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Heat recovery ventilators and energy recovery ventilators — Method of test for performance —

Part 2: Assessment of measurement uncertainty of performance parameters

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Foreword

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A list of all parts in the ISO 16494 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document is intended to be a practical guide to assist laboratory personnel in evaluating the uncertainties in the measurement of the performance of ventilators falling under the scope of ISO 16494:2014. It contains a brief introduction to the theoretical basis for the calculations, and contains examples of uncertainty budget sheets that can be used as a basis for the determination of the uncertainty of measurement.

Heat recovery ventilators and energy recovery ventilators — Method of test for performance —

Part 2: Assessment of measurement uncertainty of performance parameters

1 Scope

This document provides guidance for practical applications of those principles in the measurement of the performance of ventilators falling under the scope of ISO 16494:2014. The references listed in the Bibliography give detailed information on the principles and theory of uncertainty as applied to measurements.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 16494, *Heat recovery ventilators and energy recovery ventilators — Method of test for performance*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 16494 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at https://www.iso.org/obp

3.1
calibration
operation that, under specified conditions, in a first step establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication

3.2
correction
modification applied to a measured quantity value to compensate for a known systematic effect

3.3
instrumental drift
continuous change in an indication, related neither to a change in the quantity being measured nor to a change of any recognized influence quantity

3.4
resolution
smallest change in a quantity being measured that causes a perceptible change in the corresponding indication

Note 1 to entry: In the case of a digital instrument, this value corresponds to the number of digits of the reading of the instrument. This value might be different on the overall range of the instrument.

3.5
stability
ability of a measuring instrument or measuring system to maintain its metrological properties constant with time

3.6 Type of evaluation of uncertainty

3.6.1
type A evaluation of standard uncertainty
evaluation of standard uncertainty based on any valid statistical method for treating data

Note 1 to entry: Examples are calculating the standard deviation of the mean of a series of independent observations, using the method of least squares to fit a curve to data in order to evaluate the parameters of the curve and their standard deviations, and carrying out an analysis of variance in order to identify and quantify random effects in certain kinds of measurements. If the measurement situation is especially complicated, one should consider obtaining the guidance of a statistician.

3.6.2
type B evaluation of standard uncertainty
evaluation of standard uncertainty that is usually based on scientific judgment using all the relevant information available

Note 1 to entry: Relevant information can include previous measurement data, experience with, or general knowledge of, the behaviour and property of relevant materials and instruments, manufacturer's specifications, data provided in calibration and other reports, and uncertainties assigned to reference data taken from handbooks.

3.7
uncertainty due to the lack of homogeneity
component specific to air temperature measurements where several probes are used simultaneously

Note 1 to entry: In this case the air temperature value used is the mean of the measurements of the different probes.

4 Symbols

For the purposes of this document, the symbols defined in ISO 16494:2014 and the following apply.

Symbol	Description	Unit
A	Nozzle throat area	m^2
$C_{1,2,3,4}$	Tracer gas concentrations at stations 1,2,3,4	10^6
C_D	Nozzle discharge coefficient	1 NOTE
C_p	Specific heat of dry air	kJ/(kg K)
h	Enthalpy	kJ/kg
$NSAR$	Net supply airflow ratio	%
P_{aux}	Input power to any other electrical components in the ventilator	W
P_{em}	Input power to all electric motors in the ventilator	W
P_{in}	Input power to ventilator	W

NOTE Some quantities of dimension 1 are defined as ratios of two quantities of the same kind. The coherent derived unit is the number 1. (ISO 80000-1:2009, 3.8).

Symbol	Description	Unit
ps	Static pressure	Pa
pv	Velocity pressure	Pa
P_v	Nozzle Pressure	Pa
P_{vma}	Power value of moving air	W
Q	Gross airflow volume	m^3/s
Q_i	Airflow rate calculated using the data from test "I" as described in ISO 16494:2014 B.2.1.1 through B.2.2.2.	m^3/s
qm_i	Air mass flow rate	kg/s
Q_{SA}	Supply airflow	m^3/s
Q_{SANet}	Net supply airflow	m^3/s
$qm_{2,net}$	Net supply mass flow rate	kg/s
t	Time	s
T	Temperature	K
V	Air volume in test chamber	m^3
v'_n	Specific Volume	m^3/kg
U	Expanded uncertainty of a measurement	Same as measurand
u	Standard uncertainty of a measurement	Same as measurand
UEATR	Unit exhaust air transfer ratio	%
COE	Coefficient of Energy	1 NOTE
EW	Effective Work	W
e	Effectiveness	Ratio
ρ	Density	kg/m^3

NOTE Some quantities of dimension 1 are defined as ratios of two quantities of the same kind. The coherent derived unit is the number 1. (ISO 80000-1:2009, 3.8).

Subscript	Description
sensible	Indicates parameter refers to sensible energy
latent	Indicates parameter refers to latent energy
total	Indicates parameter refers to total (enthalpic) energy
ducted	Indicates parameter refers to a ducted ventilator
unducted	Indicates parameter refers to an unducted ventilator
1,2,3,4	Refers to station 1, 2, 3 or 4
SA	Supply air
SANet	Net supply air

5 Explanatory notes useful in laboratory application

5.1 Uncertainty

No measurement of a real quantity can be exact; there is always some uncertainty involved in the measurement. Uncertainty may arise because of measuring instruments not being exact, because the conditions of the test are not precise, or for many other reasons, including human error. Uncertainty may be expressed as a range of test results (e.g. 10 kW ± 0,1 kW), or as a fraction or percentage of the test result (e.g. 10 kW ± 1 %).

5.2 Confidence level

Confidence level refers to the probability that the true result of a measurement lies within the range stated by the uncertainty. For example, if the measurement of a power is given as 10,0 kW ± 1 % at a confidence level of 95 %, this means that there is not more than 5 % probability that the true value of the power is outside the range 9,90 kW to 10,10 kW. A confidence level of 95 % is usually used for engineering measurements; this provides a good compromise between reliability of measurements and the cost of making those measurements.

5.3 Evaluation of uncertainties

Two types of uncertainty evaluation are recognized by ISO/IEC Guide 98-3. A type A evaluation involves statistical methods of evaluation of the uncertainties, and may only be used where there are repeated measurements of the same quantity. A type B evaluation is one using any other means, and may require the use of knowledge of the measurement system, such as calibration certificates for instruments and experience in determining what factors may produce uncertainties in the measurement.

5.4 Steps in evaluation of uncertainty in measurements

To evaluate the uncertainty in a measurement, it is necessary to follow a series of steps.

a) A mathematical model of the measurement system is developed, that lists all the factors that contribute to the measurement.

b) Examination of this model will determine the magnitude of the contribution of each source of uncertainty to the final measurement uncertainty.

c) In many cases the units of the final measurement will differ from the units of the various measurements involved. For example, the measurement of the effective work of an energy-recovery ventilator will involve measurements such as temperatures, pressures, and electrical power. In these cases, it is necessary to determine weighting factors to describe the effect that uncertainties in these measurements will have on the final measurement of capacity. These weighting factors are known as sensitivity coefficients.

d) Once all the factors contributing to the final measurement are evaluated, together with their sensitivity coefficients, they are combined to give the overall uncertainty in the final measurement.

5.5 Uncertainty of measurements

5.5.1 Uncertainty of individual measurements

The uncertainty of measurement of each individual measurement should take into account the different components of uncertainties as described below, where appropriate.

Table 1 — Components of uncertainties for individual measurements

Source of uncertainty	**Evaluation basis**	**Value from calibration certificate or actual value**	**Probability distribution**	**Coverage factor, *k* (ISO/IEC Guide 99:2007, 2.38)[a]**	**Standard uncertainty**
Calibration	Calibration certificate	U_1	Normal	2	$u_1 = \frac{U_1}{2}$
Resolution	Specifications	U_2	Rectangular	$2\times\sqrt{3}$	$u_2 = \frac{U_2}{2\times\sqrt{3}}$
Correction	Calibration certificate	U_3	— (see 5.5.1 NOTE 1 and NOTE 2)	— (see 5.5.1 NOTE 1 and NOTE 2)	u_3 (see 5.5.1 NOTE 1 and NOTE 2)
Drift	Calibration certificate	U_4	Rectangular	$\sqrt{3}$	$u_4 = \frac{U_4}{\sqrt{3}}$
Stability (in time)	Mean	S_5	Standard deviation on a mean value	$\sqrt{N_T}$	$s_5 = \frac{S_5}{\sqrt{N_T}}$
[a] Number larger than one by which a combined standard measurement uncertainty is multiplied to obtain an expanded measurement uncertainty.					

The expanded uncertainty, *U*, is thus calculated as follows.

a) If the calibration correction is applied:

$$U = 2\times\sqrt{{u_1}^2 + {u_2}^2 + {u_3}^2 + {u_4}^2 + {u_i}^2 + \left(\frac{S_5}{\sqrt{N_T}}\right)^2} \quad (1)$$

NOTE 1 If the calibration correction value U_3 is applied directly, then the evaluated value of $u_3 = 0$. In case that the averaged value of deviations at several calibration points is applied as correction factor, the value of u_3 arising from incomplete correction is evaluated from the variance of deviations remaining after the correction value has been applied to each calibration data.

b) If the calibration correction is not applied:

$$U = 2\times\sqrt{{u_1}^2 + {u_2}^2 + {u_4}^2 + {u_i}^2 + \left(\frac{S_5}{\sqrt{N_T}}\right)^2} + U_3 \quad (2)$$

NOTE 2 Avoid calculating the expanded uncertainty without applying the correction. However, if the correction value is small compared to the uncertainty, it could be decided that correction is not needed. If the value of the calibration correction U_3 is entered in Formula (2), then $u_3 = 0$.

5.5.2 Uncertainty of a mean value from several measurements

If several sensors are used for determining a mean value, this mean value is calculated with the following formula:

$$T_\mathrm{m}=\frac{\sum_{\mathrm{i}=1}^{\mathrm{N}} T_\mathrm{i}}{N} \quad (3)$$

where

T_m is the mean value;

T_i is the value measured by the sensor i;

N is the number of sensors.

The uncertainty of this mean value should be calculated from the uncertainty of each individual measurement to which an additional component for homogeneity is added as follows, assuming the individual measurements to be correlated:

$$u(T_\mathrm{m})=\sqrt{\left(\frac{\sum_{i=1}^{N} u(T_\mathrm{i})}{N}\right)^2+\left(\frac{s}{\sqrt{N}}\right)^2}$$

leading to:

$$U(T_\mathrm{m})=2\times u(T_\mathrm{m})=2\times\sqrt{\left(\frac{\sum_{i=1}^{N} u(T_\mathrm{i})}{N}\right)^2+\left(\frac{s}{\sqrt{N}}\right)^2}=2\times\sqrt{\left(\frac{\sum_{i=1}^{N} U(T_\mathrm{i})}{2\times N}\right)^2+\left(\frac{s}{\sqrt{N}}\right)^2} \quad (4)$$

where

$u(T_\mathrm{m})$ is the combined standard uncertainty on the mean value;

$U(T_\mathrm{m})$ is the expanded uncertainty on the mean value ($k = 2$, confidence level approximately 95 %);

$u(T_\mathrm{i})$ is the standard measurement uncertainty of the sensor *i*, determined according to Table 1;

$U(T_\mathrm{i})$ is the expanded measurement uncertainty of the sensor *i*, determined according to Table 1;

s is the standard deviation on the mean value (calculating from the N individual measurements, T_i).

NOTE 1 According to ISO/IEC Guide 98-3:2008, 5.2.2 NOTE 1, for the very special case where all of the input estimates are correlated with correlation coefficients equal to +1, the uncertainty of measurements with the following formula:

$$u_\mathrm{c}^2(y)=\left(\sum_{i=1}^{N} c_\mathrm{i} u(x_\mathrm{i})\right)^2$$

Leads to, for the mean value, $(T_\mathrm{m})=\frac{\sqrt{\left(\sum_{i-1}^{N} u(T_\mathrm{i})\right)^2}}{N}=\sqrt{\left(\frac{\sum_{i-1}^{N} u(T_\mathrm{i})}{N}\right)^2}$ (5)

NOTE 2 See ISO 3534-1 for guidance in evaluating the uncertainty of the mean value obtained from repeated measurements of the same parameter.

5.5.3 Uncertainty of a value obtained by using a smoothing curve

If a value, $V(m)$, is determined from a measurement m and the use of a smoothing curve, then the term:

$$u^2\left(V\left(m\right)\right)$$

should be replaced by:

$$\left[\left(\frac{\partial V}{\partial m}|m_i\right)^2 \cdot u^2\left(m_i\right)+u_{smooth}^2\left(V\left(m\right)\right)\right] \quad (6)$$

where

$u(m_i)$ is the standard uncertainty on each measurement m_i (determined according to Table 1);

$u_{smooth}(V(m))$ is the standard uncertainty component due to the smoothing of the law. Usually, this term is evaluated as the maximum deviation between the smoothing curve and the experimental measurements;

$\frac{\partial V}{\partial m}|m_i$ is the derivative of the smoothing curve with respect to measurement m_i.

6 Evaluation of uncertainty

6.1 Airflow performance

6.1.1 Air volume flow rate

6.1.1.1 Measured parameters affecting the measurement

— Discharge coefficient;

— Nozzle throat area;

— Nozzle pressure;

— Specific volume.

6.1.1.2 Air volume flow rate measurement

Air volume flow rate is calculated as follows:

$$Q=C_D A\sqrt{2\,P_v v'_n} \quad (7)$$

where

C_D is the nozzle(s) discharge coefficient (dimensionless);

A is the nozzle(s) throat area (m^2);

P_v is the nozzle pressure (Pa);

v'_n is the specific volume (m^3/kg).

6.1.1.3 Uncertainty calculation — Specific case

When the air volume flow rate is determined by using a nozzle chamber, the calculation of the relative uncertainty of measurement is made as follows:

$$\left(\frac{u(Q)}{Q}\right)^2 = \left(\frac{u(C_D)}{C_D}\right)^2 + \left(\frac{u(A)}{A}\right)^2 + \left(\frac{u(p_v)}{2p_v}\right)^2 + \left(\frac{u(v'_n)}{2v'_n}\right)^2 \quad (8)$$

When the air volume flow rate is determined by using a nozzle chamber, the calculation of the absolute uncertainty of measurement is made as follows:

$$\left(u(Q)\right)^2 = \left(u(C_D)A\sqrt{2p_v v'_n}\right)^2 + \left(u(A)C_D\sqrt{2p_v v'_n}\right)^2 + \left(\frac{u(p_v)C_D A\sqrt{2p_v v'_n}}{2p_v}\right)^2 + \left(\frac{u(v'_n)C_D A\sqrt{2p_v v'_n}}{2v'_n}\right)^2 \quad (9)$$

6.1.2 Air mass flow rate

6.1.2.1 Measured parameters affecting the measurement

— Air volume flow rate;

— Air density.

6.1.2.2 Air mass flow rate

When mass flow rates are calculated, they can be determined from the relevant air volume flow rate by the following formula:

$$qm_i = Q_i \rho_i \quad (10)$$

where

qm_i is the relevant air volume flow rate i (m³/s);

ρ_i is the density of air stream i (kg/m³).

6.1.2.3 Uncertainty calculation — General case

$$u(qm_i)^2 = \left(u(Q_i)\rho_i\right)^2 + \left(u(\rho_i)Q_i\right)^2 \quad (11)$$

6.1.3 Static pressure differential

6.1.3.1 Measured parameters affecting the measurement

— Inlet pressure;

— Outlet pressure.

6.1.3.2 Static pressure differential

Static pressure differential is described by the following formulae:

$$ps_{2-1} = \left|ps_2 - ps_1\right| \quad (12)$$

$$ps_{4-3} = \left| ps_4 - ps_3 \right| \tag{13}$$

where ps_n is the static pressure at station n (Pa).

6.1.3.3 Uncertainty calculation — General case

$$u\left(ps_{2-1}\right)^2 = \left(u\left(ps_2\right)\right)^2 + \left(u\left(ps_1\right)\right)^2 \tag{14}$$

$$u\left(ps_{4-3}\right)^2 = \left(u\left(ps_4\right)\right)^2 + \left(u\left(ps_3\right)\right)^2 \tag{15}$$

6.2 Unit exhaust air transfer ratio

6.2.1 Measured parameters affecting test results

— Tracer gas concentrations.

6.2.2 UEATR measurement

The unit exhaust air transfer ratio is calculated as follows:

$$UEATR = \frac{C_2 - C_1}{C_3 - C_1} \times 100 \tag{16}$$

where

UEATR	is the unit exhaust air transfer ratio (%);
C_1	is the tracer gas concentration at entering supply air(station 1);
C_2	is the tracer gas concentration at leaving supply air (station 2);
C_3	is the tracer gas concentration at entering exhaust air (station 3).

6.2.3 Uncertainty calculation — General case

The uncertainty calculation is given by the general formula:

$$u\left(UEATR\right)^2 = \left[\left(\frac{u\left(C_2\right)}{\left(C_3 - C_1\right)}\right) \times 100\right]^2 + \left[\left(\frac{\left(C_2 - C_1\right)}{\left(C_3 - C_1\right)} - \frac{\left(C_2 - C_1 + u\left(C_1\right)\right)}{\left(C_3 - C_1 + u\left(C_1\right)\right)}\right) \times 100\right]^2 + \left[\left(\frac{\left(C_2 - C_1\right)}{\left(C_3 - C_1\right)} - \frac{\left(C_2 - C_1\right)}{\left(C_3 - u\left(C_3\right) - C_1\right)}\right) \times 100\right]^2 \tag{17}$$

6.3 Net supply airflow

6.3.1 Net supply airflow ducted units

6.3.1.1 Measured parameters affecting test results

— *UEATR;*

— Supply airflow.