (10b)$$

Alternatively equation (10a) may be written:

$$v = 4.04 \sqrt{p_d \frac{1.2}{\rho}} \quad m/s \qquad (10c)$$

Corrections for air density

a. During the proportional balancing of air terminal devices and branch ducts no correction is required for varying air density on condition that the whole system is balanced in the same working conditions. Therefore, for example, the reheaters in air terminal devices and duct branches must be shut off.

b. Corrections for air density in measurement with Pitot tubes and micromanometers are carried out in conformity with the method described in Chapter 5.1. This correction refers to the density at the time of the measurement.

As the rated velocity is usually obtained from a rated airflow of density 1.2 kg/m^3 at the fan inlet, the velocity measured is comparable with that rated only if the density at the time of measurement is also 1.2. If the density deviates the velocity measured must first be corrected to be valid at ρ = 1.2, as the fan always transports the same flow of air independent of its density. Subject to the parameters being equal, correction is only required if the density ρ_m at the time of measurement deviates from ρ_f at the fan inlet. In this case is obtained the equation.

$$v_k = v_m \times \frac{\rho_m}{\rho_f} \quad m/s$$

where

v_k = corrected velocity m/s

v_m = measured velocity m/s

Note that heating or cooling coils in ducts between the fan room and the measuring site must be shut off before the measurement of v_m is carried out.

RECOMMENDED METHODS

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5. METHODS FOR MEASURING IN DUCTS

Survey of R-methods

Method	Designation	Method error
Traversing with Pitot tube in duct with:	A1	
circular cross section	A11	4-6% recommended measuring plane 7% alternative measuring plane
rectangular cross section	A12	4% recommended measuring plane 7% alternative measuring plane
Permanent measuring devices:		
X-measuring tube LFMC	A21-1	See installation requirements for method concerned at error limits 5 and 10%
X-measuring tube LFMR	A21-2	
Duct air measuring device EHBA	A22	
Duct air measuring device DAMD	A23	
Annubar	A24	
Pressure measurement in circular 90° bend	A25-1	
Measuring bend BUM 90	A25-2	
Measuring device Iris	A26	
Measuring ring MR	A27	
Measuring damper SGH	A28-1	
Measuring damper SKS-M	A28-2	
Measuring unit CME	A29	
Determination of airflow rate using a tracer gas	A3	5 or 10%

5.1 Traversing with a Pitot tube in duct with circular or rectangular cross section (Method A11 and A12)

The method signifies that the airflow rate is calculated from a series of velocity measurements in the cross section of a duct. Determination of velocity is done with a Pitot tube with which the dynamic pressure at the measuring point is obtained. The velocity is calculated from this pressure.

Equipment

- Pitot tube (graduated in cm)
- Rubber or plastic tubes
- Manometer (micromanometer, U-tube)
- Thermometer
- (Aneroid barometer)
- Equipment for making holes, and plastic plugs
- Stand for Pitot tube (used in cramped measuring situations)
- Steel measuring tape
- Report forms
- Ladder

Preparations (measuring site)

1. Measuring shall be carried out in a measurement plane located as FIGURE 5. Note that the distance between the measurement plane and *the following* obstacles to the flow shall be 2 to 3 x d (or with rectangular ducts 2 or 3 times the hydraulic diameters d_h).

2. Remove external insulation. Avoid measuring in internally insulated ducts as it is difficult to determine the dimensions accurately. If measurement does occur in internally insulated ducts then the measuring points in accordance with TABLES 1 and 3 must be recalculated.

3. Ensure the lighting at the measurement position is good.

Preparations (instruments)

1. Set up the manometer horizontally on a stable base.
2. Couple the tubes between the Pitot tube and the manometer.
3. Check that the column of liquid is free from air.
4. Adjust the manometer to the correct angle. To obtain the best reading accuracy it is important to use the angle that gives the greatest deflection.
5. If necessary check and adjust the manometer's zero setting.

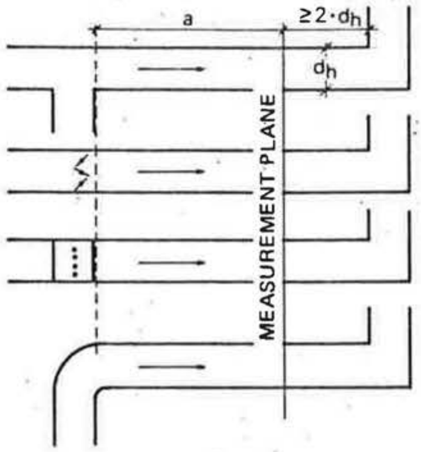


FIGURE 5. Guide for positioning of the measurement plane.

Circular cross section:

a $\geq$ 5d at recommended measurement plane

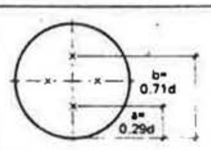
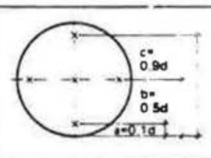
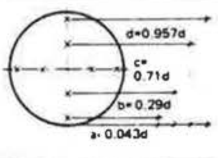
a $\geq$ 3d at alternative measurement plane

Rectangular cross section:

a $\geq 6d_h$ at recommended measurement plane

a $\geq 3d_h$ at alternative measurement plane

TABLE 1. Positions of measuring points at measurement in recommended measurement plane. Circular cross section.
Measurements shall preferably be done in conformity with case A
or if this is impossible in conformity with case B

Nominal diam. mm 1)	Measurement plane	Positions of measuring points, a–d, mm			
		a	b	c	d
100 125 } 2) 160		29 36 46	71 89 114		
200 250 315 400		20 25 32 40	100 125 160 200	180 225 283 360	
500 630 800 1 000 1 250		22 27 34 43 54	145 185 230 290 360	355 445 570 710 890	478 603 766 957 1 196

1. In accordance with duct standard SIS 82 72 06. For the older standard, SIS 82 72 03, points are selected in accordance with TABLE 5.

2. Diameter of the Pitot tube ought not to exceed 1/30 of the duct's diameter. With duct dimensions < 200 mm a Pitot tube with diameter 3-4 mm should be used.

TABLE 2. Positions of measuring points at measurement in the alternative measurement plane. Circular cross section.

Measurements shall be carried out along two diameters in the best of the measurement planes investigated.

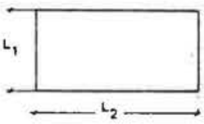
The number of measuring points, depending on dimension group, shall be:

$d \leq 160$	at least	6 measuring points per diameter
$200 \leq d \leq 400$	at least	9 measuring points per diameter
$500 \leq d \leq 1\,250$	at least	10 measuring points per diameter

In selection of measuring points along the particular diameters the following applies:

- o the first and last measuring points shall lie 15 mm from the wall of the duct
- o the other measuring points shall be distributed evenly between the first and last points
- o any maximum or minimum velocity shall be determined both as to position and size.

TABLE 3. Positions of the measuring points in the recommended measurement plane. Rectangular cross section.



In accordance with new duct standard SIS 82 72 04

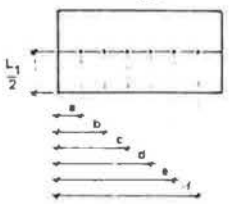
Two alternatives for L_2: I $200 < L_2 \leq 300$; II $400 < L_2 \leq 2\,000$

For alt. I note that: $a = 0.08 \cdot L_2$, $b = 0.43 \cdot L_2$, $c = 0.57 \cdot L_2$, $d = 0.92 \cdot L_2$

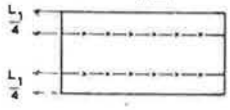
For alt. II note that: $a = 0.060 \cdot L_2$, $b = 0.235 \cdot L_2$, $c = 0.430 \cdot L_2$, $d = 0.570 \cdot L_2$, $e = 0.765 \cdot L_2$, $f = 0.940 \cdot L_2$

Three alternatives for L_1:

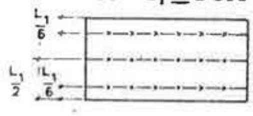
① $200 < L_1 \leq 400$



② $400 < L_1 \leq 800$



③ $800 < L_1 \leq 2\,000$



For these alternatives the following positions of measuring points are then obtained:

L_2	200	250	300	400	500	600	800	1 000	1 200	1 400	1 600	1 800	2 000
a	16	20	25	25	30	35	50	60	70	85	95	110	120
b	85	110	130	95	120	140	190	235	280	330	375	420	470
c	115	140	170	170	215	260	345	430	515	600	690	775	860
d	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

Measurement

It is important that the Pitot tube is held parallel with the direction of flow (a faulty inclination may produce a faulty measurement value, too high or low) and at the correct measuring point.

Select the measuring points. Here are used the distances given in FIGURE 5 as a guide in selection of the measurement plane. Following certain types of disturbances, for example a throttling device, considerably greater distances may be required. With circular ducts the measurement plane should be located at least 150 mm upstream of the connection piece. In the case of rectangular ducts the measurement plane should be situated at least 50 mm upstream of the slip joint. Rectangular ducts with a dimension of $\geq$ 600 mm are usually cracked. If possible measurements should be carried out from a side which is not cracked.

First determine the distribution of velocity in the measurement plane. For velocities below 3 m/s a Pitot tube should not be used for measuring.

1. Measure the dynamic pressure at the centre of the cross section.

2. Find the position of the maximum dynamic pressure and note its position and value.

2.1 If this maximum is situated farther from the duct wall than 0.1 d (0.1 d_h) and the maximal dynamic pressure is less than 2 x dynamic pressure at the centre, *the measurement plane is accepted* and measurement points are then selected according to TABLES 1 and 3 with regard to the measurement plane recommended.

2.2 If both conditions are not fulfilled a new recommended measurement plane is sought.

2.3 If no measurement plane that fulfills the conditions can be discovered then the alternative measurement plane is selected in accordance with 2.4 below.

2.4 The maximal dynamic pressure is located farther from the duct wall than 0.1 d (0.1 d_h) and less than 4 x dynamic pressure at the centre. Further, counterflow may not occur, that is the dynamic pressure may not be negative. Measuring points are selected here from TABLES 2 and 4.

3. If no measurement plane that fulfills the conditions, according to 2.1 and 2.4, can be located, airflow measurement with a Pitot tube should not be carried out.

4. After measuring the holes are sealed.

Report

In report forms A 1:1 and A 1:2 (pages 26 and 27) are noted also, in addition to the measurement values (dynamic pressure), the barometric pressure, temperature of airflow and duct dimensions including distance to any obstacles to the flow. Further, any pulsations in velocity are noted. Note that when measuring in accordance with TABLE 2 the positions of the measuring points must be entered on form A 1:2.

In calculation of the airflow rate correction must be made for:

1. instrument error. This is done using the manufacturer's instructions or the instructions given in the calibration certificate of the instrument,
2. air temperature and barometric pressure. This correction (k_1) is carried out as TABLE 6. For accurate measurements the barometric reading must be added to the change in pressure caused by the fan,
3. shape of duct (measuring points used). This correction (k_2) is carried out as follows:
   a) *circular cross section:*
      $d \leq 160$ mm → $k_2 = 0.96$
      $200 \leq d \leq 400$ mm → $k_2 = 0.97$
      $500 \leq d \leq 1\ 250$ mm → $k_2 = 0.98$
   b) *rectangular cross section:*
      small insertion side ($L_1 > L_2$) → $k_2 = 0.94$
      large insertion side ($L_1 < L_2$) → $k_2 = 0.98$
   c) *square cross section* ($L_1 = L_2$):
      $k_2 = 0.96$

Measurement errors

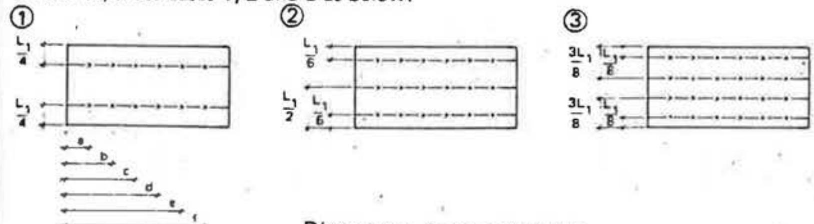
Errors caused by measuring instrument: systematic measurement errors may occur, among other reasons, because of a faulty inclination (> 10°) of the Pitot tube, air bubbles in the micromanometer's shank or because the manometer does not have the correct angle of inclination.

Method errors (see VVS AMA 72, p 22): random errors can occur for example because of a skewed velocity profile in the cross section to be measured. The error, with the recommended measurement plane and case A, is approximately 4%. With measurement in accordance with case B the method error increases to 6%. With an alternative measurement plane the method error is 7%.

Reading errors (See VVS AMA 72, p 22): in pressure measurement the reading error can be set at ±0.3 of a scale division. In pulsating pressure (velocity) there is in addition 1/8 of the amplitude of the pressure reading. The reading errors at different amplitudes and different manometer inclinations are shown in TABLE 7.

TABLE 4. Positions of measurement points when measuring in alternative measurement plane. Rectangular cross section.

In relation to Table 3 the number of measurement lines are altered for the separate cases 1, 2 and 3 as below:



Distances a–f as in TABLE 3.

TABLE 5. Positions of measurement points when measuring in recommended measurement plane with duct dimensions in accordance with the older standard, SIS 82 73 03. Circular cross section.

Preferably the measurements shall be carried out in accordance with case A

or if this is impossible case B

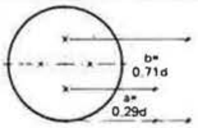
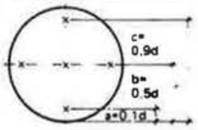
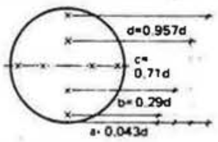
Size	Measurement plane	Positions of measuring points, a–d, mm			
		a	b	c	d
10 13 15		30 39 44	72 94 108		
20 25 30 35 40		20 25 31 36 41	102 125 155 180 205	185 230 275 320 365	
50 60 80 100 125		22 26 35 44 55	150 180 235 295 365	360 435 575 720 900	485 585 780 970 1 215

TABLE 6. Correction factor k_1 for temperature and static pressure.

Temperature in duct °C	Static pressure in duct mbar		
	970 - 1 000	1 000 - 1 030	1 030 - 1 060
- 10 + 10	0.98	0.96	0.95
+ 11 + 30	1.02	1.00	0.98
+ 31 + 51	1.05	1.04	1.02

TABLE 7. Reading error in Pa at different amplitudes and manometer inclinations

Estimated average amplitude in mm	0	2	5	10	20
Manometer inclination K					
1	±3	±6	±9	±16	±28
0.1	±0.3	±0.6	±0.9	±1.6	±2.8
0.05	±0.2	±0.3	±0.5	±0.8	±1.4

Example: If the average amplitude is estimated to 4 mm at an 0.1 inclination, a reading error is obtained on the manometer of 0.8 Pa. If the measurement value has been estimated as 80 Pa the relative reading error thus becomes

$$\frac{0.8}{80} \times 100 = 1\%$$

Evaluation

a. Recommended measurement plane: The method of procedure is shown in measurement report A 1:1.

b. Alternative measurement plane: Evaluation is carried out in accordance with measurement report A 1:2 in combination with the drawing of the product $v_k \times r$ for the two diameters in the measurement plane, see FIGURES 6a and 6b. The numerical values of $v_k \times r$ are obtained from measurement report A 1:2.

In FIGURE 6b the function $v_k \times r$ is approximated with triangles, where the heights of the triangles h_1, h_2, h_3 and h_4 are determined. The triangles are drawn into the figure so that the triangular areas become equal to the sectioned areas. The airflow q in m/s is obtained from the following equation:

$$q = \frac{\pi d}{8} (h_1 + h_2 + h_3 + h_4) \ m^3/s$$

Remarks

Measurement of airflow velocity with a hot-wire anemometer:
To determine the airflow in a duct a hot-wire anemometer can be used for measurement of the airflow velocity on condition that:

- the hot-wire anemometer has a probe with an approximately point-shaped sensor,
- the handle of the instrument is not thicker than the comparative Pitot tube would be,
- the same rules and correction factors are used as apply for measuring with a Pitot tube, but with the exception of correction factor k_1,

- the hot-wire anemometer is carefully calibrated at the temperature prevailing in the duct. (If the calibration is only carried out at 20°C and the measurement at, say, 30°C an error of more than 10% of the airflow velocity may occur.

It is advantageous however to use the Pitot tube for checking the dynamic pressure at the centre of the duct as well as the maximal dynamic pressure and its position.

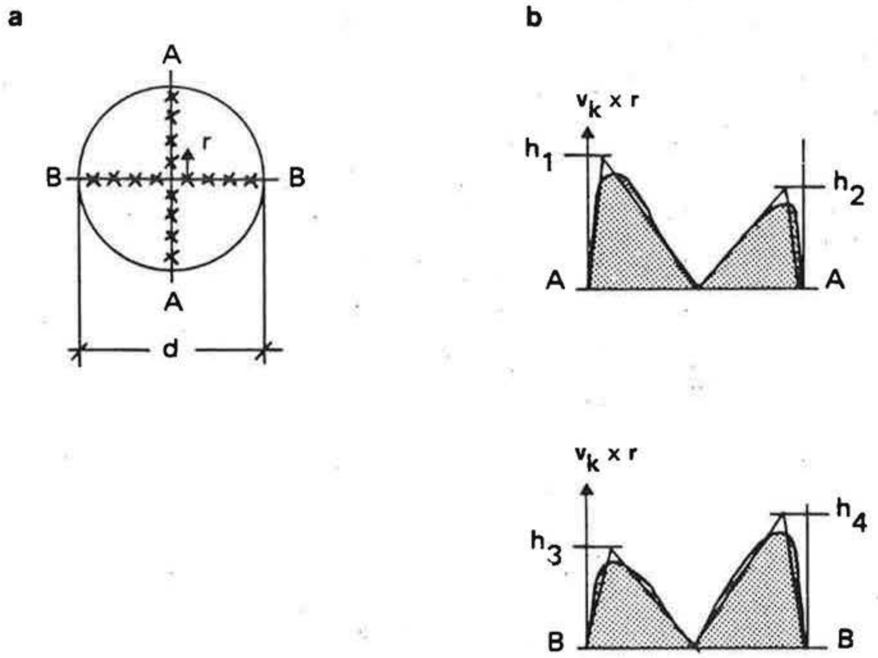


FIGURE 6. Evaluation method when using alternative measurement plane.

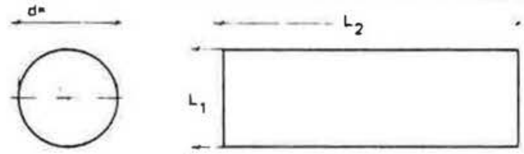
	MEASUREMENT REPORT A1:1	
	Measurement of airflow rate in duct, Pitot tube *Recommended measurement plane and alternative measurement plane when cross section is rectangular*	Assignment No Date Measured by Page of

Object	Measurement position (drawing numbers, etc.)

Obstacles to flow at measurement position: **Before:** Type Distance **After:** Type Distance

State dimensions

Mark positions of measuring points



Designation as TABLES 1 and 3, alternatively distance in mm	Manometer reading	Inclination of manometer	Dynamic pressure, Pa	Correction for instrument Pa	Corrected dynamic pressure Pa	Velocity v m/s
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						

Total ....

Average velocity v_m .... m/s

Correction for temperature and static pressure k_1 .... °C .... mbar (TABLE 6)

Correction k_2 for shape of duct ....

Corrected velocity $v_k = v_m \times k_1 \times k_2$ m/s .... m/s

Cross section area of duct A .... m^2

Airflow rate $q = v_k \times A$ .... m^3/s

Notes:

Dynamic pressure at centre ....

Max. dynamic pressure ....

Amplitude ± .... mm

Position of max. dynamic pressure .... mm from the duct

Outdoor temperature .... °C

Barometric pressure
B = ... mbar

Static over or under-pressure in duct
ΔP_s .... Pa x 0.01 = ... mbar

Static pressure in duct
$P_s = B +/- \Delta P_s$ = ... mbar

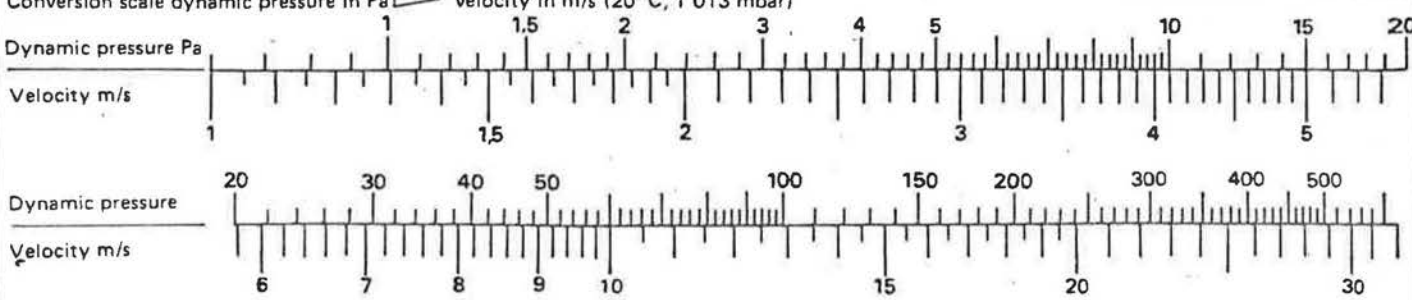
Instrument error m_1 .... %

Method error m_2 .... %

Reading error m_3 .... %
(TABLE 7)

Probable error $\overline{m}$ .... %

Conversion scale dynamic pressure in Pa ▷ velocity in m/s (20 °C, 1 013 mbar)



MEASUREMENT REPORT A1:2

Measurement of airflow rate in duct, Pitot tube

Alternative measurement plane

Assignment No.
Date
Measured by
Page of

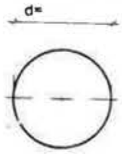
Object

Measurement position (drawing numbers, etc.)

›stacles to flow at measurement position: **Before:** Type Distance **After:** Type Distance

State dimensions

ark positions
measuring points



Temperature............ °C in duct
Static pressure............ mbar in duct

Correction factor k_1....... (TABLE 6)

Distance r according to GURE 6, m) ▽	Manometer reading	Inclination of manometer	Dynamic pressure Pa	Correction for instrument Pa	Corrected dynamic pressure Pa	Velocity v m/s	Corrected velocity v_k ($v \times k_1$) m/s	$v_k \times r$ m²/s
2								
3								
5								
6								
8								
9								
11								
14								
17								
20								
22								
23								

$$q = \frac{\pi \times d}{8} \; (h_1 + h_2 + h_3 + h_4) \; m^3/s$$

Notes:

Dynamic pressure at centre............

Max. dynamic pressure................

Amplitude ±.......................mm

Position of max. dynamic pressure....
...............mm from the duct

Outdoor temperature................ °C

Barometric pressure
B = ...mbar

Static over or under-pressure in duct
ΔP_s.......... Pa × 0.01 = ... mbar

Static pressure in duct
$P_s = B +/- \Delta P_s$ = ... mbar

Instrument error m_1................%

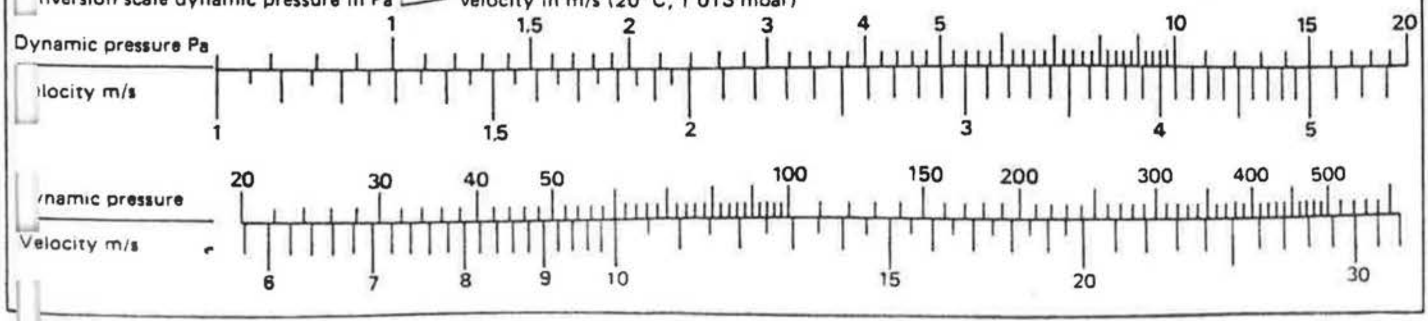
Method error m_2.....................%

Reading error m_3 ....%

(TABLE 7)

Probable error $\overline{m}$.....................%

›nversion scale dynamic pressure in Pa ▷ velocity in m/s (20 °C, 1 013 mbar)



Completed sample

MEASUREMENT REPORT A1:2

Measurement of airflow rate in duct, Pitot tube

Alternative measurement plane

Assignment No	
Date	
Measured by	
Page	of

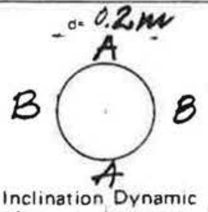
Object

Measurement position (drawing numbers, etc.)

Obstacles to flow at measurement position: **Before:** Type *Bend* Distance *0.6 m* **After:** Type *Bend* Distance *0.4 m*

State dimensions

Mark positions of measuring points



Temperature *25* °C in duct

Static pressure *10~1* mbar in duct

Correction factor k_1 .... (TABLE 6)

Distance r according to FIGURE 6, r (m)	Manometer reading	Inclination of manometer	Dynamic pressure Pa	Correction for instrument Pa	Corrected dynamic pressure Pa	Velocity v m/s	Corrected velocity v_k ($v \times k_1$) m/s	$v_k \times r$ m²/s
1 0.085	90	1/10	90	-3	87	12.0	12.0	1.02
2 0.066	83		83	-5	80	11.6	11.6	0.766
3 0.047	76		76	-3	73	11.0	11.0	0.517
4 0.028	69		69	-2	64	10.6	10.6	0.297
5 0.009	52		52	-2	50	9.1	9.1	0.082
6 0.009	39		39	-1	38	7.9	7.9	0.071
7 0.028	44		44	-1	43	8.5	8.5	0.238
8 0.047	50		50	-1	49	9.0	9.0	0.423
9 0.066	62		62	-2	60	10.0	10.0	0.660
10 0.085	65		65	-2	63	10.3	10.3	0.876
11								
12 0.085	93		93	-3	90	12.2	12.2	1.037
13 0.066	96		96	-3	93	12.4	12.4	0.818
14 0.047	82		82	-3	79	11.5	11.5	0.540
15 0.028	60		60	-2	58	9.8	9.8	0.274
16 0.009	49		49	-1	48	8.9	8.9	0.080
17 0.009	42		42	-1	41	8.3	8.3	0.075
18 0.028	38		38	-1	37	7.8	7.8	0.218
19 0.047	52		52	-2	50	9.1	9.1	0.428
20 0.066	63		63	-2	61	10.1	10.1	0.667
21 0.085	66		66	-2	64	10.3	10.3	0.876
22								
23								
24								

Notes:

- Dynamic pressure at centre *40*
- Max. dynamic pressure *96*
- Amplitude ± *5* mm
- Position of max. dynamic pressure .... mm from the duct
- Outdoor temperature *−6* °C
- Barometric pressure B = *1017* mbar
- Static over or under-pressure in duct ΔP_s *400* Pa × 0.01 = *4* mbar
- Static pressure in duct $P_s = B +/- \Delta P_s$ = *1021* mbar

$$q = \frac{\pi \times d}{8} (h_1 + h_2 + h_3 + h_4) \text{ m}^3/\text{s}$$

$$q = \frac{\pi \times 0.2}{8} (0.83 + 0.88 + 0.85 + 1.02)$$

$$q = 0.289 \text{ m}^3/\text{s} \pm 8\%$$

(h_1 to h_4 recived from FIGURE 7)

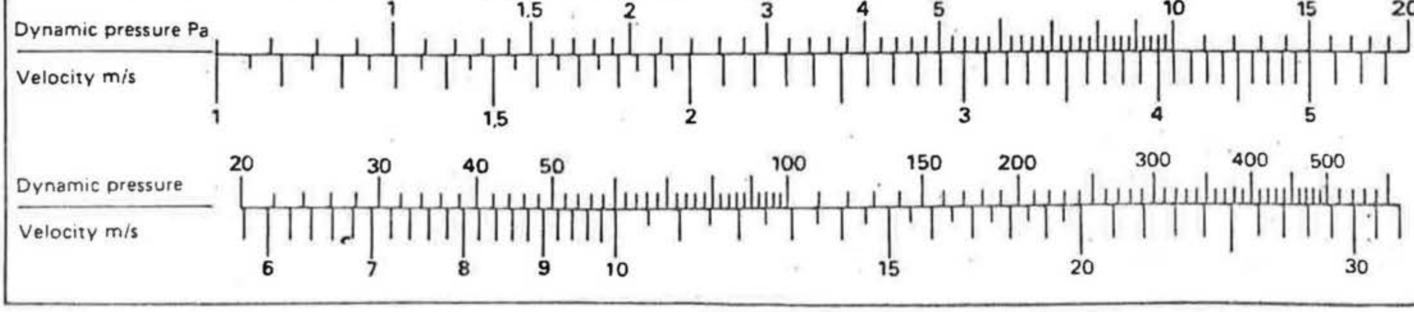
Instrument error m_1 *3* %

Method error m_2 *7* %

Reading error m_3 $\frac{0.9}{50} \times 100 = 1.8$ %

Probable error $\bar{m}$ *8* % (TABLE 7)

Conversion scale dynamic pressure in Pa ⊳ velocity in m/s (20 °C, 1 013 mbar)



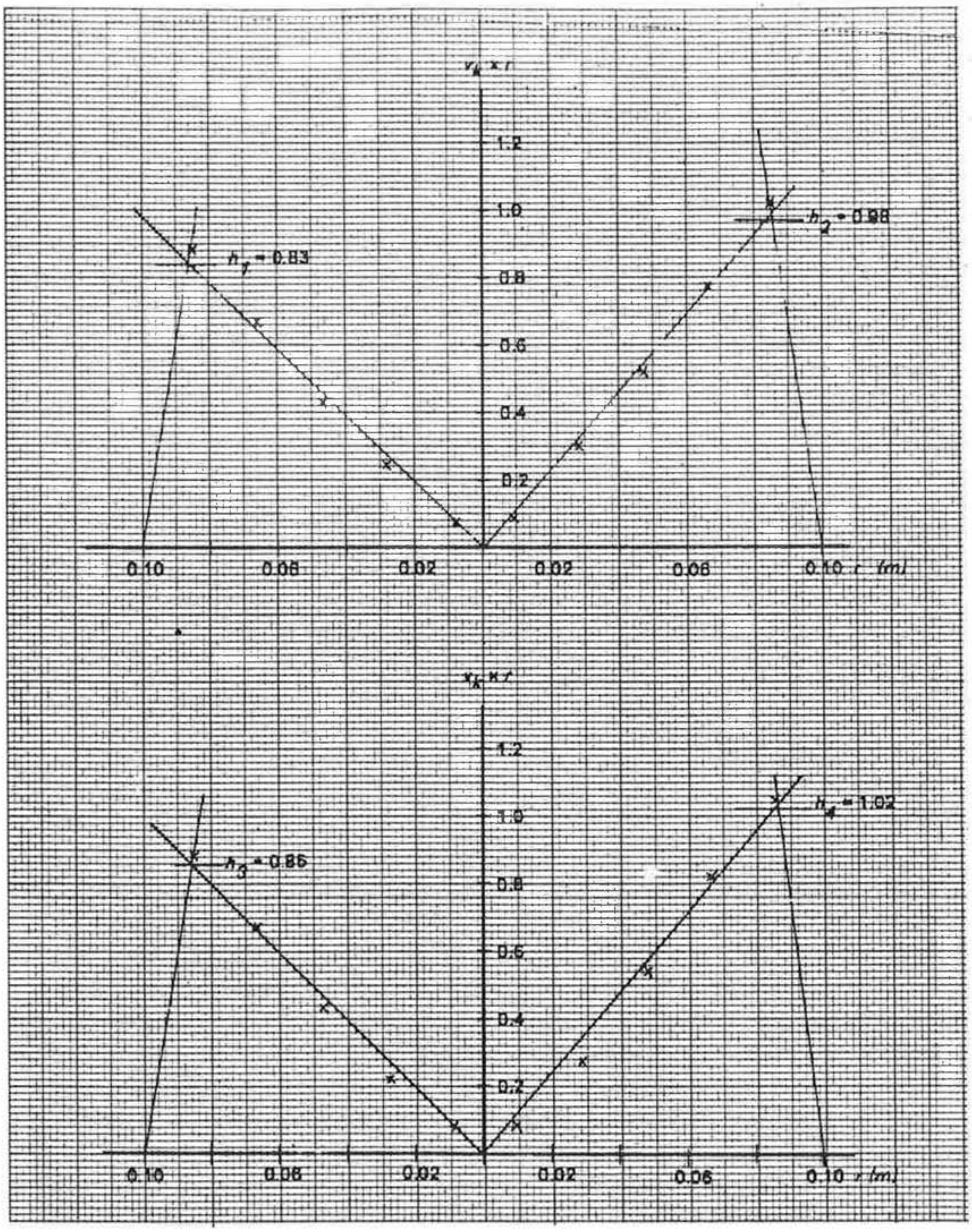


FIGURE 7. Evaluation with alternative measurement plane. Example.

5.2 Permanent measuring devices (Method A 21 - A 29)

The rules given below for permanent measuring devices give the necessary installation measurements in ventilation systems so that the error caused by positioning and size of airflow does not exceed the error limits ±5% or ±10% (for method A 26 8%).

The rules include stated measuring devices mounted in ducts where the air velocity lies between 3 and 15 m/s.

The rules are based on investigations where 90° bends with the same dimensions as the ducts and in some cases throttling dampers have been utilized as disturbing elements.

5.2.1 Measuring X-tubes types LFMC and LFMR (Method A 21)

The measuring X-tube is manufactured in standard dimensions for both circular and rectangular ventilation ducts.

The measuring device is intended for permanent installation in the duct system. When measurement is to be carried out a manometer is attached by tubes to the two measurement outlets of the X-tube - see FIGURE 8. The flow as a function of the measured pressure difference is obtained from the manufacturer's data sheet.

Measuring device LFMC in circular duct - Method A 21-1. Measuring device LFMR in rectangular duct - Method A 21-2.

Equipment

- o Manometer
- o Rubber or plastic tubes for connecting to pressure nozzles
- o Diagram (the airflow as a function of characteristic pressure).

Measurement error

The method error m_2 = 5% or 10% subject to the minimum requirements for straight sections preceding and following the measurement device as shown in TABLES 8a and 8b.

Calibration method

See reference /4/.

Suppliers

Mät- och Underhållskontroll AB, Stockholm, Sweden.
Industriventilation AB. Växjö, Sweden.

TABLE 8a. Requisite straight sections preceding and following circular measuring device, LFMC.

Type of disturbance	Straight section preceding device m_2 = 5%	m_2 = 10%
One 90° bend preceding device	5.5 x D	-[1]
Two 90° bends preceding device, both bends in same plane	6.5 x D	-[1]
Two 90° bends preceding device, bends in a plane at right-angles to each other	14 x D	-[1]

The straight section downstream from the measuring device ≥ 2 x D to the nearest disturbance. D indicates the duct's internal diameter.

[1] Error does not exceed error limits at least practical installation distance.

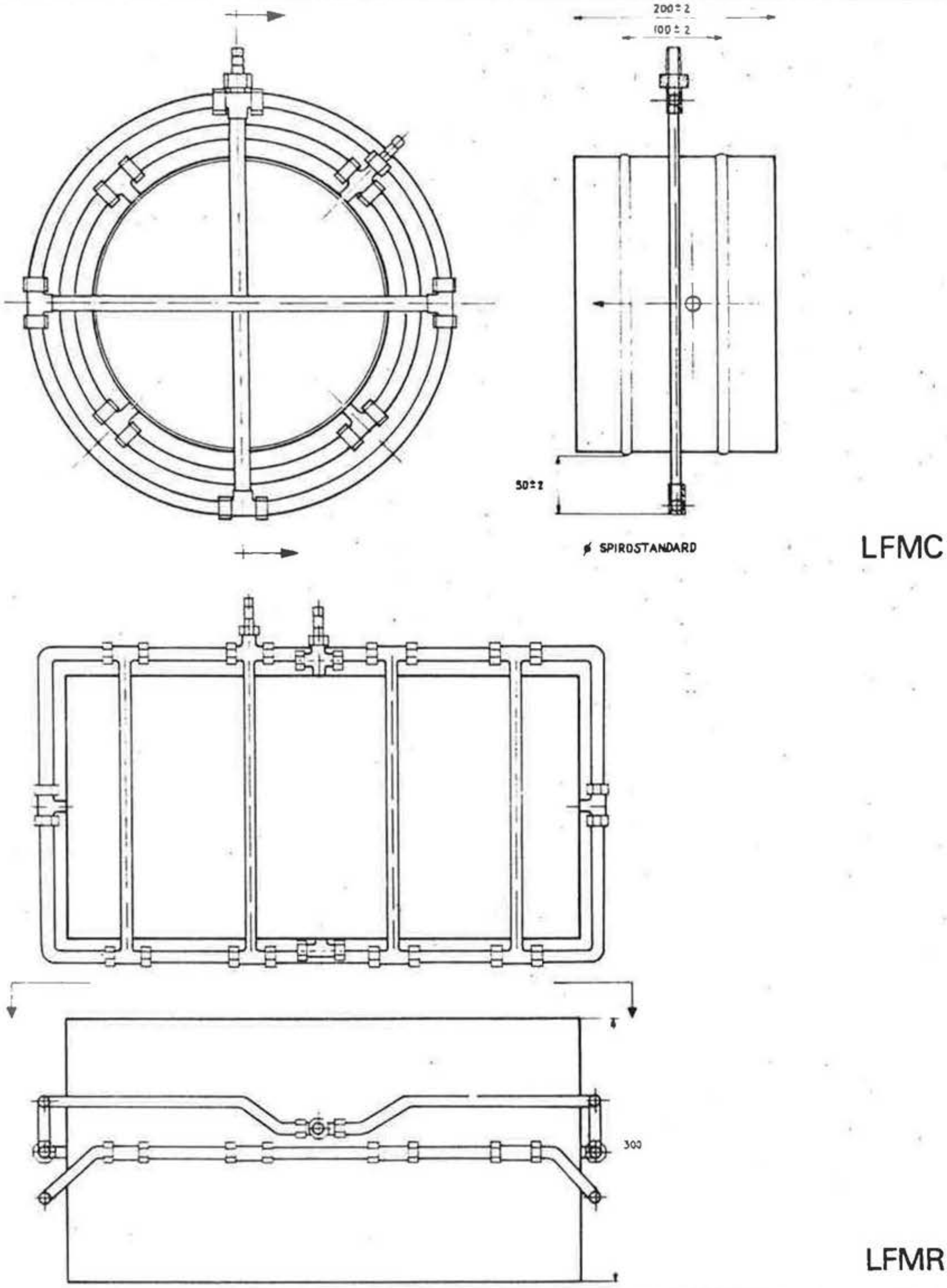


FIGURE 8. Measuring X-tube, airflow measurement device, types LFMC and LFMR.

TABLE 8b. Requisite straight sections preceding rectangular measuring device, LFMR.

Type of disturbance	Straight section preceding device $m_2 = 5\%$	$m_2 = 10\%$
One horizontal 90° bend preceding device	$10 \times d_h$	$2 \times d_h$
Two horizontal 90° bends preceding device	$13 \times d_h$	$2 \times d_h$
One vertical 90° bend preceding device	-[1]	-[1]
Two vertical 90° bends preceding device	$2 \times d_h$	-[1]

[1] The error does not exceed the error limits at least practical installation distance.

The straight section downstream from the measuring device $\geq 2 \times d_h$ to the nearest disturbance.
d_h gives the hydraulic diameter of the duct.

5.2.2 Airflow measuring device EHBA (Method A 22)

Airflow measuring device EHBA is a device for measuring the airflow in circular duct systems. It is intended for permanent installation and can be used for both instantaneous as well as continual airflow measurements. See FIGURE 9. The measuring device will comply with the duct standard and has two nozzles for connecting the measuring tube to the manometer. For installation and measurement instructions see the manufacturer's recommendations.

Equipment

- o Manometer
- o Measuring tubes for connecting to pressure nozzles
- o Flow chart

Measurement error

The method error $m_2 = 5\%$ with the minimum demand for straight sections as stated in the manufacturer's measurement instructions.

Calibration method

See reference /4/

Supplier

Fläkt AB, Stockholm, Sweden.

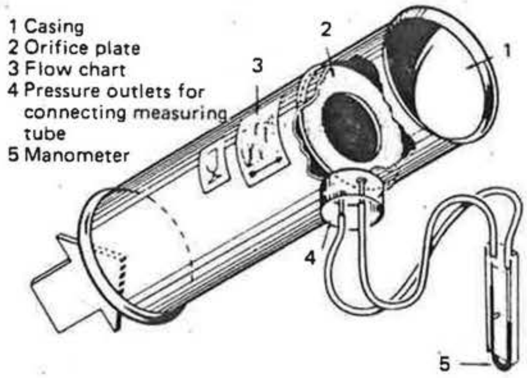


FIGURE 9. Principle construction of airflow measuring device EHBA

5.2.3 Duct Air Measuring Device, DAMD (Method A 23)

This measuring device, DAMD (Duct Air Monitor Device) manufactured by the Air Monitor Corporation, USA, functions in principle as the measuring X-tube in 5.2.1. But the probes are placed somewhat differently and require an airflow straightener.

The device is available for both circular and rectangular ducts within the flow rate area 0.07-70 m^3/s. It can be completed with a reading instrument graduated either for velocity or flow rate.

Equipment

- o Manometer
- o Measuring tubes for connecting to pressure nozzles
- o Flow chart

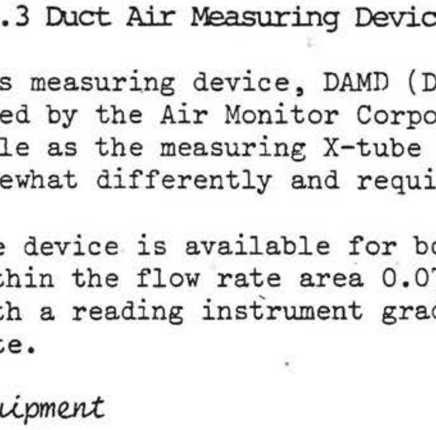


FIGURE 10. DAMD
T = total pressure nozzle
S = nozzle for static pressure

Measurement error

The method error m_2 = 5% or 10% for the minimum demands for straight sections before and after the measuring point shown in TABLE 9.

Calibration method

See reference /4/.

TABLE 9. Requisite straight sections preceding measuring device DAMD

Type of disturbance	Straight section preceding device m_2 = 5%	m_2 = 10%
One 90° bend preceding device	7.5 x D	-[1]
Two 90° bends preceding device, both bends in same plane	5.5 x D	-[1]
Two 90° bends preceding device, bends in plane at right angles to each other	5.0 x D	-[1]

The straight section downstream from the device ≥ 2 x D to the nearest disturbance. D gives internal diameter of duct.

[1] The error does not exceed the error limits at the least practical installation distance.

5.2.4 Annubar (Method A 24)

The Annubar airflow measuring device is constructed for measuring in liquids or gases. FIGURE 11 shows the principle of the probe construction. The measurement device is available in sizes suitable for duct diameters up to 900 mm for ventilation systems. Larger measuring probes are available for other applications.

Annubar type 73 is suitable for duct diameters of 40-400 mm.
Annubar type 74 is suitable for duct diameters 80-900 mm.

A characteristic pressure Δp is measured with the measuring probe and with knowledge of the probe's length and dimension of the duct, the flow, q, is calculated using the information given in the manufacturer's catalogue. The measuring device can be fitted with a reading instrument graduated either for pressure or flow rate.

There is also a simpler version of the permanent measuring device called Airbar. However, the method error and length of the straight section required are not known.

Equipment

- o Manometer
- o Measuring tubes for connecting to pressure nozzles
- o Flow chart

Measurement error

The method error m_2 = 5% or 10% subject to the minimum requirement for straight sections preceding or following the measurement device - see TABLE 10.

Calibration method

See reference /4/.

Supplier

Gustaf Fagerberg AB, Stockholm, Gothenburg and Sundsvall, Sweden.

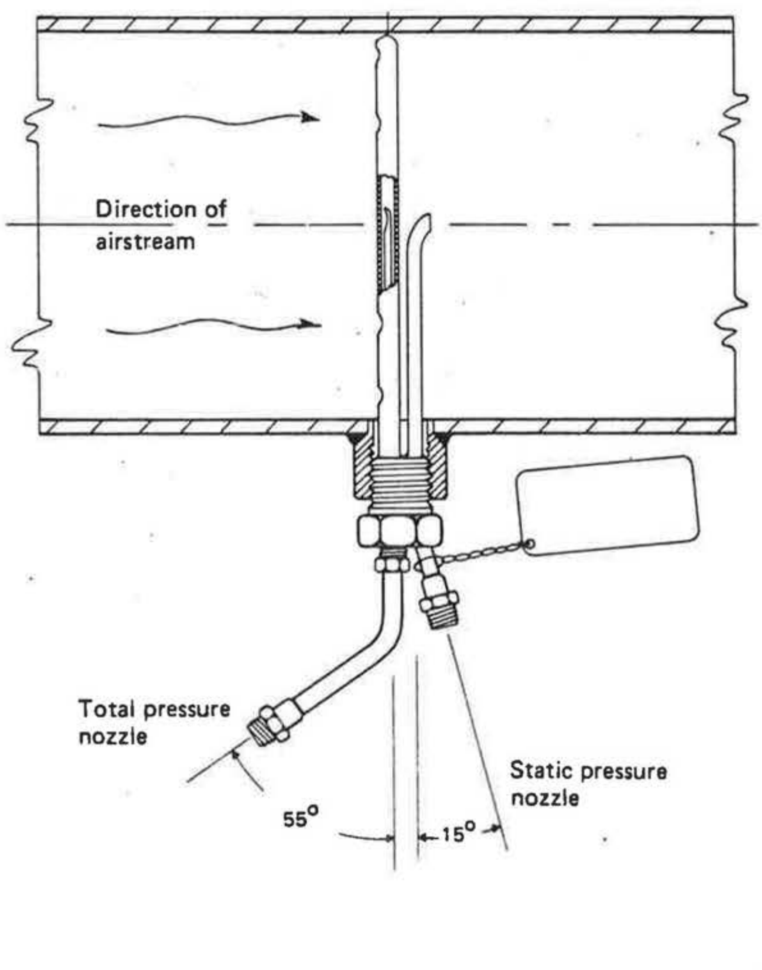


FIGURE 11. Principle construction of Annubar airflow measuring device type 73.

TABLE 10. Straight sections required preceding measuring device Annubar.

Type of disturbance	Straight section preceding device $m_2 = 5\%$	$m_2 = 10\%$
One 90° bend preceding device	7.0 x D	-[1]
Two 90° bends preceding device, both bends in same plane	7.5 x D	-[1]
Two 90° bends preceding device, bends in plane at right-angles to each other	8.0 x D	6.5 x D

Straight section downstream from measuring device ≥ 2 x D to nearest disturbance. D gives internal diameter of duct.

[1] Error does not exceed limits of error at the least practical installation distance.

5.2.5 Pressure measurement in bend of a duct (Method A 25-1)

Here the method consists of measuring the pressure-differences between two points lying on the same line from the centre of a bend and in the central plane of the bend, see FIGURE 12a. One of the measuring points lies in the duct at the bend's inner radius and the other at the bend's outer radius (see more detailed description in Technical Report No. 19, 1973:4 - in Swedish - from Institution for Heating and Ventilation Technology, Royal Institute of Technology, Stockholm, Sweden).

A pressure difference Δp is measured with a micromanometer between the two measuring outlets (M in FIGURE 12a) and the flow obtained from DIAGRAM 1 for compression moulded bends. DIAGRAM 1 applies for $\rho = 1.2$ kg/m³. For other densities the flow obtained in DIAGRAM 1 is multiplied by

$$\sqrt{\frac{1.2}{\rho}}$$

or alternatively with the value according to TABLE 6 (page 23).

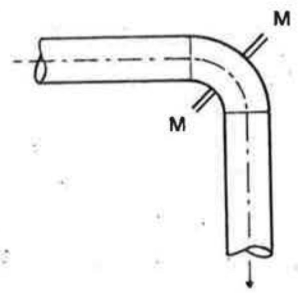


FIGURE 12a. Bend with pressure nozzles M.

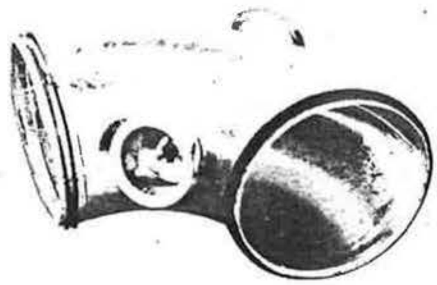


FIGURE 12b. BUM 90^{o} measuring bend.

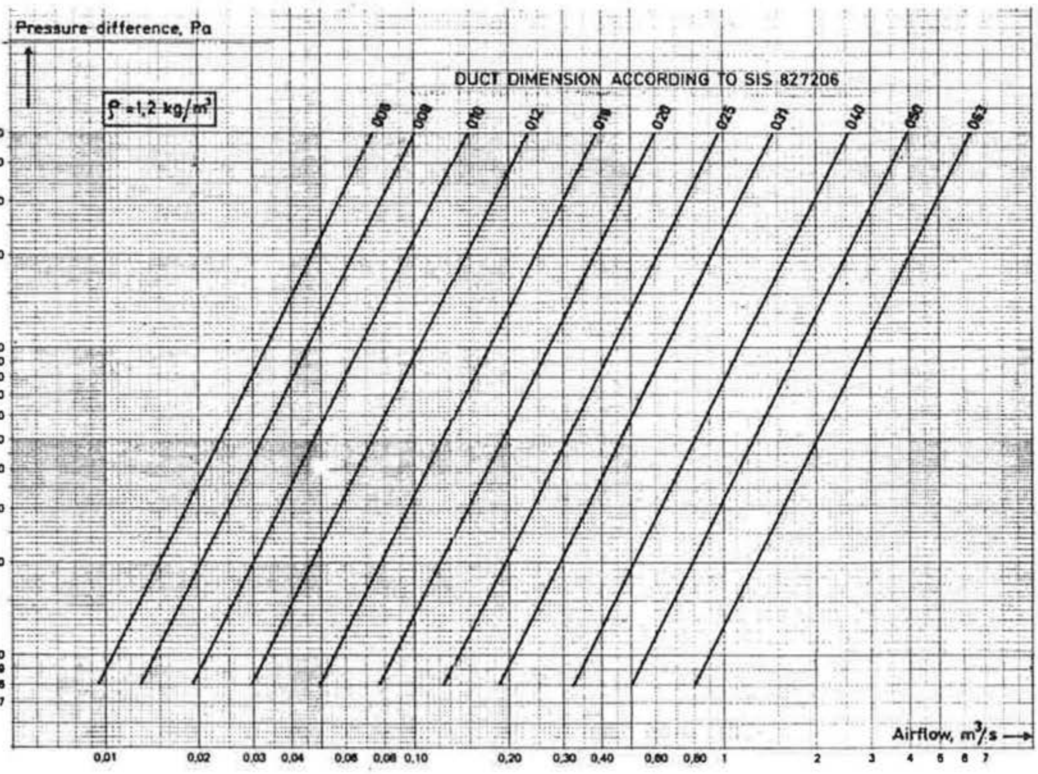


DIAGRAM 1.

Equipment

- o Manometer
- o Measuring tubes for connecting to pressure nozzles
- o Flow chart, see DIAGRAM 1.

Measurement error

The method error m_2 = 5% respectively 10% subject to the minimum requirements for straight sections preceding and following the measuring device shown in TABLE 11a.

Calibration method

See reference /4/.

5.2.6 BUM 90° measuring bend (Method A 25-2)

This method is almost identical with method A 25-1. The difference lies in a somewhat different location of the pressure outlet, see FIGURE 12b. The same diagram (DIAGRAM 1) for determination of the flow as applies for method A25-1 also holds for this method.

Measurement error

The method error m_2 = 5% respectively 10% on condition that the requirements for straight sections shown in TABLE 11b are fulfilled.

Calibration method

See reference /4/.

Supplier

Lindab Ventilation, Båstad, Sweden

TABLE 11a. Straight sections required preceding bend of a duct

Type of disturbance	Straight section preceding device m_2 = 5%	m_2 = 10%
One 90° bend preceding the device, both in same plane	8 x D	4 x D
One 90° bend preceding the device in plane at right-angles to each other	7 x D	4 x D
Throttling damper preceding the device	10 x D	4 x D

The straight section downstream from the measuring device ≥ 2 x D to the nearest disturbance. D gives the duct's internal diameter.

TABLE 11b. Straight sections required preceding measuring device BUM 90.

Type of disturbance	Straight section preceding device m_2 = 5%	m_2 = 10%
One 90° bend in plane at right-angles to the device	8.5 x D	4.5 x D
Two 90° bends preceding the device in same plane as device	7.5 x D	4 x D
Two 90° bends preceding the device. Bends in plane at right-angles to each other	6.5 x D	3 x D
Throttling damper (45°) preceding device	9 x D	6 x D

The straight section following the measuring device $\geq$ 2 x D to the nearest disturbance. D gives internal diameter of duct.

5.2.7 The Iris regulator and measuring device (Method A 26)

The Iris regulator and measuring device is an adjustable measuring device for obtaining different rates of flow. The device is provided with a 1-9 scale for the setting of the Iris damper. Measurement of pressure drop occurs through nozzles situated on both sides of the device. Because of its adjustability the device is specially intended for use in connection with the adjustment of ventilation systems.

Equipment

- Manometer
- Measuring tubes for connecting to pressure nozzles
- Flow chart

Measurement error

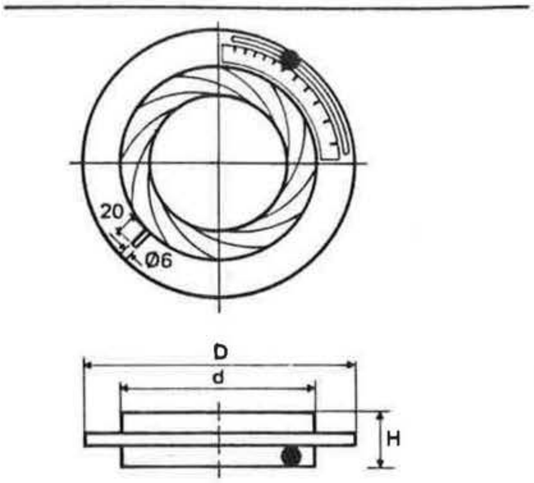
The method error m_2 = 8% with the installation instructions supplied by the manufacturer, that is straight duct section $\geq$ 5d preceding and straight duct section $\geq$ 2d following the device.

Calibration method

See reference /4/

Supplier

Jan Grimming AB, Hägersten, Sweden.



Size	010	012	016	020	025	031	040	050	063	080
d	98	123	158	198	248	213	398	498	628	798
D	150	210	230	280	350	420	560	710	950	1200
H	65	65	65	65	70	70	150	150	150	150

FIGURE 13. The Iris regulator and measuring device.

5.2.8 Measuring ring MR (Method A 27)

Measuring ring MR is a nonadjustable measuring device for measuring the airflow in ventilation installations. The airflow is determined by measuring the difference in pressure that arises across the measuring ring and from readings on a calibration curve of the equivalent flow. Measuring ring MR is available in sizes up to 1250 mm.

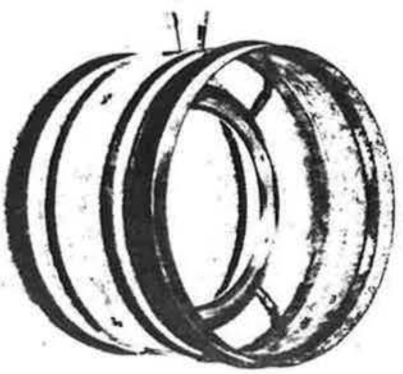


FIGURE 14. Measuring ring MR

Equipment

- o Manometer
- o Measuring tubes for connecting to pressure nozzles
- o Flow chart

Measurement error

The method error m_2 = 5% respectively 10% subject to the minimum requirements for straight sections preceding and following the measuring device shown in TABLE 12.

Calibration

Se reference /4/

Supplier

Jan Grimming AB, Hägersten, Sweden

TABLE 12. Straight section required preceding measuring ring MR

Type of disturbance	Straight section preceding device m_2 = 5%	m_2 = 10%
One 90° bend preceding device	4 x D	-1)
Two 90° bends preceding device, both bends in same plane	2 x D	-1)
Two 90° bends preceding device, bends in plane at right-angles to each other	2 x D	-1)
Throttling damper (45°) preceding device	7 x D	2 x D

1) The error does not exceed the error limit at the least practical installation distance.

Note: Straight section after the device ≥ 2 x D to the nearest disturbance.

5.2.9 Measuring damper SGH (Method A 28-1)

This measuring damper, manufactured by AB Bahco Ventilation, is illustrated in FIGURE 15. It consists of a sliding plate in a special fixture. Measurement of pressure decrease across the damper is done through nozzles situated at both sides of the device. The damper, because of its possibilities of different settings, is intended as a combined adjustment and measuring device.

Equipment

- Manometer
- Measuring tubes for connecting to pressure nozzles
- Flow chart

TABLE 13. Straight sections required preceding measuring damper SGH

Type of disturbance	Straight section preceding device $m_2 = 5\%$	$m_2 = 10\%$
One 90° bend preceding device	6 x D	2 x D
Two 90° bends preceding device, both bends in same plane	8 x D	2 x D
Two 90° bends preceding device, bends in plane at right-angles to each other	6 x D	2 x D

Note: Straight section after the device ≥ 2 x D to nearest disturbance. D gives internal diameter of duct.

Table 13 is valid on condition that the sliding damper covers at least 40% of the duct's internal diameter.

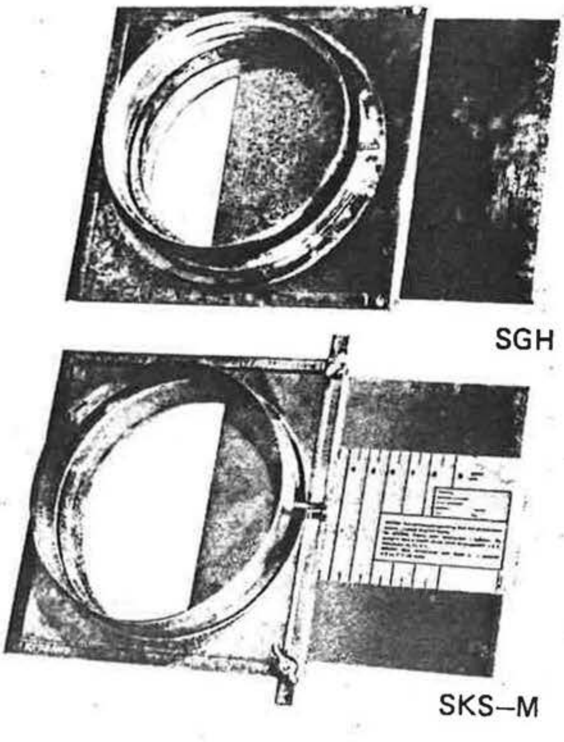


FIGURE 15. Measuring dampers SGH and SKS-M

Measurement error

Method error m_2 = 5% or 10% on condition that the requirement for straight sections shown in TABLE 13 is fulfilled.

Calibration method

See reference /4/

5.2.10 Measuring damper SKS-M (Method A 28-2)

This measuring damper, manufactured by Ingenjörsfirman Ole A Larsen A/S of Norway, is illustrated in FIGURE 15. As measuring damper SGH, it consists of a sliding plate in a special fixture. Measurement of pressure drop across the damper is done through nozzles positioned at opposite sides of the device.

Equipment

- o Manometer
- o Measuring tubes for connecting to pressure nozzles
- o Flow chart

Measurement error

Method error m_2 = 5% or 10% on condition that the requirement for straight sections in TABLE 13 is fulfilled.

Calibration method

See reference /4/.

Supplier

Beterma Maskin AB, Hägersten, Sweden.

TABLE 14. Straight sections required preceding measuring damper SKS-M

Type of disturbance	Straight section preceding device m_2 = 5%	m_2 = 10%
One 90° bend preceding device	7 x D	5 x D
Two 90° bends preceding device, both bends in same plane	7 x D	4 x D
Two 90° bends preceding device, bends in plane at right-angles to each other	8 x D	5 x D

Straight section after device $\geq$ 2 x D to nearest disturbance.
D gives internal diameter of duct.

The Table is valid for all settings 1-9. For setting 4 and above the lower values given in TABLE 13 may be used.

5.2.11 Measuring unit CME (Method A 29)

Measuring unit CME is a nonadjustable device for measurement of the airflow in ventilation systems. The unit is made by Stifab AB. Airflow rate is determined by measurement of the pressure difference across the central body. The airflow rate is then obtained from the manufacturer's diagram.

Equipment

- o Manometer
- O Measuring tubes for connecting to pressure nozzles
- o Flow chart

Measuring error

Method error m_2 = 5% or 10% at the minimum requirements, shown in TABLE 15, for straight sections preceding and following the measuring device.

Calibration method

See reference /4/.

Supplier

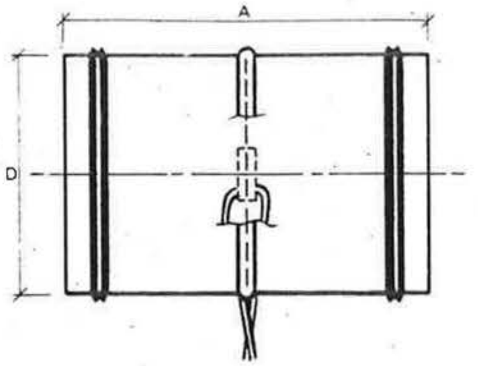
Stifab AB, Jönköping, Sweden.

TABLE 15. Straight sections required preceding measuring device CME

Type of disturbance	Straight section preceding device	
	m_2 = 5%	m_2 = 10%
One 90° bend preceding device	3 x D	-1)
Two 90° bends preceding device, both in same plane	2 x D	-1)
Two 90° bends preceding device, bends in plane at right-angles to each other	2 x D	-1)
Throttling damper (45°) preceding device	6 x D	2 x D

1) The error does not exceed the error limit at the least practical distance for installation.

Note: The straight section downstream from device $\geq$ 2 x D to the nearest disturbance.



Size ø D	A mm	Weight kg
012	90	0.3
016	90	0.4
020	90	0.5
025	90	0.7
031	90	0.9
040	91	1.2
050	130	2.4
063	130	3.2

FIGURE 16. Rating details for permanent measuring unit CME

5.3 Determination of airflow rate using tracer gas (Method A 3)

One of the difficulties involved in measuring the airflow rate in ventilation ducts is that there are often insufficient straight sections preceding or following the measurement plane. This applies both in measuring with permanent measuring devices and also when a Pitot tube is used.

On the other hand, when tracer gas is used for the measurement of airflow rate, it is an advantage to have many turbulences induced by dampers, bends, etc. For the tracer gas method may only be used when a homogeneous mixture of the tracer gas in the air can be maintained. The method is based on injecting a known low rate of a tracer gas into the ventilation duct. When the tracer gas further downstream has become well-mixed with the ventilation air the concentration of the tracer gas is determined, when the airflow rate can also be determined.

Description of method

The method presumes a continual, known flow rate of tracer gas, $q_s (m^3/s)$ and that the tracer gas is well mixed with the air transported in the duct, q (m^3/s). If the concentration in the cross section used for sampling is called C_s with steady-state condition the following relation is obtained:

$$q = \frac{q_s}{C_s}$$

If the air contains a certain initial concentration C_i of the tracer gas the relation becomes:

$$q = \frac{q_s}{C_s - C_i}$$

where

q = transported airflow rate, m^3/s

q_s = injected tracer gas flow rate, m^3/s

C_s = gas concentration at steady-state in the cross section used for sampling

C_i = initial concentration of tracer gas in the duct.

See further description in ISO 4053/1 - 1977 (E).

Equipment

- o Tracer gas analyzer
- o Tracer gas (N_2O) + reduction valve (manometer)
- o Flowmeter for tracer gas (rotameter)
- o Probe for distribution of tracer gas in the duct
- o Probe for sampling
- o Drill for making holes in the duct
- o Plastic plugs to plug holes when measurement completed.

An example of how measuring equipment can be arranged is illustrated in FIGURES 17b and c.

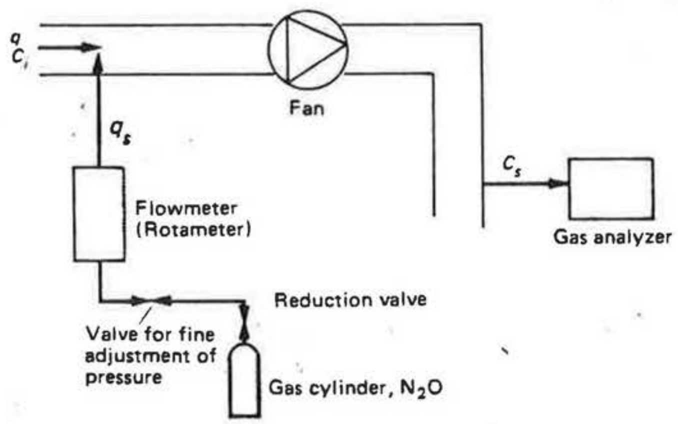


FIGURE 17a. Measuring layout - skeleton diagram. Method A 3.

The injection nozzles for tracer gas are arranged here so that the tracer gas is distributed at four points along a diameter that is 63% of the duct's internal diameter. After the nozzle fixture has been inserted into the duct two of the four nozzle tubes are diverted and all four tubes are adjusted so that the nozzles reach their intended positions in the duct with regard to the dimension of the duct concerned. The nozzle fixture for sampling is dealt with in a similar fashion.

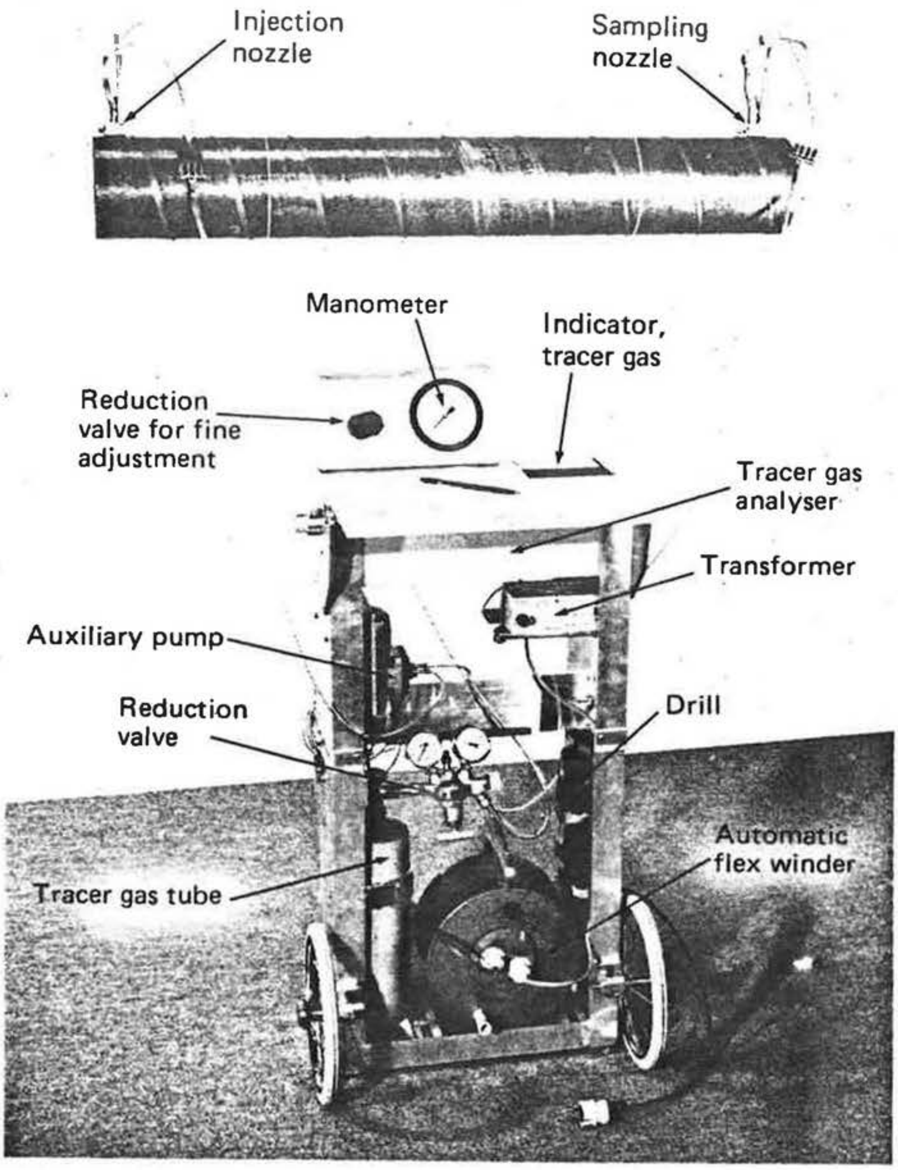


FIGURE 17b. Example of how measuring equipment can be arranged for measuring as method A 3.

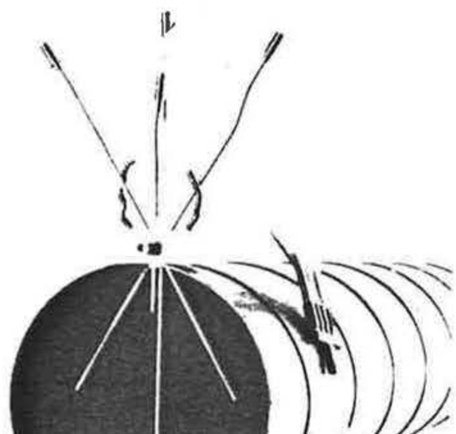


FIGURE 17c. Example of equipment for distribution of tracer gas

Calculation of the airflow rate

The airflow rate is calculated in accordance with the above formulae. If a rotameter is used as a flowmeter for tracer gas it must be calibrated for the actual tracer gas. It is quite impossible to use a single factor for conversion of the rotameter's calibration curve from air to tracer gas.

The flow rate of the tracer gas, q_s, is converted to apply at the prevailing temperature in the ventilation duct. Therefore the temperature of the tracer gas must be measured when passing through the rotameter. The corrected flow rate is obtained from:

$$q_{s_{corr}} = q_{s_{tr}} \frac{\rho_{t_f}}{\rho_{t_d}}$$

where

$q_{s_{tr}}$ = tracer gas flow rate at tracer gas temperature at flowmeter

ρ_t = density of tracer gas

ρ_{t_f} = density of tracer gas at flowmeter

ρ_{t_d} = density of tracer gas at duct air temperature

Temperature of tracer gas (N_2O) ^oC	Density of tracer gas ρ_t, kg/m^3
5	1.93
20	1.83
35	1.73

The airflow rate, q, in the duct is obtained as:

$$q = \frac{q_{s_{corr}}}{C_s - C_i}$$

Measurement error

Probable measurement error, $\bar{m}$, is made up by:

instrument error, m_1
method error, m_2
reading error, m_3

Errors apply for determination of flow rate of the tracer gas and in part of determination of its concentration. If the flow rate of the tracer gas can be arrived at with the measurement error $\bar{m}_f$% and the concentration of this gas (C_s) can be determined with the measurement error $\bar{m}_k$% the probable measurement error becomes $\bar{m}_q$ in q:

$$\bar{m}_q = \sqrt{(\bar{m}_f)^2 + (\bar{m}_k)^2}$$

If a homogenous mixture of the tracer gas is obtained the method error is usually negligible and solely due to leakage from the duct between the tracer gas injection and the sampling cross section. If a tracer gas analyzer of good quality is used the measurement error $\bar{m}_q$ can be estimated to 7%.

Requirements for a homogenous mixture of tracer gas

The distance necessary to enable the tracer gas to mix with the air in the duct is called the mixing length. This mixing length is defined as the shortest distance at which the greatest variation in C_s is less than a previously determined value. The mixing length is therefore not a fixed value but varies subject to the permitted variation in the concentration.

To obtain the highest accuracy in measurement of the airflow rate it is necessary to ensure the least possible variation during the measuring phase. But in practice greater variations have to be accepted because sufficiently-long straight sections are not available. If the tracer gas is injected similarly through a number of openings in the cross section (at least four) and if the sampling is carried out at more than one point, then a considerable decrease in the mixing length can be obtained. See TABLE 16.

A considerable decrease in the mixing length is also obtained if the tracer gas is injected upstream of a fan. See TABLE 16.

TABLE 16. Requisite relative mixing length (L/d_h) for method errors of 5 and 10%.

Type of test rig	L/d_h for error	
	m_2 = 5%	m_2 = 10%
Straight duct without disturbance Injection at centre Sampling at centre	80	60
Straight duct without disturbance Injection through a ring whose diameter is 63% of the duct's (4 holes in ring) a) Sampling at centre	25	20
b) Sampling at 4 points in duct (situated as in injection)	15	10
Duct with two 90° bends Injection through a ring whose diameter is 63% of the duct's (4 holes in ring) a) Sampling at centre	20	15
b) Sampling at 4 points in the duct (situated as in injection)	10	5
Injection preceding a fan and sampling following fan Injection through a ring whose diameter is 63% of the duct's (4 holes)	10	5

6. METHODS FOR MEASURING AT EXHAUST AIR DEVICES AND AIR INTAKE GRILLES

Survey of R-methods

Method	Designation	Method error
Traversing with a hot-wire anemometer on rectangular device using 4-point method	B 1	5-8%
Measuring pressure drop with:		
probe	B 21	5%
permanent measuring outlet	B 22	5%
Measuring with anemometer equipped with a hood	B 3	5%
Measuring of centre velocity in circular exhaust air openings	B 4	7%
Measuring with rotating vane anemometer on intake grilles	B 5	8%

6.1 Traversing with hot-wire anemometer on rectangular devices by the 4-point method (Method B 1)

The method, which is applicable to rectangular or square exhaust air grilles, assumes the measurement of the air velocity at four points - see FIGURE 18. The measuring probe must be located at a definite distance from the grille. It is important that this distance is correct so that the stated correction factors shall be applicable. The measuring probe shall be of the hot-wire anemometer type with a rather point-shaped sensor.

The airflow rate is obtained from the equation:

$$q = k \times v_m \times A \qquad m^3/s$$

where

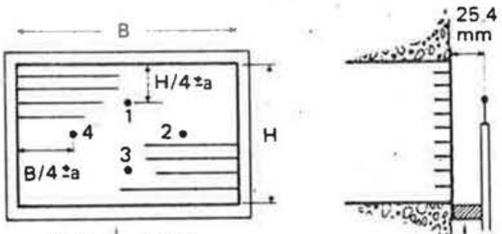
k = flow rate factor as DIAGRAMS 2-10

v_m = average velocity at measuring points 1-4, m/s. Here, as always, consideration must be given to the instrument correction for the four sub-measurements prior to calculation of the average value

A = total area of grille openings (B x H), m^2

Equipment

- Hot-wire instrument (including distance block, 25.4 mm, see FIGURE 18).
- Thermometer
- Steel measuring tape
- Report forms (B 1)
- Drawings



H, B	a,mm
<200	1
200-500	2
>500	4

FIGURE 18. Location of measuring points when measuring according to method B 1.

Preparations

Measure the dimensions of the device, B and H, as FIGURE 19.

If the device is equipped with a damper the relative opening d_1/d_2 is estimated according to FIGURE 19.

Prepare the instrument, check and adjust zero setting, battery voltage, etc.

Note blade-angle of the device according to the manufacturer's information.

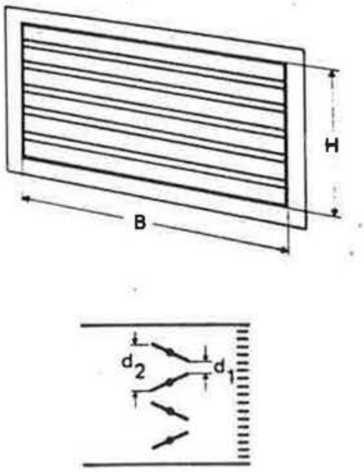


FIGURE 19. Dimensions B and H of measuring device. Estimate relative opening of device d_1/d_2.

Measuring

Measure the air velocity at points 1, 2, 3 and 4 (FIGURE 18) in plane situated 25.4 mm ±0.5 mm in front of the grille. Measurement (with points in the order 1, 2, 3 and 4) is made twice. A reading is taken after 15 seconds at each point so as to obtain a representative average value. Measure the air temperature.

Limitations

The exhaust air grille must be situated in a wall and in the same plane as the wall.

Report

In report B 1 are entered the values read for velocities and air temperatures, duct dimensions, damper position and the blade-angle of the device. In addition velocity pulsations are noted.

The average value of the velocities obtained is then calculated. In calculation of the airflow rate correction is made for instrument errors, method errors and air temperature.

Correction for instrument errors and air temperature is carried out using the calibration curve for the instrument used and with consideration of the air temperature noted.

Correction for measuring points used: the average value of the velocities obtained is corrected in accordance with report B 1, when the correction factor is obtained from DIAGRAMS 2-10.

Measurement error

Error of the measuring instrument m_1: random errors as stated by manufacturer or as the information in the calibration chart.

Method error m_2: systematic measurement errors occur, among other things, when the measuring probe is positioned at a wrong angle or at a wrong distance from the grille. Random method-errors are presumed to be ±5% within accuracy range 1 (see DIAGRAMS 2-10) and ±8% within measuring accuracy range 2.

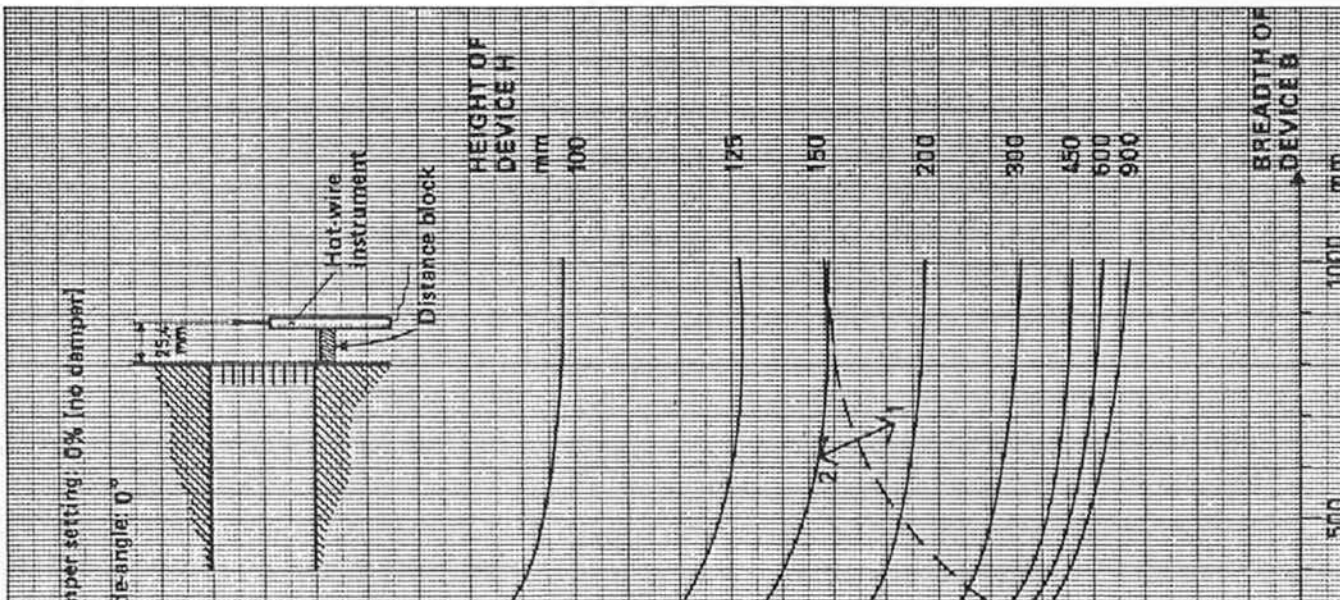


DIAGRAM 2. Measurement of airflow rate with rectangular exhaust air device and air intake grille using a hot-wire instrument. Correction for measuring points (flow factor k).

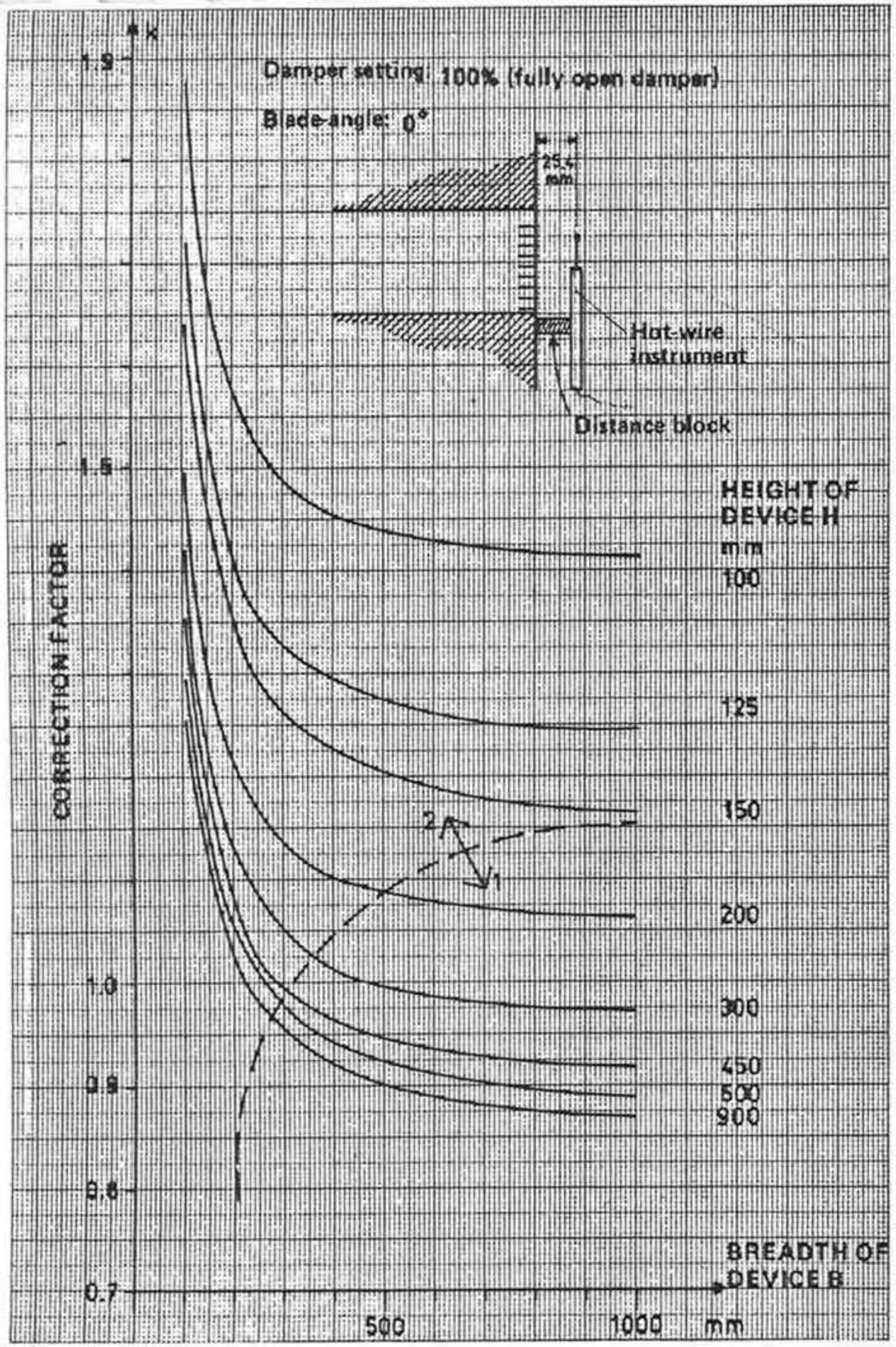


DIAGRAM 4. Measurement of airflow rate with rectangular exhaust air device and air intake grille using a hot-wire instrument. Correction for measuring points (flow factor k).

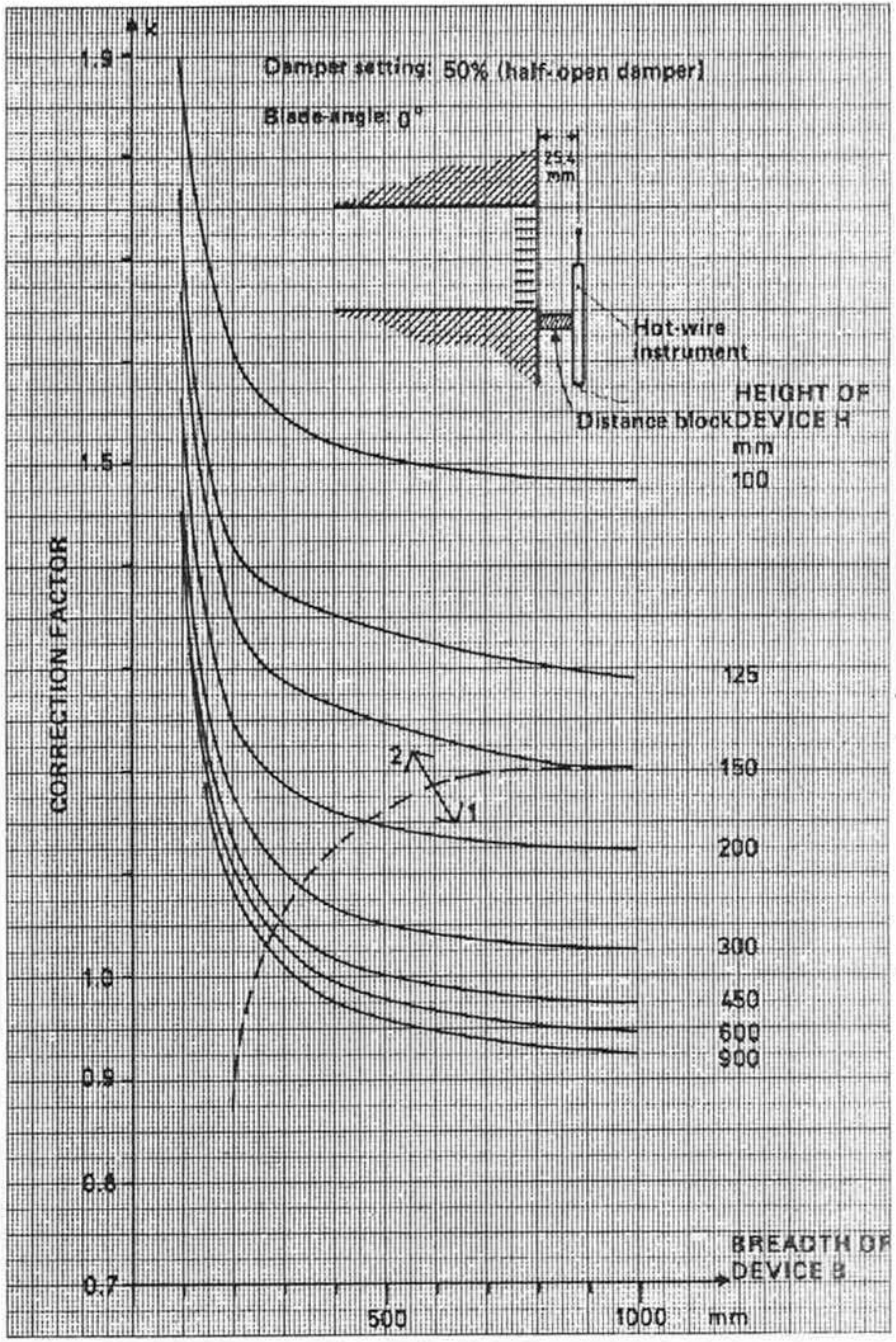


DIAGRAM 3. Measurement of airflow rate with rectangular exhaust air device and air intake grille using a hot-wire instrument. Correction for measuring points (flow factor k).

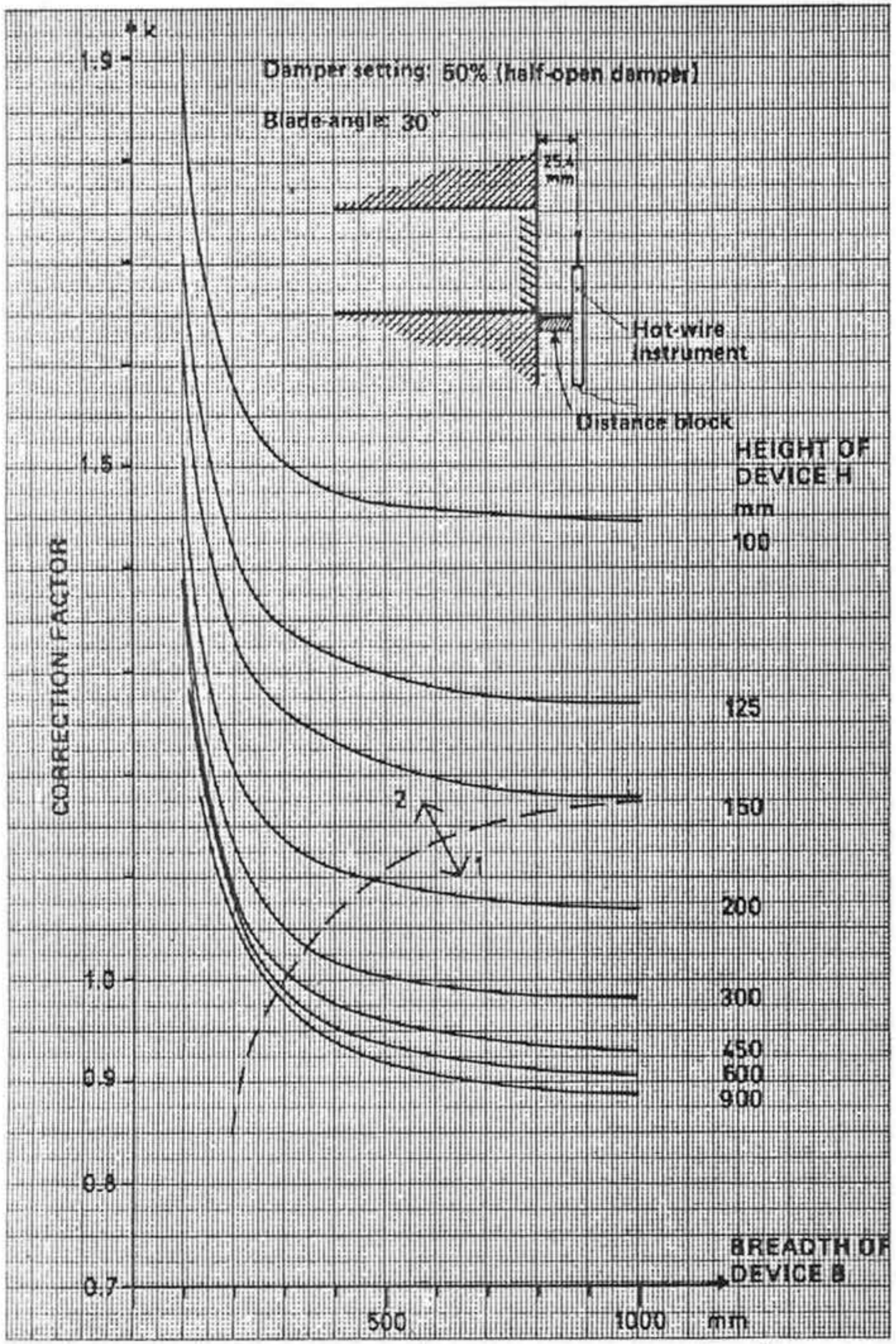


DIAGRAM 6. Measurement of airflow rate with rectangular exhaust air device and air intake grille using a hot-wire instrument. Correction for measuring points (flow factor k).

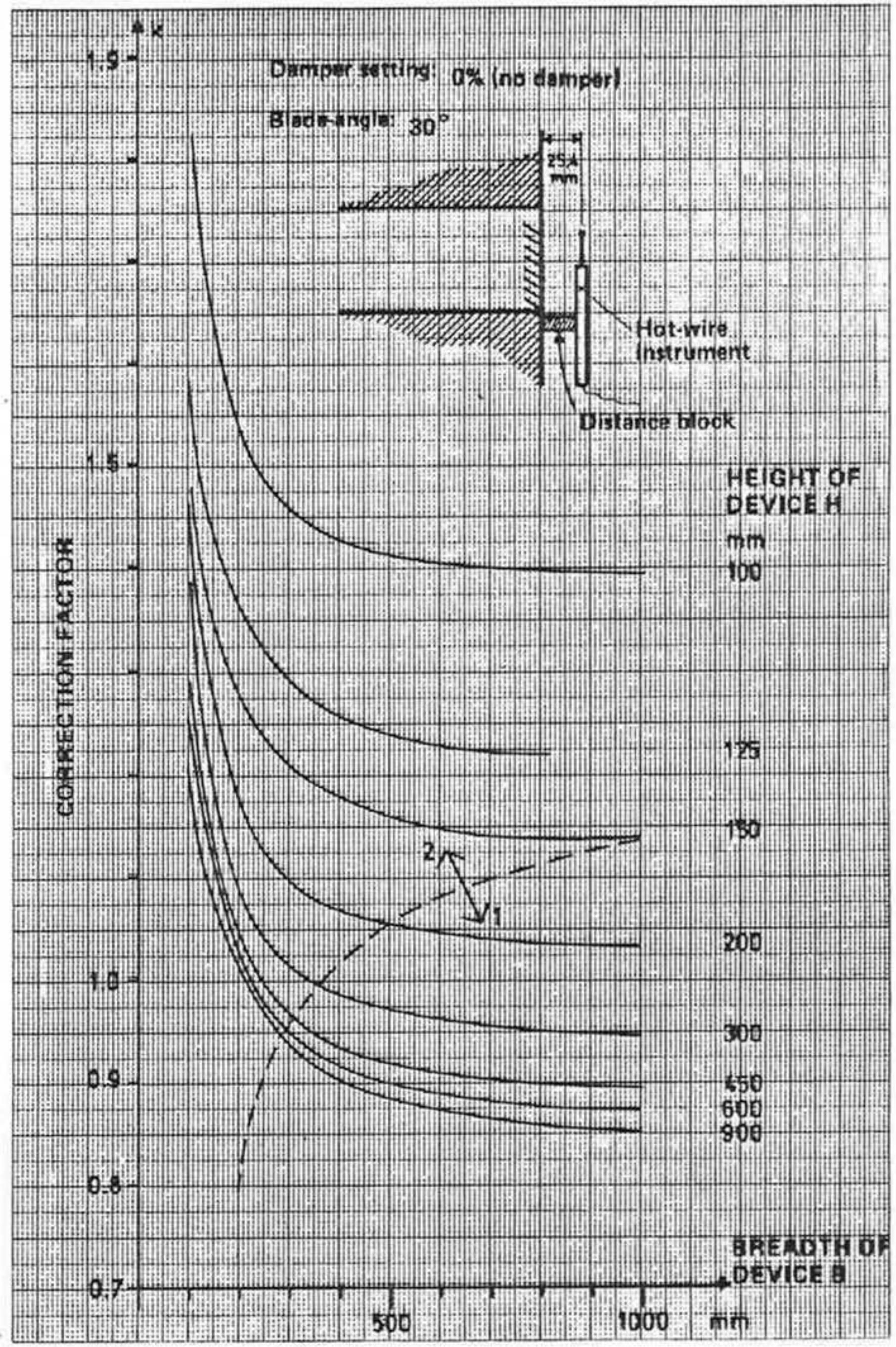


DIAGRAM 5. Measurement of airflow rate with rectangular exhaust air device and air intake grille using a hot-wire instrument. Correction for measuring points (flow factor k).

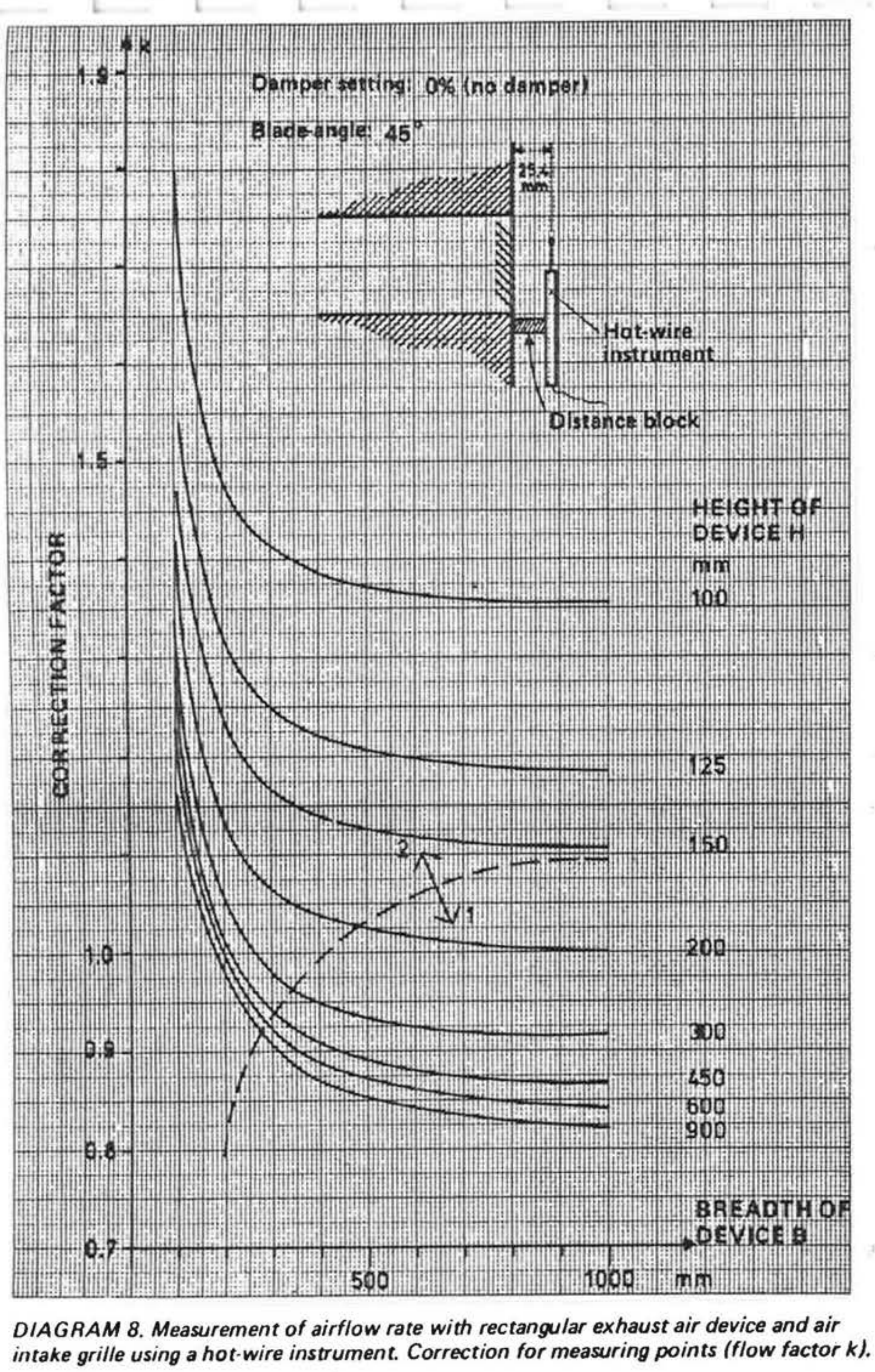


DIAGRAM 8. Measurement of airflow rate with rectangular exhaust air device and air intake grille using a hot-wire instrument. Correction for measuring points (flow factor k).

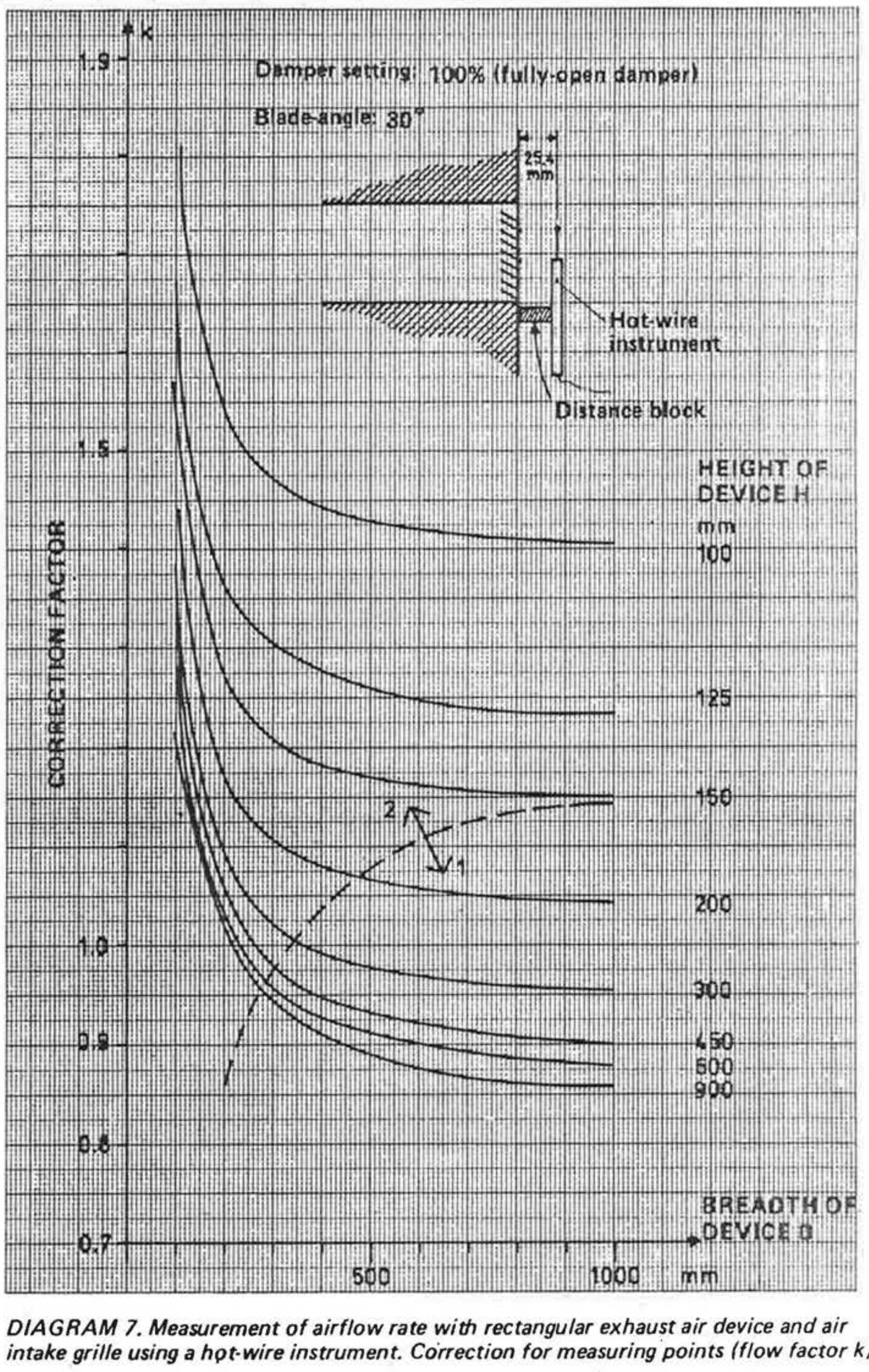


DIAGRAM 7. Measurement of airflow rate with rectangular exhaust air device and air intake grille using a hot-wire instrument. Correction for measuring points (flow factor k).

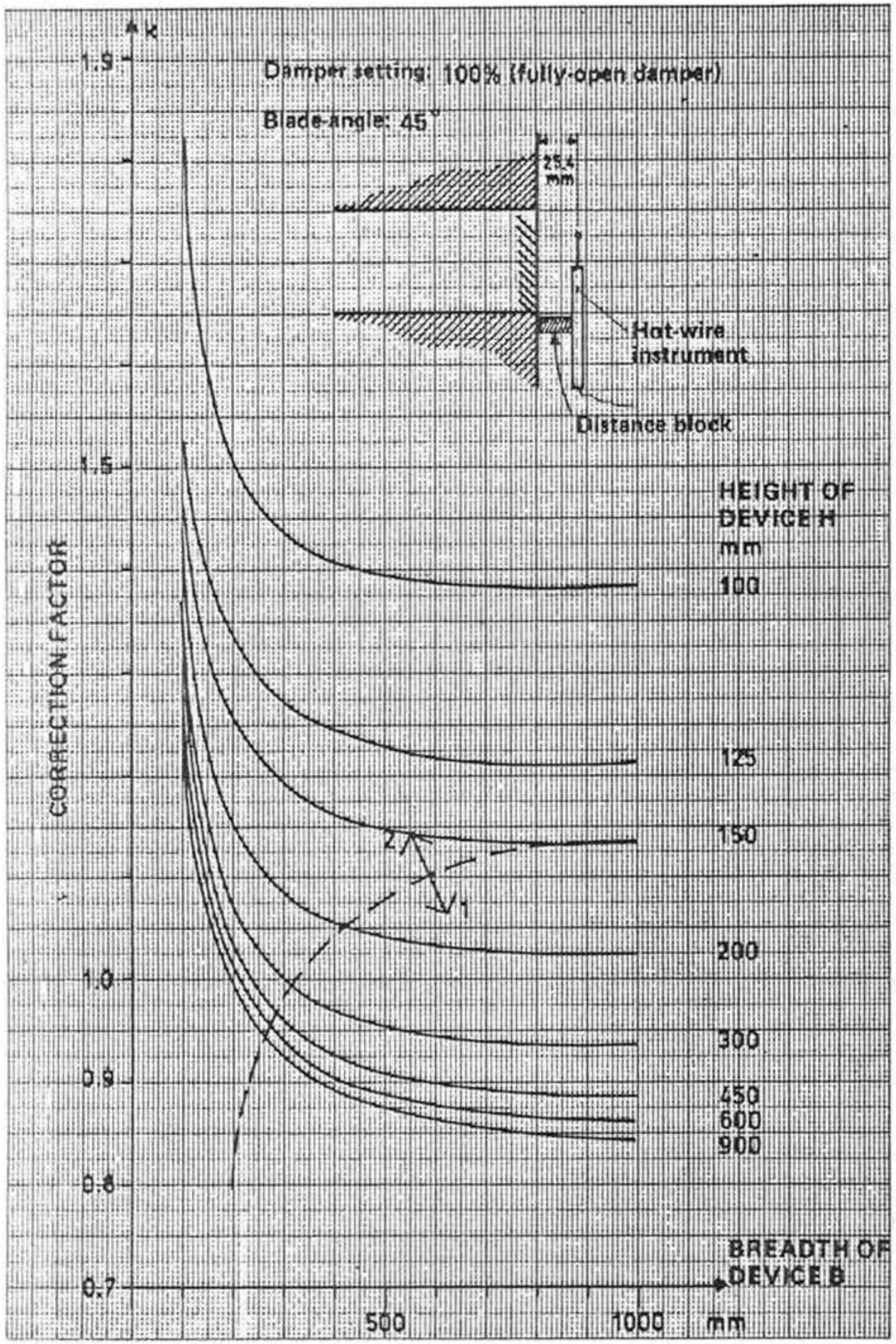


DIAGRAM 10. Measurement of airflow rate with rectangular exhaust air device and air intake grille using a hot-wire instrument. Correction for measuring points (flow factor k)

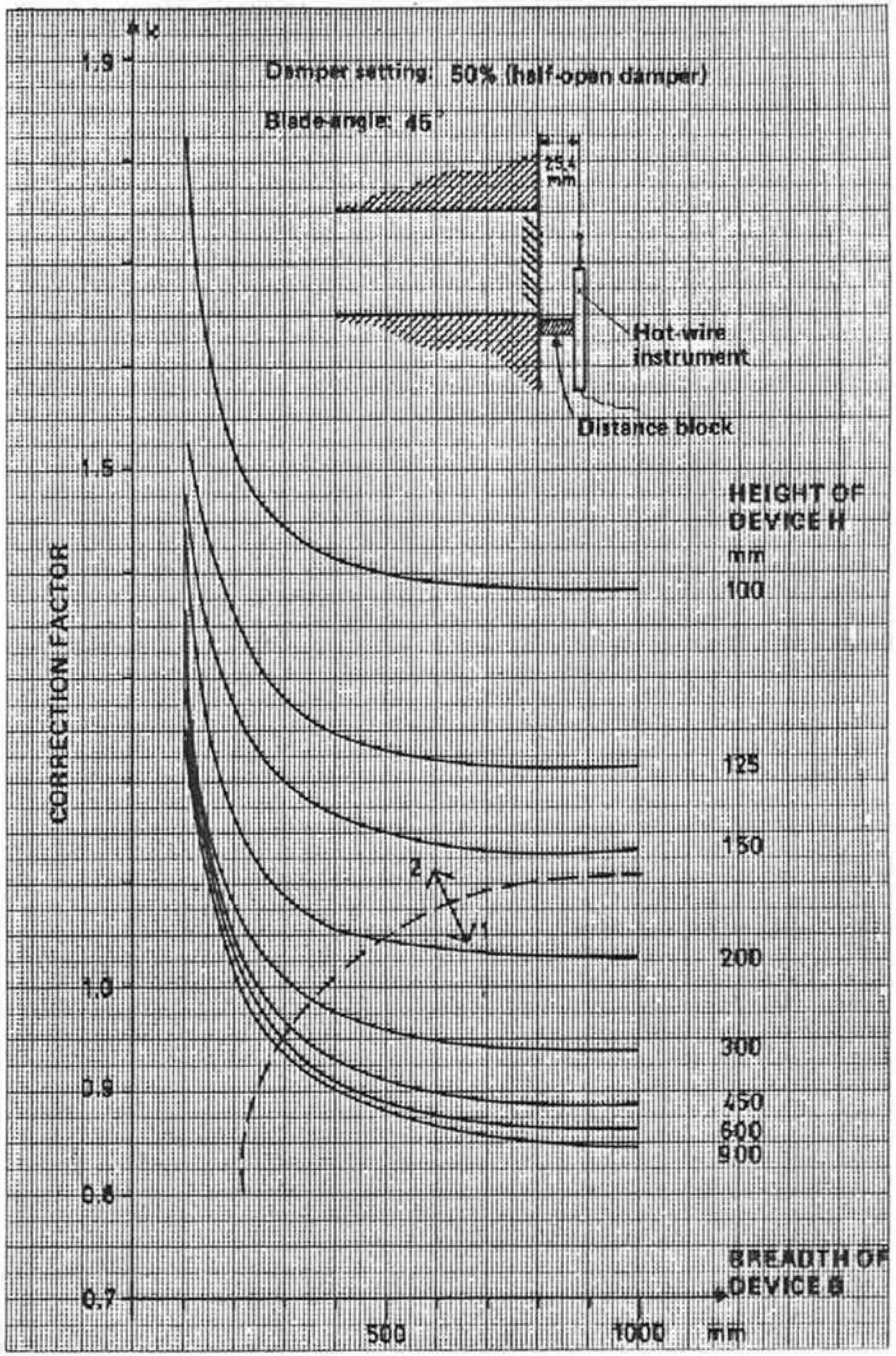


DIAGRAM 9. Measurement of airflow rate with rectangular exhaust air device and air intake grille using a hot-wire instrument. Correction for measuring points (flow factor k)

	MEASUREMENT REPORT B1 Measuring of airflow rate at rectangular exhaust air device and intake grille with hot-wire instrument	Assignment No. Date Measured by Page of

Object	Measurement position (drawing numbers, etc.)

Device No.	$B \times H$ mm	Area A m^2	$B/4$ mm	$H/4$ mm	Damper opening %	Blade-angle °	Meas. point	Velocity Reading m/s	Correction (instrument calibration) m/s	Measured m/s

Instrument error m_1 ± .... %
Method error m_2 ± .... %
Reading error m_3 ± .... %
Probable error ± .... %

Air temperature reading .... °C

Σv .... m/s
$v_m = 1/8 \times \Sigma v$ .... m/s
Method correction k as DIAG. 2–10
Flow $q = A \times v_m \times k$ .... m^3/s

Device No.	$B \times H$ mm	Area A m^2	$B/4$ mm	$H/4$ mm	Damper opening %	Blade-angle °	Meas. point	Velocity Reading m/s	Correction (instrument calibration) m/s	Measured m/s

Instrument error m_1 ± .... %
Method error m_2 ± .... %
Reading error m_3 ± .... %
Probable error ± .... %

Air temperature reading .... °C

Σv .... m/s
$v_m = 1/8 \times \Sigma v$ .... m/s
Method correction k as DIAG. 2–10
Flow $q = A \times v_m \times k$ .... m^3/s

Device No.	$B \times H$ mm	Area A m^2	$B/4$ mm	$H/4$ mm	Damper opening %	Blade-angle °	Meas. point	Velocity Reading m/s	Correction (instrument calibration) m/s	Measured m/s

Instrument error m_1 ± .... %
Method error m_2 ± .... %
Reading error m_3 ± .... %
Probable error ± .... %

Air temperature reading .... °C

Σv .... m/s
$v_m = 1/8 \times \Sigma v$ .... m/s
Method correction k as DIAG. 2–10
Flow $q = A \times v_m \times k$ .... m^3/s

6.2 Measuring pressure drop with probe (Method B 21)

A measuring probe is introduced behind the device where a characteristic pressure drop is measured. The airflow is obtained from a chart as a function of the characteristic pressure drop and the setting of the device.

Limitations

Because of the pressure conditions downstream from an exhaust air device the following points must be fulfilled for this method:

- o The manufacturer/supplier of the device must state exactly where the measurement of pressure shall be carried out and how the measuring probe shall be designed, or supply a special measuring probe.
- o The manufacturer/supplier of the device must supply a diagram of the airflow as a function of the characteristic pressure difference.

Equipment

- o Measuring probe in accordance with the manufacturer's instructions
- o Manometer
- o Tubes, rubber/plastic tubes to connect probe and manometer
- o Chart of characteristic pressure as a function of airflow and intended for this kind of measurement

Measurement error

The measuring method requires great care with regard to the positioning of the measuring probe. The method error, m_2, if the above-mentioned aspects are given attention, is approximately ±5%.

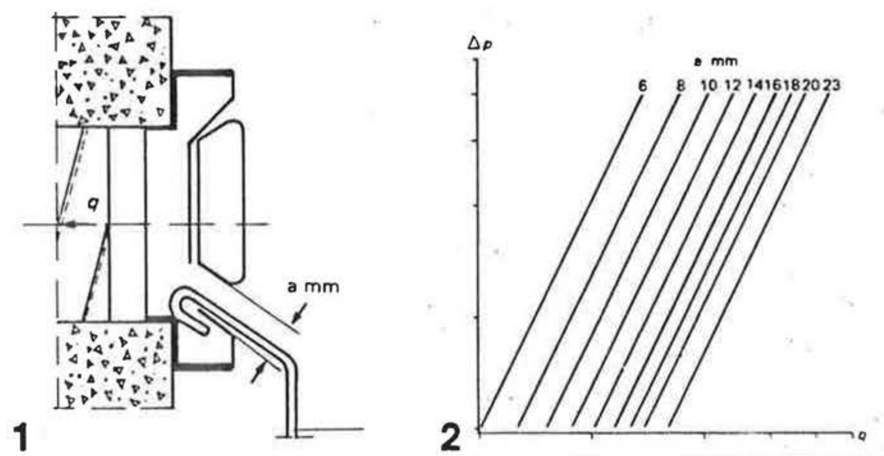


FIGURE 20. Example of measuring as method B 21.
1) Measuring probe, which is connected to manometer.
2) Diagram showing characteristic pressure difference as a function of the airflow rate with the slot width as a parameter.

6.3 Pressure drop measurement by permanent measuring nozzle (Method B 22)

During manufacture the device is fitted with a permanent pressure outlet or a special measuring mouthpiece. A manometer is connected to whichever is fitted and a characteristic pressure is obtained. The airflow rate is obtained from a chart as a function of the characteristic pressure difference and the reading of the instrument.

Limitations

Only a limited number of air terminal devices and fittings are prepared for this kind of measuring. It should be a useful method in practice for integrated light fittings, where it is otherwise very difficult to carry out measurements.

In practice the measuring outlet may be so placed that it is necessary to remove a casing or a protective plate, which can be very time-consuming and often have the effect that the measuring method is impracticable.

Equipment

- o Manometer
- o Connecting tubes
- o Chart of airflow as a function of pressure drop measured.

Measurement error

Accuracy of the measuring method depends on:

- o reliability of the manufacturer's chart
- o effect of possible spread between different devices
- o possible deposit of dirt in the device

With a well-manufactured and clean device of good design m_2 = 5% can be obtained.

6.4 Measuring with an anemometer fitted with a hood (Method B 3)

There are at present available a few different types of hot-wire instruments for the determination of airflow rate through exhaust air devices. Well-known makes are Swema's AFM-66B and Wallac's GGA-23S for which measuring hoods AM-300, 600 and 1200 are available. In addition to these instruments there is also a mechanical airflow meter, Veab LM-200. These three instruments have different ranges of flow as appears from TABLE 17.

You can yourself construct a measuring instrument consisting of a hood fitted with, for example, a rotating vane anemometer at one end.

Limitations

The calibration curves of the instruments are influenced to a certain degree by the type of exhaust air device on which it is used. The instruments may give an error of ±5% depending on the type of valve. Calibration in combination with the actual installation of the instrument should therefore be carried out if the greatest possible precision is to be obtained.

All measuring instruments fitted with a hood affect the airflow through the device because pressure drop occurs in the measuring hood. This effect is unavoidable if the measuring instrument is not provided with an auxiliary fan that compensates for this drop in pressure. Easily handled instruments of this type are not available at present. However, by means of a rather simple calculation it is possible to allow for this influence on the airflow rate. The following equation applies:

$$q = q_m \sqrt{\frac{\Delta p_s}{\Delta p_{sm}}} \qquad m^3/s \quad (l/s)$$

where

q = airflow rate through device at pressure drop Δp_s when the measuring instrument is not coupled

q_m = airflow rate through device at pressure drop Δp_{sm} across the device when the measuring instrument is coupled

Δp_{sm} = static underpressure downstream from the device minus the pressure drop across the measuring hood.

Alternatively TABLE 18 can be used.

Equipment

- Flowmeter
- Calibration curve for instrument in combination with the actual measuring device
- Micromanometer including connecting tubes.

Measurement error

If the instrument is calibrated together with the device with which it is to be used the error, m_2, is estimated at 5%. Correction for pressure drop across the measuring hood is obtained from TABLE 18.

TABLE 17. Flowmeters

Type of instrument	Airflow range m^3/h	l/s
Swema AFM-66B	5-30, 30-230	1.4 - 64
Wallac + AM-300	20-300	5.5 - 83
Wallac + AM-600	50-750	14 - 208
Wallac + AM-1200	100-1500	28 - 417
Veab LM-200	20-200	5.5 - 55

TABLE 18. Correction factor for pressure drop across flowmeter

Pressure drop across the flowmeter as a % of the pressure drop across the exhaust air device [1)]	Correction factor
5	1.01
10	1.05
20	1.11

1) Inclusive pressure drop to nearest bifurcation.

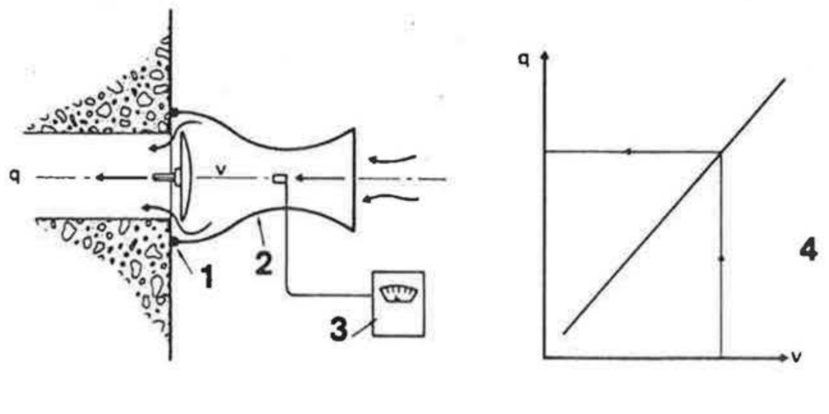


FIGURE 21. Example of measuring as method B 3.
1) Sealing
2) Measuring hood
3) Indicator instrument graduated e.g. m/s
4) Calibration curve showing measured airflow rate q as a function of measured velocity v.

6.5 Measuring of velocity at centre of circular exhaust air openings (Method B 4)

With this method the velocity is measured at the centre of the exhaust air-duct's opening, when the value obtained is multiplied by a factor k in accordance with DIAGRAMS 11 and 12 in order to obtain the average velocity over the cross section. The product of the average velocity and the duct area gives the airflow rate, that is:

$$q = k \times v_c \times A$$

where

q = airflow rate in duct, m^3/s

k = correction factor according to DIAGRAMS 11 and 12

v_c = velocity measured at centre of duct, m/s

A = cross section area of duct, m^2.

Limitations

DIAGRAM 11 applies for duct opening without flange.
DIAGRAM 12 applies for a flange breadth that is 20% of the diameter or greater.

The instruments for which the method can be utilized are:

- Pitot tube Ø 3 mm, l = 32 mm (see TABLE 19)
- Pitot tube Ø 4 mm, l = 66 mm
- Hot-wire anemometer Alnor 8500
- Hot-wire anemometer Wallac GGA 23S
- Hot-wire anemometer TSI 1650

Measurement error

The method error m_2 = 7%.

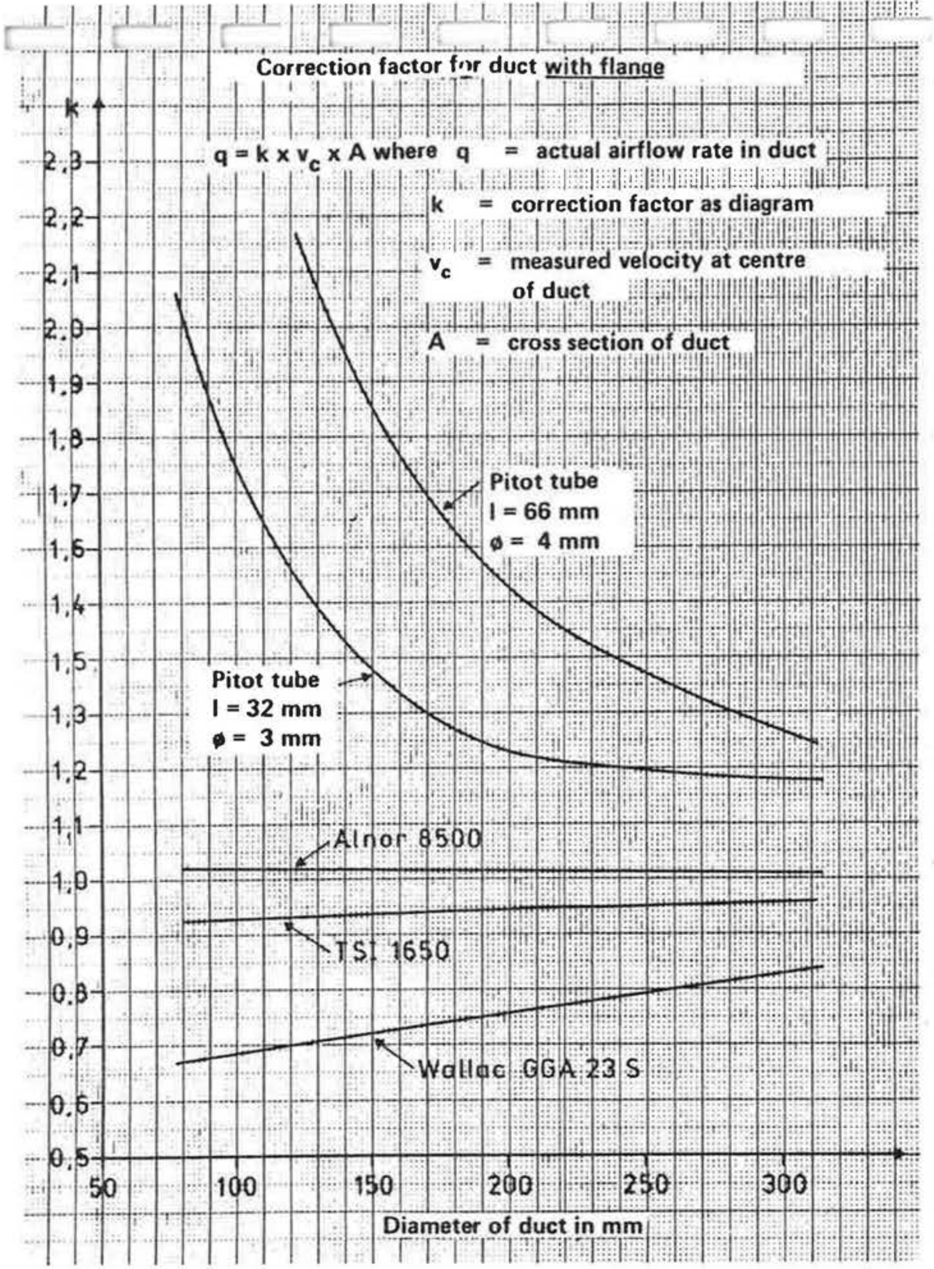


DIAGRAM 12. Correction factor for duct with flange.

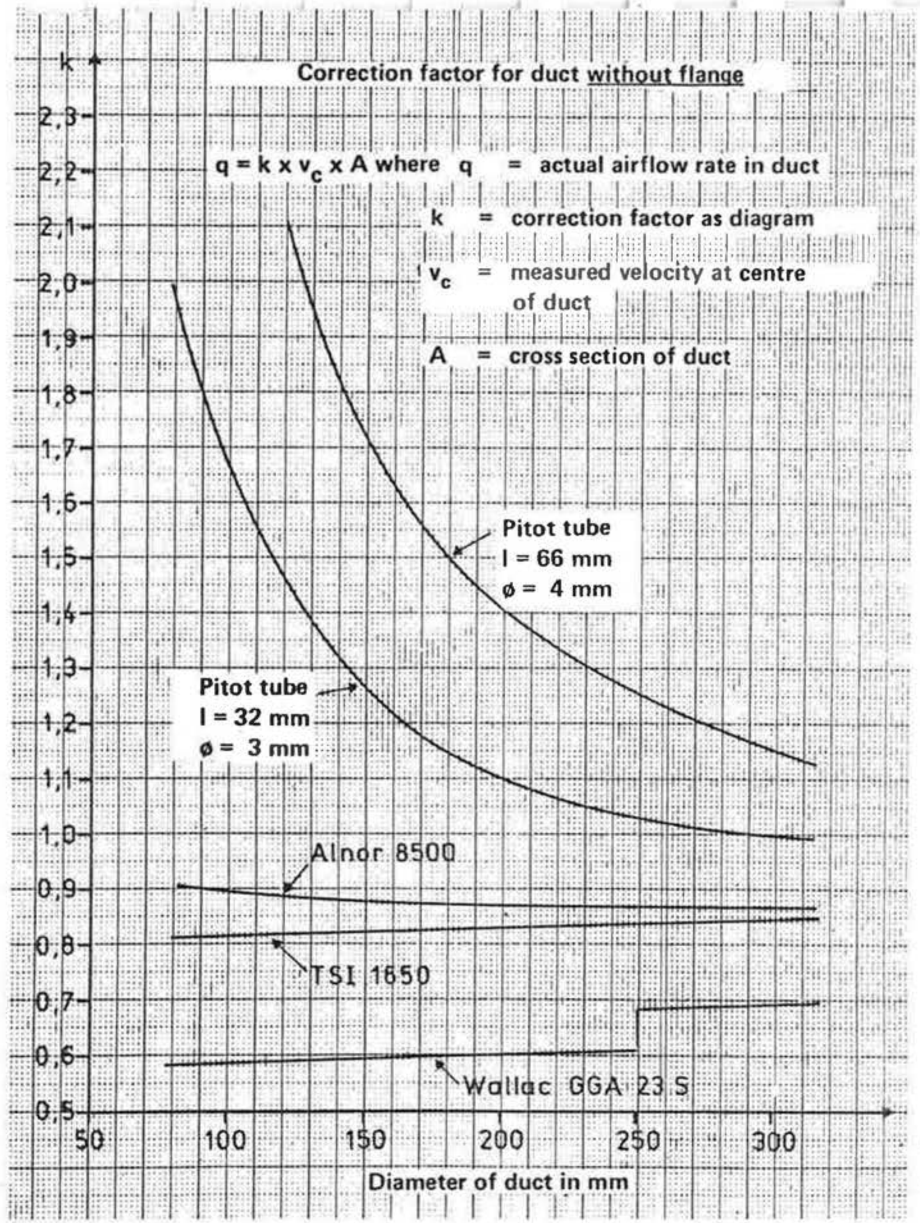
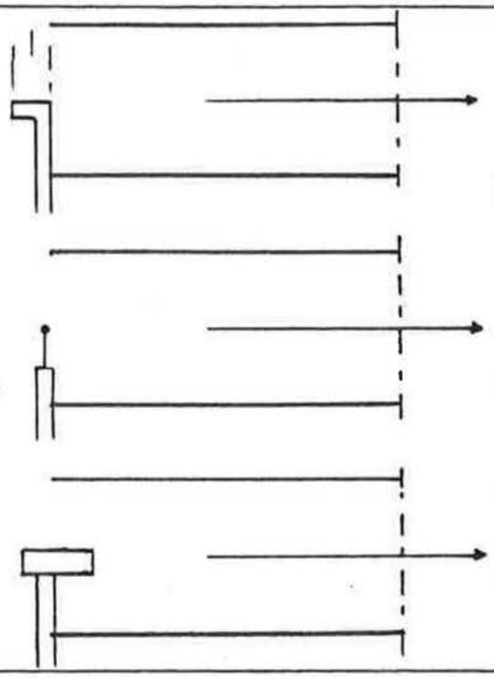


DIAGRAM 11. Correction factor for duct without flange: the break in the curve for Wallac GGA 23S is due to the dimensions of the probe's handle. For duct diameters ≥ 250 mm the probe reaches somewhat further from the entrance of the duct.

TABLE 19. Location of instrument

Instrument	Location	Velocity zone m/s
Pitot tube: Ø 3 mm or 4 mm Length ℓ has great influence on the factor		3-40
Hot-wire anemometers:		
Alnor 8500, probe with small extension (point-shaped probe)		1-10
TSI 1650, probe with small extension (point-shaped probe)		1-30
Wallac GGA 23S, probe in tube		1-20

6.6 Measuring by rotating vane anemometer on air intake grilles (Method B 5)

When measuring the airflow rate through exhaust air grilles, for example air intake grilles, using a rotating vane anemometer the following points must be observed:

- The method described applies to grilles mounted in a wall.
- Before measuring the gross area of the grille is divided into rectangles whose side is maximum 300 mm long depending on the size of the grille and appearance of the velocity profile - see FIGURE 22.
- When a rotating vane anemometer with separate stopwatch is used the anemometer is held for 10-15 seconds in the centre of each square.

  The anemometer must touch the front of the grille. At the end of every 10 or 15-second period the instrument is transferred from one square to another without the rotation being stopped. At the end of the final period the anemometer is stopped and the stopwatch is read. The anemometer value is divided by the time registered and the value obtained is corrected with reference to the anemometer's calibration curve when the 'measured velocity' is obtained.
- When a direct-reading rotating vane anemometer is used the procedure is the same in principle, but with the difference that the average velocity of the airflow must be determined for every placement of the anemometer. When the velocity at the centre of every square is obtained every value measured is corrected with regard to the

anemometer's calibration curve. Then the average value is obtained for the airflow velocities measured.

o The true airflow rate q is obtained from:

$$q = k_1 \times k_2 \times k_3 \times k_4 \times v_m \times A$$

where

k_1 = correction factor for type of grille - see DIAGRAM 13

k_2 = correction factor for airflow velocity - see DIAGRAM 14

k_3 = correction factor for rotating vane anemometer - see FIGURE 22

k_4 = correction factor for blade-angle of grille - see FIGURE 23

v_m = average velocity measured m/s

A = gross area of grille (B x H) m^2

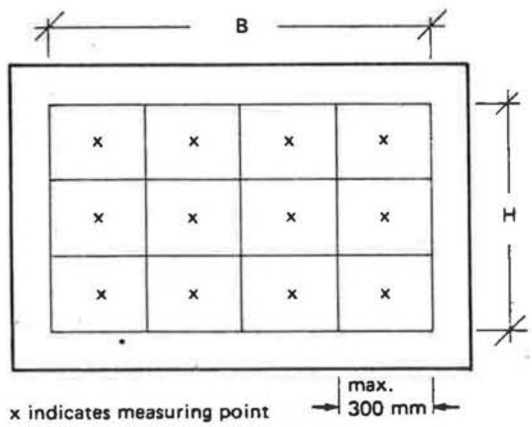


FIGURE 22. Method B 5. Division of grille area into squares.

Correction factor k_3 for rotating vane anemometer's diameter, d mm

Ø d mm	k_3
20	1.15
65	1.0
100-105	0.88

Correction factor k_4 for blade-angle of grille

Blade-angle	k_4
45°	0.98
0°	1.0

FIGURE 23. Method B 5. Correction factors k_3 for rotating vane anemometer's diameter and k_4 for blade-angle of grille.

Limitations

- As correction factors have not been obtained for all types of grilles and anemometers the method cannot be used generally.
- The rotating vane anemometer must be calibrated in a wind tunnel having a cross section area $\geq 0.5\ m^2$ or in a smaller wind tunnel where the blocking effect is known.
- Small grilles cannot be measured. The least dimensions have been fixed at h x b = 0.3 x 0.5 m

Measurement error

Subject to the grille and anemometer being covered by the charts and tables provided the method error can be taken as 8%. Otherwise the method cannot be recommended except for relative measurements.

DIAGRAM 13. Correction factor k_1 for grille size. The type of grille, in the form of the pressure drop at a frontal velocity of 3 m/s, is included as a parameter.

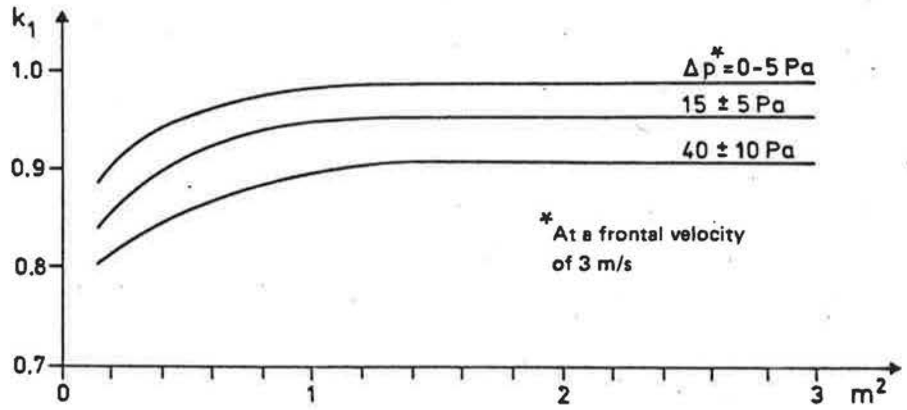
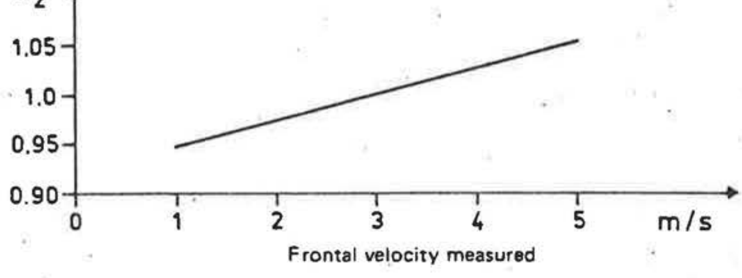


DIAGRAM 14. Correction factor k_2 for airflow velocity measured.



7. METHODS FOR MEASURING ON SUPPLY AIR TERMINAL DEVICES

Survey of R-methods

Method	Designation	Method error
Measurement of pressure drop with built-in pressure measuring nozzles	C 2	5%
Bag method	C 5	3%
Measuring with conventional hood-anemometers supplemented with extension hood	C 3	5%

7.1 Measuring of pressure drop with built-in pressure measuring nozzles (Method C 2)

During manufacture the device is fitted with a built-in nozzle or a special nozzle for measuring. To this is connected a manometer and a characteristic pressure is measured. The airflow rate is obtained from a chart as a function of the characteristic pressure difference and the setting of the device.

Limitations

Only a limited number of devices have been designed for this kind of measuring. It could be a practically useful measuring method for integrated light fittings, where it is otherwise very difficult to carry out measurements.

In practice the measuring outlet can be so located that it is necessary to remove a casing or protective plate, which can be very time consuming. This has the effect that in many cases this method of measuring is not applicable in practice.

Equipment

- o Manometer
- o Connecting tubes
- o Chart of airflow rate as a function of the pressure drop measured.

Measurement error

Accuracy of the measurement method depends on:

- o reliability of the manufacturer's chart
- o effect of possible dispersion between different devices
- o soiling of the device

If carried out well and with a clean device m_2 = 5% can be obtained.

Examples of areas of use

For induction units, which are usually equipped with nozzles whose pressure drop is relatively high, measurement of pressure across the nozzles is a useful measuring method. $m_2 \approx 3\%$ if the pressure drop across the nozzles $\geq$ 150 Pa (15 mm WG). However, the way of connecting the unit to the supply air duct may influence the pressure distribution and thus the accuracy of measurement.

Calibration method

Will be evolved as a complement to reference /4/.

7.2 The bag method (Method C 5)

The method, illustrated by FIGURE 24, implies that a rolled-up measuring bag, of a certain volume and mounted upon a frame, is placed over the device so that this is completely covered. The time that elapses until the bag is filled with air to a certain overpressure is noted. The airflow rate is then obtained from the equation:

$$q = \frac{V}{t} \ m^3/s$$

where

V = volume of measuring bag, m^3

t = filling time, s

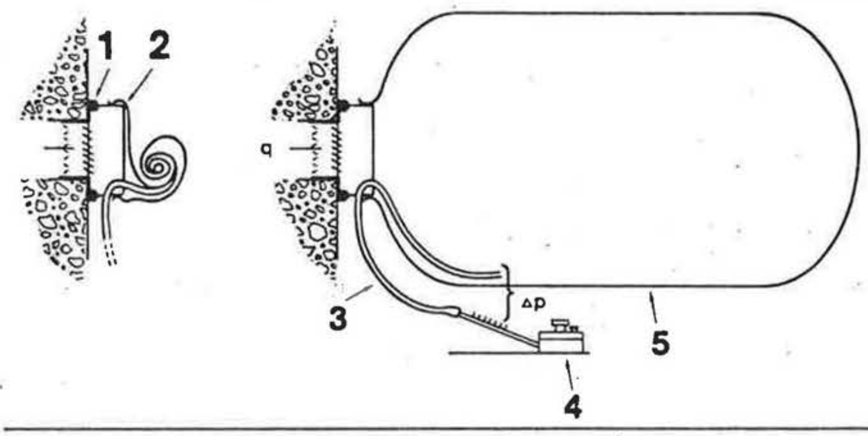


FIGURE 24. Sketch of measurement in accordance with the bag method.

1) Sealing
2) Frame to which the plastic bag is fastened
3) Measuring tube Ø 5 mm, connected to micromanometer
4) Micromanometer
5) Plastic sack (plastic bag), thickness of material 0.03-0.04 mm.

Limitations

The lower limit of the pressure drop for a device is, when measuring a device mounted in a ceiling, approximately 10 Pa; when the device is installed in a wall it is approximately 50 Pa. When the device is in a wall it is necessary for the personnel concerned to help to lift the measuring bag whilst it is filling, in order to decrease the pressure in the bag.

Equipment

- o Calibrated measuring bags of different volumes
- o Frames of suitable internal measurements
- o Stopwatch
- o Manometer and tube
- o Report forms

The measuring bag can be made of a plastic material with a thickness of 0.02 - 0.04 mm.

Preparations

Using data from drawings the devices to be measured are numbered. Details of external dimensions are entered on the report form for each device concerned, and also the projected and presumed airflow rate, and suitable size of bag.

Volume of the bag shall be such that the filling time does not fall below 10 seconds. The bag is fastened to the frame and the pressure tube of the manometer is inserted into the bag.

The manometer is made ready (horizontal position). The tube is connected and a check is made that the liquid pillar is free of air. The manometer's zero setting is adjusted.

Measuring

The frame with the rolled-up (airless) bag is placed over the device and concurrently the stopwatch is started.

Filling time to an overpressure of 3 Pa is noted. If the filling time is under 10 seconds the measurement is repeated with a bag of greater volume.

If such a greater bag is not available the measurement should be repeated 2-3 times.

Report

Volume of the bag and filling times obtained are entered on report form C 5.

Measurement error

Error of measuring instrument: depends on accuracy in the calibration of volume of the plastic bags.

Errors can occur through, among other things, an unsatisfactory fastening of the frame over the device, which can cause leakage. Laboratory measurements have shown that a method error of ≅ ±3% can be set.

The reading error for the stopwatch can be estimated to ±0.1 s.

Supplier

Measuring bags including frames and other accessories can be obtained from Mätforum Hans Blixt AB, Solna, Sweden. An outfit for automatic timing of the filling of measuring bags is available from AB Elektrometer, Bromma, Sweden.

	MEASUREMENT REPORT C5 Measuring of airflow rate on supply air terminal devices	Assignment No.
		Date
		Measured by
		Page of

Object	Measurement position (drawing numbers, etc.)

Device No. (also noted on drawing)	Preparations: Dimension ø or $H \times B$ mm	Projected airflow rate m^3/s	Suitable volume of bag m^3	Measurements: Volume used of bag m^3	Filling time, sec: 1	2	3	average value	Airflow rate m^3/s
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									

Calculation of errors

Instrument error m_1

± .... %

Method error m_2

± .... %

Reading error m_3

± .... %

Probable error $\overline{m}$

± .... %

7.3 Measuring with an anemometer fitted with hood (Method C 3)

Instruments of this type specially constructed for use on supply air terminal devices are currently not available on the Scandinavian market.

To obtain a good degree of measuring accuracy with the instruments mentioned in chapter 6.4, regardless of whether the airstream is oblique or symmetric, an extra hood is required. This complementary hood for the measuring unit should have a length 3 times the greatest hydraulic diameter cf the hood.

In addition to the flow rate measuring devices mentioned in chapter 6.4 a measuring instrument can also be utilized consisting of a hood whose length is 3 times the greatest hydraulic diameter of the hood. The anemometer used is a rotating vane anemometer positioned in the circular outlet of the hood. To obtain the best measuring result the outlet diameter of the hood should be 1.5 times the diameter of the rotating vane anemometer.

Limitations

The methods require calibration to be carried out in combination with the supply air device concerned. All measuring instruments fitted with a hood influence the airflow through the instrument as a certain degree of pressure drop is set up in the measuring hood. This effect is unavoidable unless the measuring instrument is provided with an auxiliary fan that compensates for that pressure drop. But, such instruments are not available at present. An allowance can be made for this effect on the airflow rate by calculation. The following equation applies:

$$q = q_m \times \sqrt{\frac{\Delta p_s}{\Delta p_{sm}}} \quad m^3/s$$

where

q = airflow rate through the device at pressure drop Δp_s when the measuring instrument is not connected

q_m = airflow rate through the device at pressure drop Δp_{sm} across the device when the measuring instrument is connected

Δp_{sm} = static overpressure preceding the device, decreased by the pressure drop across the measuring hood. Pa.

With knowledge of the pressure drop across the hood the correction factor from TABLE 18 can be utilized.

Measurement error

m_2 = 5% on condition that the instrument is calibrated in combination with the supply air terminal device concerned and that the correction for the pressure drop across the measuring hood is made.

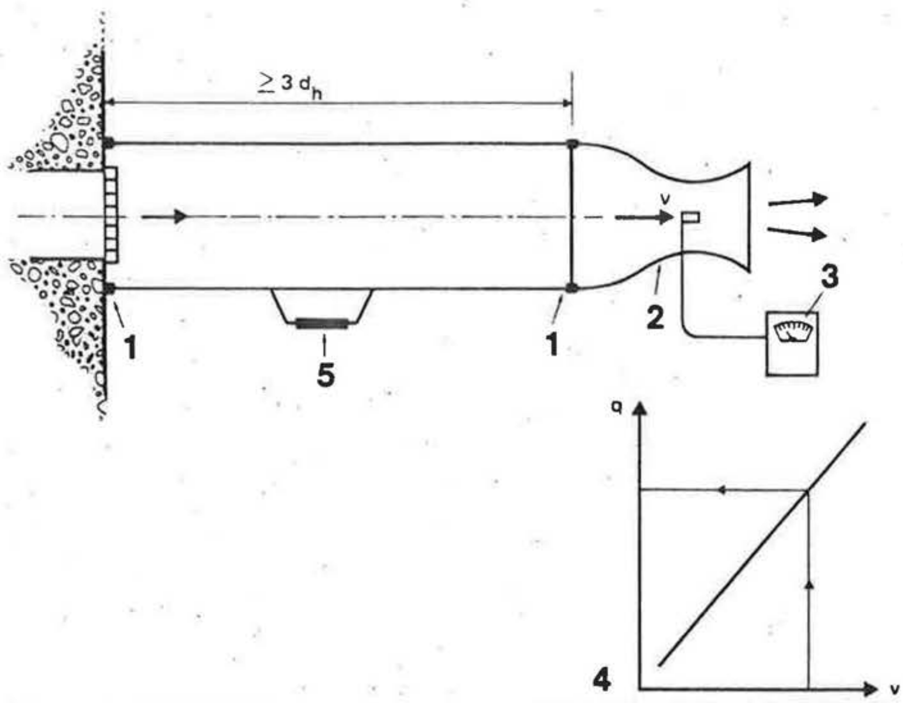


FIGURE 25. Example of measuring as method C 3.
1) Sealing
2) Measuring hood
3) Indicator instrument graduated in e.g. m/s
4) Calibration curve showing measured airflow rate q as a function of measured velocity v.
5) Extension hood.

8 METHODS FOR MEASURING AIR CHANGE RATE

Survey of R-methods

Method	Designation of method	Probable measurement error
Dräger tube with carbon dioxide as tracer gas	D 1	±7%
Gas analyser of the interference refractometer type with helium or carbon dioxide as tracer gas[1)]	D 2	±4%
Gas analyser of the absorbtion of infrared radiation type with nitrous oxide as tracer gas	D 3	±4%

1) Helium is intended for use in a room of small volume. In small rooms the carbon dioxide content in a person's exhalations may influence the determination of the air change rate.

8.1 Dräger tube with carbon dioxide as tracer gas (Method D 1)

Equipment

- o Dräger analysis equipment (model 21/31), one or more
- o Reagent tubes with catalogue numbers CH 23501 (1.2-0.1 vol.% CO_2) and CH 30801 (0.3-0.02 vol.% CO_2)
- o Fan(s)
- o Pressure flask with liquid carbon dioxide
- o Reducing valve
- o Stopwatch
- o Tape measure
- o Micromanometer with pressure probe (alternatively a precision aneroid barometer)
- o Adhesive tape
- o Report forms D1:1-2

Preparations

Use fans to mix the gas well with the room air. Check the airtightness of the Dräger pump. Insert an unopened Dräger tube in the pump and check that the bellows have not expanded fully in less than ten minutes. Determine volume of room with deductions for any furniture, etc.

Further, measure the pressure level of the room with respect to adjoining rooms, and atmosphere. Thus can be decided whether the supply or the exhaust devices have the greater airflow rate and consequently shall be assigned to the measured value of the air change rate.

Measuring

Determine the background level of CO_2 before the tracer gas is dosed (the concentration usually lies at 0.03-0.04 vol.% CO_2). Dose the tracer gas to 0.7-0.8 vol.%. The points selected for gas analysis in the room shall lie > 1 m from the walls and have an air velocity < 0.3 m/s.

Determine the number of points in the room for gas analysis from TABLE 20 and repeat the tests at the same locations.

Do not carry out measurements in a room less than 40 m^3. The carbon dioxide content of exhaled air from a person then influences measurement. The upper limit for the air change rate is 4-5 air changes per hour.

The analysis tube cannot be saved for later evaluation as the coloration of the tube continues after the test is completed.

When the gas has been dosed and well mixed with the air of the room (3-5 min.) some preparatory samples are taken to verify if the mixing of tracer gas with the air in the room is good. Following this, sampling can begin. Start the stopwatch and note the time at commencement of the first pump-stroke and also at the last stroke when the bellows have expanded fully. Read the carbon dioxide concentration immediately and note the value on the report form.

Select the number of measurement values from TABLE 21.

Report

On report form D1:1 and 2 (p 78), in addition to the measurement values, are also noted volume of room, pressure conditions and the projected airflow rate. Further factors that also influence the measurement such as outdoor air temperature and wind direction, etc, are also noted.

Measurement error

Measuring instrument's error: the probable error for Dräger tube CH 235 is ±5 to ±10%. The lower figure applies for the higher measurement-values, whilst the higher figure applies to the lower values. For tube CH 308 the probable error is ±10 to ±15%, otherwise data about CH 235 applies.

Both types of analysis tube must be used in order to obtain good accuracy.

Reading error: this is assessed to be 3-5% of the value read.

The resultant accuracy is dependent on the accuracy of the individual measurement, the length of the measuring period, size of the air change rate and the number of measuring points utilized during the measuring period. The measuring procedure laid down gives a probable measurement error of ±7%.

Evaluation

Plot the values obtained on the control chart and check that the points form a straight line.

The values obtained are dealt with in accordance with report D1:1. The totals shown are calculated. The air change rate is calculated by the least square method (slope in the chart). The intersection with the ordinate is also calculated. (Formulae at foot on report form D1:2).
Using the relation:

$$n = \frac{\ln \dfrac{C_o - C_b}{C_i - C_b}}{t_i}$$

where

n = air change rate (number of air changes per unit of time)

C_b = concentration of carbon dioxide in the atmosphere

C_i = room air concentration at time, $t = t_i$

C_o = room air concentration at time, $t = 0$

the definite position of the line can be drawn on the control chart.

TABLE 20. Number of points for gas analysis in the room

Volume of room (m^3)	No. of points
40 - 100	1
100 - 200	2
> 200	3 - 5

TABLE 21. Number of measurement values and length of test period.

No. of air changes (per hour)	No. of measurement values	Length of test period (min)
1	10	90
2	8	60
4	6	40

8.2 Gas analyser of the interference refractometer type with helium or carbon dioxide as tracer gas (Method D 2)

Equipment

- o Gas analyser. Riken-Keiki type gas analyser model 21 intended for helium can be used. If an instrument intended for carbon dioxide is used then a reversed scale indication is obtained.
- o Fan(s)
- o Pressure flask with liquid helium
- o Reduction valve
- o Stopwatch
- o Steel measuring tape
- o Micromanometer with pressure probe
- o Adhesive tape
- o Report forms D2:1 and 2.

Preparations

Turn up the fan(s) to mix the gas well with the room air. Check that the gas analyser is ready for measuring. Adjust zero setting of the instrument in the following way: using the handpumps the instrument's test cylinders are filled (at least five strokes of the pump). Then the zero setting of the scale is carried out using the screw for this purpose.

Determine volume of the room with deductions for furniture, etc. Further, measure the pressure level with regard to the adjoining rooms, and atmosphere. In this way can be decided whether the supply or exhaust air devices have the greatest airflow rate and consequently shall be assigned to the correct value of the air change rate.

Measuring

Dose the tracer gas to at least 2/3 of the full scale deflection. The points in the room selected for gas analysis shall lie at a distance > 1 m from the walls and have an air velocity < 0.3 m/s.

Determine the number of points in the room for gas analysis as TABLE 22 and repeat the tests at the same positions.

When the gas is dosed and has become well mixed with the room air (3-5 min.) some preparatory samples are taken to ensure that the mixing of the tracer gas with the room air is good. Then sampling can be started.

The instrument's sample cylinders are filled by pumping at least five strokes. Start the stopwatch and note the time and value of the tracer gas concentration in the report.

Select the number of measurement values from TABLE 23.

	MEASUREMENT REPORT D1:1 Measuring of air change rate in room. Dräger tubes CH 23501, CH 30801	Assignment No. Date Measured by Page of

Object	Measurement position (drawing number, etc.)

Sample No. (m = No. of samples)	Sample started hrs.	Sample ended hrs.	Average value hrs.	Reading; vol % CO_2, (C_i)	Reading – background value vol % CO_2 $(C_i - C_b)$	$ln\ (C_i - C_b)$	Time diff. from start of sample min t_i	$t_i \times ln\ (C_i - C_b)$	$(t_i)^2$
1						–	0	0	0
2						–		–	
3						–		–	
4						–		–	
5						–		–	
6						–		–	
7						–		–	
8						–		–	
9						–		–	
10						–		–	
11						–		–	
12						–		–	
Background level CO_2 = ... vol % (C_b)						$\sum_{i=1}^{m} ln\ (C_i - C_b) =$ = ...	$\sum_{i=1}^{m} t_i =$ = ...	$\sum_{i=1}^{m} t_i \times ln\ (C_i - C_b) =$ = ...	$\sum_{i=1}^{m} (t_i)^2 =$ = ...

	MEASUREMENT REPORT D 1:2 Measuring of air change rate in room.. Dräger tubes CH 23501, CH 30801	Assignment No. Date Measured by Page of

Object	Measurement posn. (drawing number, etc.)

Volume of room..........m^3
(with deduction for furniture, etc.)

Other important conditions
(wind direction, wind velocity,
air temperature outdoors, etc.)

....

....

....

....

Pressure conditions
from room – to

.... = ... Pa

.... = ... Pa

.... = ... Pa

Projected airflow rate:

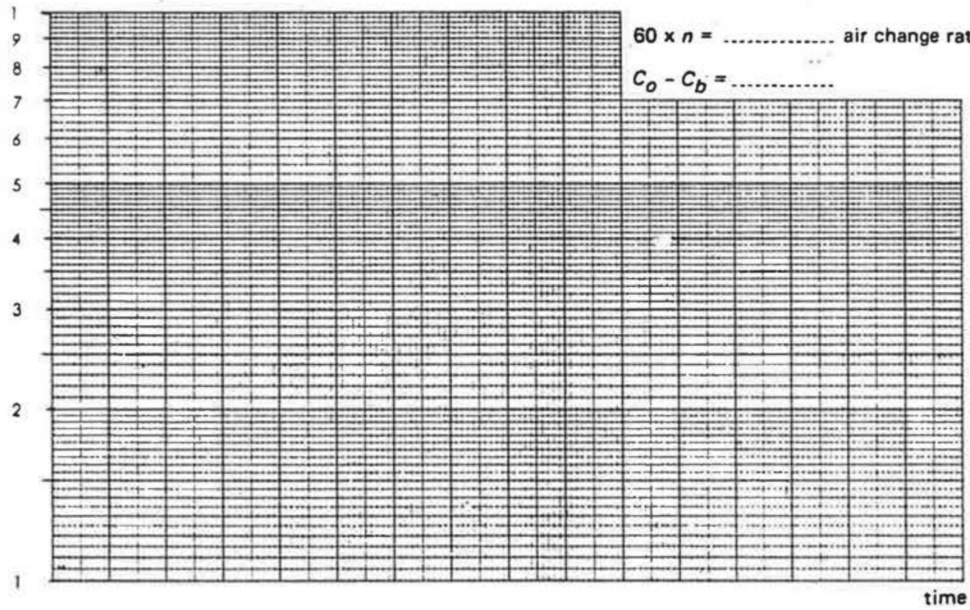
to .... m^3/s

from .... m^3/s

Probable error .... %

Control chart

$\dfrac{C_i - C_b}{C_o - C_b}$



$60 \times n$ = ... air change rate/h

$C_o - C_b$ = ...

$$n = \frac{\dfrac{\sum_{i=1}^{m} \ln (C_i - C_b)}{m} - \dfrac{\sum_{i=1}^{m} t_i \times \ln (C_i - C_b)}{\sum_{i=1}^{m} t_i}}{\dfrac{\sum_{i=1}^{m} (t_i)^2}{\sum_{i=1}^{m} t_i} - \dfrac{\sum_{i=1}^{m} t_i}{m}}$$

$$\ln (C_o - C_b) = \frac{\dfrac{\sum_{i=1}^{m} \ln (C_i - C_b)}{\sum_{i=1}^{m} t_i} - \dfrac{\sum_{i=1}^{m} t_i \times \ln (C_i - C_b)}{\sum_{i=1}^{m} (t_i)^2}}{\dfrac{m}{\sum_{i=1}^{m} t_i} - \dfrac{\sum_{i=1}^{m} t_i}{\sum_{i=1}^{m} (t_i)^2}}$$

Report

In report form D2:1 and 2 (pp 82, 83) are entered not only the measurement values but also volume of the room, pressure conditions and the designed airflow rate. Factors that might influence measurement such as outdoor air temperature, wind direction, etc, should be noted.

Measurement error

The error of the measuring instrument is provided by the supplier. For the Riken-Keiki, for example, it is stated as ±0.02%, which means that the error is ±1% of the full scale deflection.

Reading error; this is assessed to be ±0.001 vol.%.

With the measuring procedure described the probable error is ±4%.

TABLE 22. Number of points for gas analysis in the room.

Volume of room (m^3)	No. of points
< 100	1
100 - 200	2
> 200	3 - 5

TABLE 23. Number of measurement values and length of test period

No of air changes (per hour)	No. of measurement values	Length of test period (min)
1	10	45
2	8	30
4	6	20

Evaluation

Insert the measurement values on the control chart and check that the points form a straight line.

The measurement values are dealt with according to report D2:1. The totals stated are calculated. The air change rate is obtained by the least square method (slope of chart) and the intersection with the ordinate is also calculated (formulae at foot in report D2:2).

Using the relation

$$n = \frac{\ln \frac{C_o}{C_i}}{t_i}$$

where

n = air change rate (number of air changes per unit of time)

C_i = room air concentration of tracer gas at time, $t = t_i$

C_o = room air concentration of tracer gas at time, $t = 0$

the definite position of the line can be drawn on the control chart.

8.3 Gas analyser of the infrared (IR) radiation type using nitrous oxide as tracer gas (Method D 3)

Equipment

- o IR analyser
- o Chart recorder
- o Fans
- o Nitrous oxide in flask with reduction valve and manometer

Preparations

An IR analyser can be assembled as a compact unit including an analysis section, filter section and pump as well as a flow rate regulator. The analyser is also usually fitted with an indicator which shows the gas concentration prevailing. For several reasons, not least for later documentation, it is a good idea to connect a chart recorder to the analyser.

Before measuring starts the gas analyser must have reached its working temperature which, depending upon analyser's initial temperature, may require a few hours. As the IR analyser is usually designed for continuous operation it can be an advantage to connect it to the electricity supply the day before measuring is done.

When the IR analyser has achieved the correct operational temperature measuring can start.

Fans are placed so that the room air is well mixed with the gas.

Determine volume of the room with deductions for the room's contents of furniture, etc. Also check the pressure level of the room in relation to adjoining rooms, and atmosphere.

Measuring

The analyser's pump is started up and the chart recorder is plugged in. The IR analyser and the chart recorder are then calibrated together so that the zero setting on the analyser corresponds to the response the chart recorder should then show. This latter value depends on the analyser's output signal at maximal reading, and this value must be obtained when the equipments are calibrated together at purchase.

When the above has been carried out nitrous oxide is released into the room. This is suitably done intermittently so that too much gas is not released.

	MEASUREMENT REPORT D 2:1 Measuring of air change rate in room using gas analyser of the interference refractometer type	Assignment No. Date Measured by Page of

Object	Measurement posn. (drawing number, etc.)

Sample No. (m = No. of samples)	Time sample taken	Reading vol % CO_2, (C_i)	$ln\ C_i$	Time diff. from start of sample, min, t_i	$t_i \times ln\ C_i$	$(t_i)^2$	Remarks
			$\sum_{i=1}^{m} ln\ C_i =$ = ...	$\sum_{i=1}^{m} t_i =$ = ...	$\sum_{i=1}^{m} t_i \times ln\ C_i =$ = ...	$\sum_{i=1}^{m} (t_i)^2 =$ = ...	

	MEASUREMENT REPORT D2:2 Measuring of air change rate in room using gas analyser of the interference fractometer type	Assignment No. Date Measured by Page of

Object	Measurement posn. (drawing number, etc.)

Volume of room..........m^3
(with deduction for furniture, etc.)

Other important conditions
(wind direction, wind velocity,
air temperature outdoors, etc.)

....

....

....

....

Pressure conditions
from room — to

.... = ... Pa

.... = ... Pa

.... = ... Pa

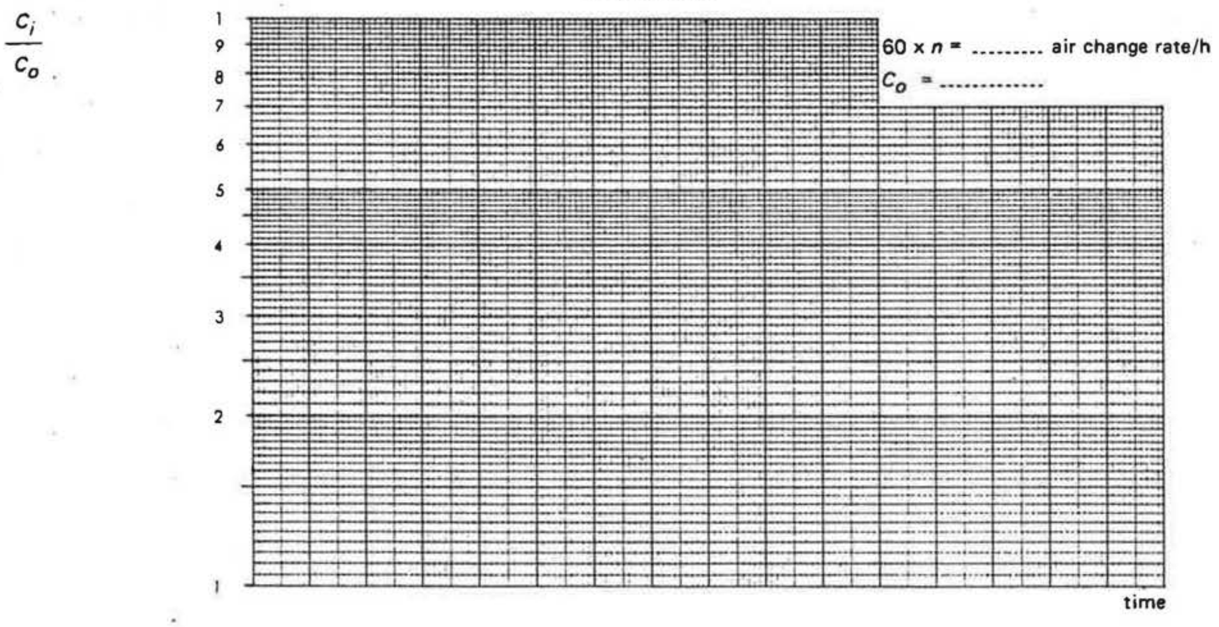
Projected airflow rate:

to .... m^3/s

from .... m^3/s

Probable error .... %

Control chart



$60 \times n =$ .... air change rate/h

$C_o =$ ....

$$n = \frac{\dfrac{\sum_{i=1}^{m} \ln C_i}{m} - \dfrac{\sum_{i=1}^{m} t_i \times \ln C_i}{\sum_{i=1}^{m} t_i}}{\dfrac{\sum_{i=1}^{m} (t_i)^2}{\sum_{i=1}^{m} t_i} - \dfrac{\sum_{i=1}^{m} t_i}{m}}$$

$$\ln \cdot C_o = \frac{\dfrac{\sum_{i=1}^{m} \ln C_i}{\sum_{i=1}^{m} t_i} - \dfrac{\sum_{i=1}^{m} t_i \times \ln C_i}{\sum_{i=1}^{m} (t_i)^2}}{\dfrac{m}{\sum_{i=1}^{m} t_i} - \dfrac{\sum_{i=1}^{m} t_i}{\sum_{i=1}^{m} (t_i)^2}}$$

From the time when the gas concentration commences to fall, the time, t, is calculated until the value is reached that, according to *the earlier joint calibration of the IR analyser and the chart recorder,* has been shown to denote a certain definite air change, N, for example 0.3, 0.5, 1.0 and so on. The air change rate, n, is then determined from:

$$n = \frac{N}{t}$$

Report

In the report, or on the record chart, the volume of the room, pressure conditions and the designed aiflow rate are also noted, as well as other factors that influence measuring such as outdoor air temperature, wind direction, etc.

Measurement error

The probable measurement error is also dependent on the length of measurement time and the air change rate. If the suggested values given in TABLE 24 for length of the measuring period are utilized, the method error is set at 4%.

TABLE 24

No. of air changes per hour	Length of measuring period (min)
0.3	120
0.5	80
1.0	40
2	20
4	10

9. MEASUREMENT OF LEAKAGE AIRFLOW RATE FROM VENTILATION DUCTS

Airtightness testing is carried out in accordance with Eurovent document 2/2 with regard to:

- Measuring equipment
- Measuring procedures
- Instruments and their calibration
- Test pressures

All in accordance with the instructions below.

Equipment

- Fan unit for airtightness testing with calibrated flowmeter (large and small airflow range) and airflow regulator (for example, damper, mixing device)
- Flexible tube with connection flanges
- Micromanometers, 0-2000 Pa (scale divisions 10 Pa)
- Equipment for making holes (plus plastic plugs)
- A stand
- Adhesive tape
- Steel measuring tape
- Report forms
- Thermometer
- Sealing equipment (rubber balls, metal sheeting, plastic, etc.)

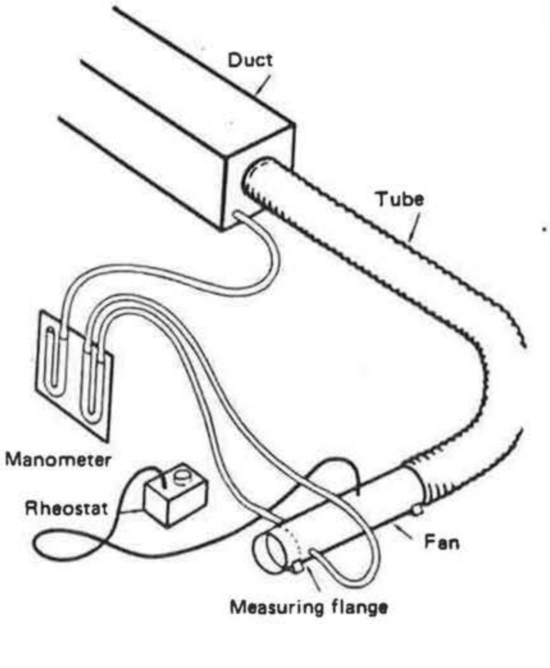


FIGURE 26. Measuring equipment for the measurement of leakage airflow rate

Preparations

Measuring shall be carried out by duct sections, selected by the inspector or in accordance with the HVAC specification issued.

The smallest duct surface area tested is 10 m^2. Larger duct surface areas should not exceed 100 m^2 for air tightness class A and 300 m^2 for class B.

Seal the duct section and determine the duct surface area (from a drawing or by measurement).

Select the connection site for the fan unit so there is satisfactory working space and light. The connection should be made with the least possible interference in ducts (for example, at bends, T-devices or inspection panels, etc., where the system can be easily taken apart and restored) and in such a manner that leakage airflow at connection points is avoided.

Prepare taps for measurement of static pressure in duct sections to be tested.

Measuring

Using the fan unit, pressure in the duct is raised to 400 Pa (or the test pressure prescribed in the HVAC specification) following which the airflow rate is adjusted so that the pressure is kept constant.

When a steady-state condition (constant pressure within ±10 Pa and constant airflow rate within ±2%) is obtained for 5 minutes the micromanometer (flowmeter) is read.

The duct section is not approved if steady-state condition cannot be achieved. When measuring has been completed the duct is restored to operational condition (pressure taps are plugged, etc.).

Report

On report E1 (page 87) are entered not only the measurement values obtained (pressure and airflow rates) but also the duct section number involved, duct dimensions, duct surface areas, air tightness class, visible defects (leaks) and whether any section could not be tested (for example, inaccessible, too much air leakage, impossible to achieve steady-state). The operational pressure is noted from a drawing or specification.

Measurement error

Correction for instrument error is carried out in accordance with the instrument maker's instructions or the calibration certificate of the instrument.

Correction for air temperature is done using the calibration curve (flowmeters are calibrated at -10°C, +15°C and +30°C).

Systematic errors can occur for example as a result of the wrong inclination of manometers and air bubbles in manometer tubes. Random errors at orifice plate measurement are minimum ±1%. Systematic errors can also occur as a result of the unsatisfactory sealing of tested duct sections.

MEASUREMENT REPORT E1

Measuring of leakage airflow rate from duct

Assignment No.	
Date	
Measured by	
Page	of
Instrument	
Calibration date	

Object	Measurement posn. (drawing No. etc.)

Duct section No. (enter also on drawing)	Duct dimensions: ø or $a \times b$, mm — As drawing	Measured	Length m	Duct surface area m^2	Test pressure, p Pa — Prescribed	Value read	Value measured	Leakage airflow rate, q m^3/s — Value read	Value measured	Leakage rate at pressure 400 Pa	Leakage factor: measured leakage airflow rate/measured duct surface area at test pressure 400 Pa $f = \frac{q}{A}$ $m^3/m^2\ s$	Remarks: Value measured = read value x correction as Diagram 15 (Approval, variations in pressure and flow, visible leaks, etc.) — Remarks	Approval
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													

Calculation errors

Duct section No	Instrument error m_1 %	Method error m_2 %	Reading error m_3 %	Probable measuring error as a % $\bar{m} = \sqrt{m_1^2 + m_2^2 + m_3^2}$
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Notes

Systematic reading errors, for example parallax, are taken into consideration. In the case of pressure readings random errors can be estimated from TABLE 7.

Evaluation

Evaluation can be carried out in accordance with report E1. When testing with another test pressure than 400 Pa the conversion of the leakage airflow rate shall be carried out using DIAGRAM 15.

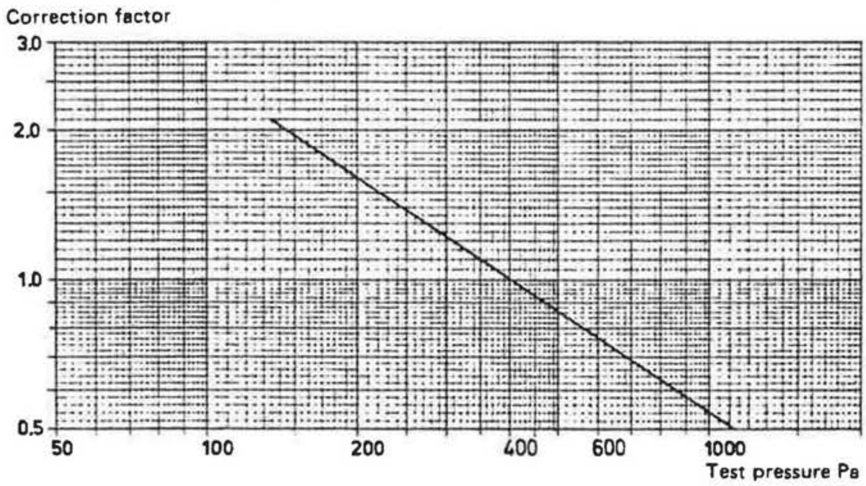


DIAGRAM 15. Example:
Test pressure 600 Pa.
Measured leakage airflow rate 0.12 m^3/s.
Factor 0.75 as diagram gives leakage rate converted to 400 Pa: 0.12 x 0.75 = 0.09 m^3/s.

OTHER METHODS

Pages 91-95

10. MEASURING IN DUCTS WITH METHODS WHICH CANNOT BE USED WITHOUT SUPPLEMENTARY CALIBRATION

10.1 Pressure measurement across ductwork component

A ductwork component is a device in a duct system, whose main function is other than the measurement of airflow rate. The measurement of pressure difference across a component can be used in certain cases for the determination of the airflow rate in a duct.

One component of special interest in the measurement of pressure difference is the heat-exchanger. Measuring across a filter is unsuitable as resistance varies with accumulation of dust. Damp cooling-coils are not suitable either as the amount of condensation affects the pressure drop. Nor is measuring across a damper advisable as it is difficult to determine the setting of the damper with sufficient precision. In order to be able to carry out the measurement the heat-exchanger should be furnished with three or more rows of tubes. The manufacturer of the component must provide a chart of the pressure differences as a function of the airflow rate for the various installation modes.

Equipment

- o Pitot tube (or pressure taps in accordance with the manufacturer's instructions)
- o Tubes
- o Manometer
- o Thermometer
- o (Aneroid barometer)
- o Drill for making holes (and plastic plugs for repair)

Preparations

When measuring across heat-exchanger check that

- o it is clean
- o it is undamaged
- o the distribution of velocity across the heat-exchanger is even.

Drill holes in the duct preceding and following the heat-exchanger as recommended by the manufacturer. Drill the holes so that no burrs are formed on the inside of the duct. Use the pressure taps recommended by the manufacturer and the special chart applicable to the measuring procedure used.

Corrections

If there is a temperature difference of the air upstream and downstream from the heat-exchanger it is necessary to correct the airflow rate. Assuming that the data from the manufacturer are valid for air of $+20^{\circ}C$ the following is obtained:

$$q_v = q \sqrt{\frac{273 + \frac{t_1 + t_2}{2}}{293}} \quad m^3/s$$

where

q_v = true airflow rate m^3/s

q = airflow rate as catalogue data m^3/s

t_1 = air temperature preceding heat-exchanger ^oC

t_2 = air temperature following heat-exchanger ^oC

In cases where the duct area upstream and downstream of the component are not equal consideration must be given to the change in dynamic pressure. This is done by measuring the total pressure difference instead of the static pressure difference.

Measurement error

Random measurement errors may occur because of, for example, a skewed velocity profile in the measurement plane and deviations from the data supplied in the manufacturer's catalogue. Systematic measurements have not been carried out and therefore the method error cannot be stated.

10.2 Measuring across a fan

FIGURE 27a illustrates characteristic and power requirement of a ventilation system where the fan has backward-curved vanes. If points A and B on the power curve are compared it is seen that the power measurement does not provide a distinct value. Two different methods, a and b, can be used here to produce a more reliable result (see below).

FIGURE 27b shows the characteristic and power requirement of a ventilation system where the fan has forward-curved vanes. Its characteristic is thus very flat. Therefore to determine the airflow rate from the fan from one measuring of total pressure would not provide a clear answer. Compare points C and D. If on the other hand the power requirement of the fan is measured, method c, which can be done with a wattmeter, the airflow rate is determined clearly.

Methods a, b and c

Traversing can be carried out with a Pitot tube (method a) where the velocity profile of the airflow is measured or, on condition that the fan's inlet and outlet ducts have the same areas, the airflow rate can be arrived at by measuring the pressure preceding and following the fan (method b). The airflow rate is then found using the difference in pressure and the number of revolutions from the fan's characteristic.

With fans having the vanes bent forwards a power measurement can be carried out (method c) in order to establish the airflow rate. The power requirement is measured with a wattmeter, where the rotational speed of the fan must also be measured.

Because of the great degree of turbulence in the airstream close to the fan the uncertainty in these different methods is great.

Measurement error

Unknown.

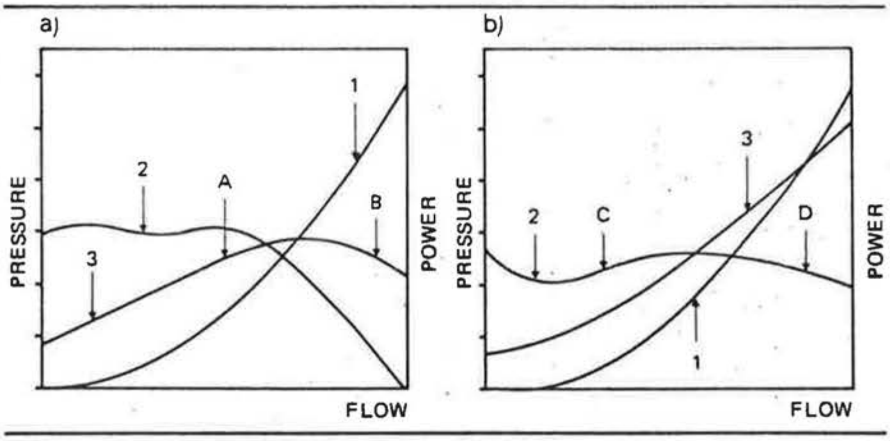


FIGURE 27.

a) Characteristic and power requirement of a ventilation system where the fan has backward-curved vanes.

b) Characteristic and power requirement of a ventilation system where the fan has forward-curved vanes.

Designations:
1. Characteristic of plant
2. Characteristic of fan (n r/m)
3. Power requirement (at n r/m) of fan.

11. MEASURING ON SUPPLY AND EXHAUST AIR DEVICES WITH METHODS WHICH CANNOT BE USED WITHOUT COMPLEMENTARY CALIBRATION OR CAN BE USED FOR RELATIVE MEASUREMENTS ONLY

11.1 Measurement of v_k with a known A_k

Through the method given in ISO/DIS 5219 (Air distribution and aid diffusion - Laboratory aerodynamic testing and rating of air terminal devices), dealing with the reporting and testing of the technical flow characteristics of air terminal devices a method has been created to carry out airflow measurements on installed devices. Manufacturers of the devices must of course state the pertinent values of A_k and v_k, as well as provide instructions on how v_k shall be measured.

The airflow rate is obtained from the equation:

$$q = v_k \times A_k$$

where

v_k = k factor velocity

A_k = k factor area

Limitations

Very few manufacturers show pertinent values for v_k and A_k according to the test method.

The method is not suitable for all devices because of the difficulty in measuring reproducible velocities.

Measurement error

Unknown.

11.2 Measurement of pressure with a probe at a reference point upstream from a supply air device

A measuring probe (capillary tube) is inserted in a fixed position following the device, where a characteristic pressure is taken. The airflow rate is obtained as a function of the pressure difference measured using a chart supplied by the manufacturer of the device.

Limitations

Because the pressure conditions upstream of a supply air device vary the following conditions must be met if the method is to be utilized:

- o The manufacturer advises where the pressure measurement shall be carried out and how the measuring probe shall be designed, or make a special measuring probe available.

- o The device manufacturer provides a chart of the flow as a function of characteristic difference in pressure.

Measurement error

This method of measuring requires great accuracy in the positioning of the measuring probe. *Under calibrated conditions*, which among other things means that the device is correctly positioned in relation to a possible bend preceding the device, the error of the measuring method becomes approximately ±5%. This also presumes small tolerances in manufacture of the device. With a less satisfactory manufacture of the supply air device the error can exceed ±15%.

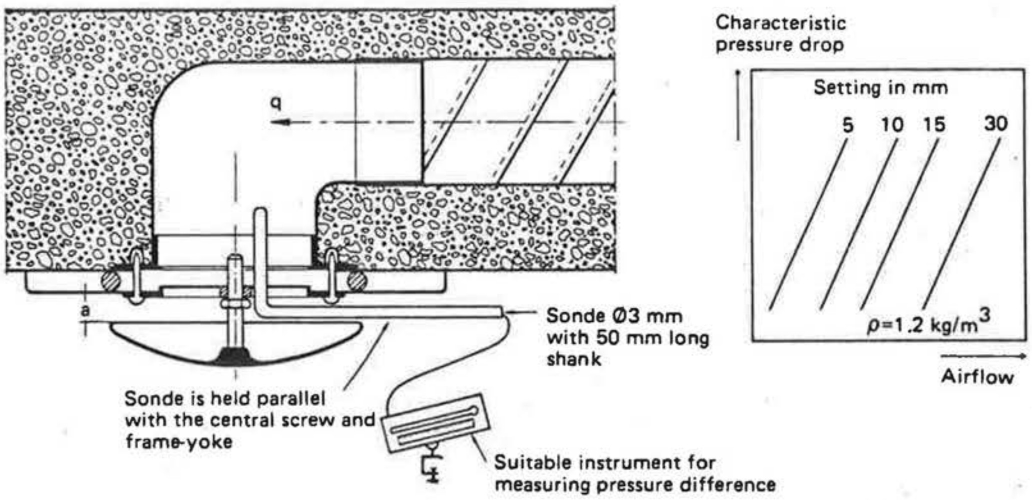


FIGURE 28. Example of measuring with a probe at a reference-point upstream from the device.

REFERENCES

/1/ *Adjustment of airflows in ventilation systems - description requirements*. Nordic guidelines. (Pub. in Swedish) Revised edition 1980. Report B3:1976, National Swedish Council for Building Research, Stockholm, Sweden.

/2/ *Checking of ventilation systems during inspection*. Nordic guidelines. (Pub. in Swedish). Revised edition 1980, Report B2:1976, National Swedish Council for Building Research, Stockholm, Sweden.

/3/ *Requirements in connection with the calibration of anemometers*. Nordic guidelines. (Pub. in Swedish). Revised edition 1980. Report B1:1976, National Swedish Coundcil for Building Research, Stockholm, Sweden.

/4/ Peterson, F., 1975: *Method for the determination of straight duct sections for permanent flowmeters in ventilation systems*. (Pub. in Swedish). Technical reports 57-62. 1975:1, Vol 3. Institution of Heating and Ventilation Technology, Royal Institute of Technology, Stockholm, Sweden.

ACKNOWLEDGEMENTS

The author wishes to thank the translater William Barrett for his strenuous work as well as Sven A Svennberg for valuable points of view in this connection.
The author is also grateful to Inger Ivares for typing and Folke Glaas for some of the figures.

THE NORDIC VENTILATION GROUP

The Nordic Ventilation Group works primarily with questions that cover the planning, construction and operation of ventilation systems. The purpose is to produce material that can help to ensure that ventilation systems function satisfactorily. The permanent members of the group come from the Nordic national institutes for building research. Representatives of a number of public and private organizations also take part in the work of the group.

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In the series Nordic Guidelines the following publications (in Swedish) have been issued in addition to the present one:

Requirements in connection with the calibration of anemometers. B1:1976. Revised edition 1980. National Swedish Council for Building Research.

Checking of ventilation systems during inspection. B2:1976. Revised edition 1980. National Swedish Council for Building Research.

Adjustment of airflows in ventilation systems - description requirements. B3:1976. Revised edition 1980. National Swedish Council for Building Research.

Measurement of thermal indoor climate. B5:1976. Revised edition 1979. National Swedish Council for Building Research.

Climatic hygiene. B8:1976. National Swedish Council for Building Research.

Checking of automatic control systems. B9:1977. National Swedish Council for Building Research.

Guidance for the designing of ventilation systems with regard to their adjustment. B5:1978. National Swedish Council for Building Research.

Method for the determination of straight duct sections for permanent flowmeters in ventilation systems. Technical Report 57 from Institute of Heating and Ventilation Technology, The Royal Institute of Technology, Stockholm, Sweden, 1975:1 (Vol 3).

Adjustment of airflows in ventilation systems - description of the proportionality method. T12:1981. National Swedish Council for Building Research.

Methods for measurement of airflow rates in ventilation systems. T32:1982. National Swedish Council for Building Research.