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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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# Contents

Page

# Foreword

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This document was prepared by Technical Committee ISO/TC 86, *Refrigeration and air-conditioning*, Subcommittee SC 6, *Testing and rating of air-conditioners and heat pumps*.

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 |
| $\rho$ | 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:

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

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:

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

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:

$$T_{\mathrm{m}} = \frac{\sum_{\mathrm{i=1}}^{\mathrm{N}} T_{\mathrm{i}}}{N} \tag{3}$$

where

$T_{\mathrm{m}}$ is the mean value;

$T_{\mathrm{i}}$ 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:

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

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, $T_{\mathrm{i}}$).

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, $$(T_{\mathrm{m}}) = \frac{\sqrt{\left(\sum_{i-1}^{N} u(T_{\mathrm{i}})\right)^2}}{N} = \sqrt{\left(\frac{\sum_{i-1}^{N} u(T_{\mathrm{i}})}{N}\right)^2} \tag{5}$$

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:

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

should be replaced by:

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

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:

$$Q = C_D A \sqrt{2 P_v v'_n} \tag{7}$$

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:

$$\left(\frac{u(Q)}{Q}\right)^2=\left(\frac{u(C_\mathrm{D})}{C_\mathrm{D}}\right)^2+\left(\frac{u(A)}{A}\right)^2+\left(\frac{u(p_\mathrm{v})}{2p_\mathrm{v}}\right)^2+\left(\frac{u(v'_\mathrm{n})}{2v'_\mathrm{n}}\right)^2 \quad (8)$$

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:

$$\begin{aligned}(u(Q))^2=&\left(u(C_\mathrm{D})A\sqrt{2p_\mathrm{v}v'_\mathrm{n}}\right)^2+\left(u(A)C_\mathrm{D}\sqrt{2p_\mathrm{v}v'_\mathrm{n}}\right)^2+\\&\left(\frac{u(p_\mathrm{v})C_\mathrm{D}A\sqrt{2p_\mathrm{v}v'_\mathrm{n}}}{2p_\mathrm{v}}\right)^2+\left(\frac{u(v'_\mathrm{n})C_\mathrm{D}A\sqrt{2p_\mathrm{v}v'_\mathrm{n}}}{2v'_\mathrm{n}}\right)^2\end{aligned} \quad (9)$$

### 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:

$$qm_\mathrm{i}=Q_\mathrm{i}\rho_\mathrm{i} \quad (10)$$

where

$qm_\mathrm{i}$ is the relevant air volume flow rate i ($m^3/s$);

$\rho_\mathrm{i}$ is the density of air stream i ($kg/m^3$).

#### 6.1.2.3 Uncertainty calculation — General case

$$u(qm_\mathrm{i})^2=(u(Q_\mathrm{i})\rho_\mathrm{i})^2+(u(\rho_\mathrm{i})Q_\mathrm{i})^2 \quad (11)$$

### 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:

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



 

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

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:

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

## 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.

#### 6.3.1.2 NSAR measurement

Net supply airflow for ducted units is calculated as follows:

$$Q_{\mathrm{SANet}} = \frac{NSAR}{100} \times Q_{\mathrm{SA}} \tag{18}$$

where

$Q_{\mathrm{SANet}}$ is the net supply airflow ($m^3/s$);

$Q_{\mathrm{SA}}$ is the supply airflow ($m^3/s$);

$NSAR$ is the net supply airflow ratio (%).

where

$$NSAR = 100 - EATR \tag{19}$$

and

$UEATR$ is the unit exhaust air transfer ratio (%).

#### 6.3.1.3 Uncertainty calculation for ducted units — General case

$$u\left(Q_{\mathrm{SANet}}\right)^2 = \left(\frac{u\left(UEATR\right)}{100} \times Q_{\mathrm{SA}}\right)^2 + \left(\frac{\left(100 - UEATR\right)}{100} \times u\left(Q_{\mathrm{SA}}\right)\right)^2 \tag{20}$$

### 6.3.2 Net supply airflow unducted ventilators

#### 6.3.2.1 Measured parameters affecting test results

— Chamber volume;

— Tracer gas concentration;

— Time.

#### 6.3.2.2 NSAR measurement

Net supply airflow for unducted ventilators is calculated as follows:

$$Q_{\mathrm{SANet}} = Q_1 - Q_2 \tag{21}$$

where

$$Q_{\mathrm{i}} = \frac{V}{t} ln \frac{\left(C_{\mathrm{i}} - C_{\mathrm{o}}\right)}{\left(C_{\mathrm{t}} - C_{\mathrm{o}}\right)} \tag{22}$$

where, when corrected to standard temperature and density:

$Q_{SANet}$ is the net supply airflow ($m^3/s$);

$Q_1$ is the average of the three calculated overall airflow rates with the unit under test in operation as described in ISO 16494:2014 B.2.1.1 and B.2.1.2 ($m^3/s$);

$Q_2$ is the average of the three calculated natural airflow rates of the test chamber with the ventilator removed as described in ISO 16494:2014 B.2.2.1 and B.2.2.2 ($m^3/s$);

$Q_i$ is the airflow rate calculated using the data from a test 'i' as described in ISO 16494:2014 B.2.1.1, B.2.1.2, B.2.2.1 and B.2.2.2 ($m^3/s$);

$V$ is the air volume in the test chamber ($m^3$);

$t$ is the length of time elapsed since the start of test unit operation (s);

$C_i$ is the initial tracer gas concentration in the test chamber (average of all measurement points);

$C_o$ is the tracer gas concentration in outdoor air (station 1);

$C_t$ is the tracer gas concentration in the test chamber after t seconds (average of all measurement points).

#### 6.3.2.3 Uncertainty calculation for unducted units — General case

$$u(Q_{SANet})^2 = u(Q_1)^2 + u(Q_2)^2 \tag{23}$$

General uncertainty formula for $Q_i$:

$$u(Q_i)^2 = \left(\frac{u(V)}{t} ln\frac{(C_i - C_o)}{(C_t - C_o)}\right)^2 + \left(\frac{u(t)V}{t^2 - u(t)t} ln\frac{(C_i - C_o)}{(C_t - C_o)}\right)^2 + \left(\frac{V}{t}\left(ln\frac{(C_i - C_o)}{(C_i - u(C_i) - C_o)}\right)\right)^2 + \left(\frac{V}{t}\left(ln\frac{(C_i - C_o)(C_t - C_o + u(C_o))}{(C_t - C_o)(C_i - C_o + u(C_o))}\right)\right)^2 + \left(\frac{V}{t}\left(ln\frac{((C_t - u(C_t) - C_o))}{(C_t - C_o)}\right)\right)^2 \tag{24}$$

## 6.4 Gross effectiveness

### 6.4.1 Measured parameters affecting the measurement

— Dry-bulb temperature;

— Absolute humidity;

— Enthalpy.

### 6.4.2 Gross effectiveness measurement

The gross sensible, latent or total effectiveness of an HRV or ERV at test conditions is calculated by the following formula:

$$\varepsilon = \frac{x_1 - x_2}{x_1 - x_3} \tag{25}$$

where $x$ equals one of the following for the test condition under consideration:

$x$ is the dry-bulb temperature (for sensible effectiveness), °C; or

$x$ is the absolute humidity ratio (for latent effectiveness), kg water/kg dry air; or

$x$ is the total enthalpy (for total effectiveness), J/kg.

#### 6.4.3 Uncertainty calculation — General case

$$u(\varepsilon)^2 = \left[\left(\frac{x_1 - x_2}{x_1 - x_3} - \frac{\left(x_1 - u(x_1) - x_2\right)}{\left(x_1 - u(x_1) - x_3\right)}\right)\right]^2 + \left[\frac{\left(u(x_2)\right)}{\left(x_1 - x_3\right)}\right]^2 + \left[\left(\frac{x_1 - x_2}{x_1 - x_3} - \frac{\left(x_1 - x_2\right)}{\left(x_1 - x_3 - u(x_3)\right)}\right)\right]^2 \tag{26}$$

### 6.5 Coefficient of energy

#### 6.5.1 Coefficient of energy: Ducted ventilators

##### 6.5.1.1 Measured parameters affecting the measurement

— Enthalpy;

— Net supply mass flow rate at station 2;

— Unit exhaust air transfer ratio;

— Specific volume of supply air at station 2;

— Static pressure;

— Dynamic pressure;

— Input power.

##### 6.5.1.2 Coefficient of Energy — Measurement

The coefficient of energy ($COE$) of a ducted ventilator is described by the following formula:

$$COE_{\text{ducted}} = \frac{\left(\left|qm_{2,\text{net}}\left(h_1 - h_2\right)\right| \times 1\,000\right) + P_{\text{vma}}}{P_{\text{in}}} \tag{27}$$

where

$h_1$ is the enthalpy of the air at station 1 (kJ/kg of dry air);

$h_2$ is the enthalpy of the air at station 2 (kJ/kg of dry air);

$qm_{2,\text{net}}$ is the net supply mass flow rate at station 2 (kg/s);

$P_{\text{vma}}$ is the power value of moving air (J/s);

$P_{\text{in}}$ is the input power to ventilator (W).

and

$$qm_{2,\text{net}} = qm_2\left(1 - \frac{UEATR}{100}\right) \tag{28}$$

and

$$P_{\text{vma}} = \left(\sum_{n=1}^{4} \left|ps_{\text{n}} + pv_{\text{n}}\right|\right) 2qm_{2,\text{net}} v_s \tag{29}$$

where

$v_s$ is the specific volume of the supply air (m$^3$/kg);

$ps_n$ is the external static pressures at the inlet(s) and outlet(s) (Pa);

$pv_n$ is the dynamic pressure at the inlet(s) and outlet(s) (Pa).

and

$$P_{in} = P_{em} + P_{aux} \tag{30}$$

where

$P_{em}$ is the input power to all electric motors in the ventilator (W);

$P_{aux}$ is the input power to any other electrical components in the ventilator (W).

#### 6.5.1.3 Uncertainty calculation — General case

$$u\left(COE_{\text{ducted}}\right)^2 = \left(\frac{\left(u\left(qm_{2,\text{net}}\right)\left(h_2 - h_1\right) \times 1\,000\right)}{P_{\text{in}}}\right)^2 + \left(\frac{\left(qm_{2,\text{net}}\left(u\left(h_2\right)\right) \times 1\,000\right)}{P_{\text{in}}}\right)^2 + \left(\frac{\left(qm_{2,\text{net}}\left(u\left(h_1\right)\right) \times 1\,000\right)}{P_{\text{in}}}\right)^2 + \left(\frac{u\left(P_{\text{vma}}\right)}{P_{\text{in}}}\right)^2 + \left(\frac{-u\left(P_{\text{in}}\right)\left\{\left|qm_{2,\text{net}}\left(h_2 - h_1\right)\right| \times 1\,000 + P_{\text{vma}}\right\}}{P_{\text{in}}^{\;2} - u\left(\mathrm{P}_{\text{in}}\right)P_{\text{in}}}\right)^2 \tag{31}$$

where

$$u\left(qm_{2,\text{net}}\right)^2 = \left(u\left(qm_2\right)\left(1 - \frac{UEATR}{100}\right)\right)^2 + \left(qm_2\left(\frac{u\left(UEATR\right)}{100}\right)\right)^2 \tag{32}$$

and

$$\left(u\left(P_{\text{vma}}\right)\right)^2 = \sum_{n=1}^{4}\left(u\left(ps_{\text{n}}\right)2qm_{2,Net}v_s\right)^2 + \sum_{n=1}^{4}\left(u\left(pv_{\text{n}}\right)2qm_{2,Net}v_s\right)^2 + \left(\sum_{n=1}^{4}\left|ps_{\text{n}} + pv_{\text{n}}\right| 2u\left(qm_{2,Net}\right)v_s\right)^2 + \left(\sum_{n=1}^{4}\left|ps_{\text{n}} + pv_{\text{n}}\right| 2qm_{2,Net}u\left(v_s\right)\right)^2 \tag{33}$$

and

$$u\left(P_{\text{in}}\right)^2 = u\left(P_{\text{em}}\right)^2 + u\left(P_{\text{aux}}\right)^2 \tag{34}$$

#### 6.5.1.4 Uncertainty calculation — Specific case

When moisture transfer is not of interest (sensible-only ventilators) or does not occur the substitution described in ISO 16494:2014, 8.7.3 can be made.

$$u\left(COE_{\text{ducted}}\right)^2 = \left(\frac{\left(u\left(qm_{2,\text{net}}\right)C_p\left(T_2 - T_1\right)\times 1\,000\right)}{P_{\text{in}}}\right)^2 + \left(\frac{\left(qm_{2,\text{net}}C_p\left(u\left(T_2\right)\right)\times 1\,000\right)}{P_{\text{in}}}\right)^2 + \left(\frac{\left(qm_{2,\text{net}}C_p\left(u\left(T_1\right)\right)\times 1\,000\right)}{P_{\text{in}}}\right)^2 + \left(\frac{u\left(P_{\text{vma}}\right)}{P_{\text{in}}}\right)^2 + \left(\frac{-u\left(P_{\text{in}}\right)\left\{\left|qm_{2,\text{net}}C_p\left(T_2 - T_1\right)\right|\times 1\,000 + P_{\text{vma}}\right\}}{P_{\text{in}}{}^2 - u\left(P_{\text{in}}\right)P_{\text{in}}}\right)^2 + \left(\frac{\left(qm_{2,\text{net}}\cdot u\left(C_p\right)\left(T_2 - T_1\right)\times 1000\right)}{P_{\text{in}}}\right)^2 \quad (35)$$

### 6.5.2 Coefficient of energy — Unducted ventilators

#### 6.5.2.1 Measured parameters affecting the measurement

- Enthalpy;
- Net supply mass flow rate at station 2;
- Unit exhaust air transfer ratio;
- Specific volume of supply air at station 2;
- Input power.

#### 6.5.2.2 Coefficient of energy — Measurement

The coefficient of energy (COE) of an unducted ventilator is described by the following formula:

$$COE_{\text{unducted}} = \frac{\left|qm_{2,\text{net}}\left(h_1 - h_2\right)\right|\times 1\,000}{P_{\text{in}}} \quad (36)$$

where

$h_1$ is the enthalpy of the air at station 1 (kJ/kg of dry air);

$h_2$ is the enthalpy of the air at station 2 (kJ/kg of dry air);

$qm_{2,\text{net}}$ is the net supply mass flow rate (kg/s);

$P_{\text{in}}$ is the input power to ventilator (W).



 

and

$$qm_{2,\mathrm{net}} = qm_2 \left(1 - \frac{UEATR}{100}\right) \tag{37}$$

and

$$P_{\mathrm{in}} = P_{\mathrm{em}} + P_{\mathrm{aux}} \tag{38}$$

where

$P_{\mathrm{em}}$ is the input power to all electric motors in the ventilator (W);

$P_{\mathrm{aux}}$ is the input power to any other electrical components in the ventilator (W).

#### 6.5.2.3 Uncertainty calculation — General case

$$u\left(COE_{\mathrm{unducted}}\right)^2 = \left(\frac{\left(u\left(qm_{2,\mathrm{net}}\right)\left(h_2 - h_1\right) \times 1\,000\right)}{P_{\mathrm{in}}}\right)^2 + \left(\frac{\left(qm_{2,\mathrm{net}}\left(u\left(h_2\right)\right) \times 1\,000\right)}{P_{\mathrm{in}}}\right)^2 + \left(\frac{\left(qm_{2,\mathrm{net}}\left(u\left(h_1\right)\right) \times 1\,000\right)}{P_{\mathrm{in}}}\right)^2 + \left(\frac{u\left(P_{\mathrm{in}}\right) qm_{2,\mathrm{net}}\left(h_2 - h_1\right) \times 1\,000}{P_{\mathrm{in}}{}^2 - u\left(P_{\mathrm{in}}\right) P_{\mathrm{in}}}\right)^2 \tag{39}$$

where

$$u\left(qm_{2,\mathrm{net}}\right)^2 = \left(u\left(qm_2\right)\left(1 - \frac{UEATR}{100}\right)\right)^2 + \left(qm_2\left(\frac{u\left(UEATR\right)}{100}\right)\right)^2 \tag{40}$$

and

$$u\left(P_{\mathrm{in}}\right)^2 = u\left(P_{\mathrm{em}}\right)^2 + u\left(P_{\mathrm{aux}}\right)^2 \tag{41}$$

#### 6.5.2.4 Uncertainty calculation — Specific case

When moisture transfer is not of interest (sensible-only ventilators) or does not occur, the substitution described in ISO 16494:2014, 8.7.3 can be made.

$$u\left(COE_{\mathrm{unducted,sensible}}\right)^2 = \left(\frac{\left(u\left(qm_{2,\mathrm{net}}\right) c_{\mathrm{p}}\left(T_2 - T_1\right) \times 1\,000\right)}{P_{\mathrm{in}}}\right)^2 + \left(\frac{\left(qm_{2,\mathrm{net}} c_{\mathrm{p}}\left(u\left(T_2\right)\right) \times 1\,000\right)}{P_{\mathrm{in}}}\right)^2 + \left(\frac{\left(qm_{2,\mathrm{net}} c_{\mathrm{p}}\left(u\left(T_1\right)\right) \times 1\,000\right)}{P_{\mathrm{in}}}\right)^2 + \left(\frac{-u\left(\mathrm{P}_{\mathrm{in}}\right) qm_{2,\mathrm{net}} c_{\mathrm{p}}\left(T_2 - T_1\right) \times 1\,000}{P_{\mathrm{in}}{}^2 - u\left(P_{\mathrm{in}}\right) P_{\mathrm{in}}}\right)^2 + \left(\frac{qm_{2,\mathrm{net}}\, u\left(C_{\mathrm{p}}\right)\left|T_2 - T_1\right| \times 1\,000}{P_{\mathrm{in}}}\right)^2 \tag{42}$$

## 6.6 Effective work (EW)

### 6.6.1 Measured parameters affecting the measurement

— *COE*;

— $P_{\text{in.}}$

### 6.6.2 Effective work: Ducted or unducted ventilators

The effective work (EW) of a ducted or unducted ventilator is described by the following formula:

$$EW = P_{\text{in}} \times (COE - 1) \quad (43)$$

### 6.6.3 Uncertainty calculation — General case

$$u(EW)^2 = \left(u(P_{\text{in}}) \times (COE - 1)\right)^2 + \left(P_{\text{in}} \times u(COE)\right)^2 \quad (44)$$

### 6.6.4 Uncertainty calculation — Specific case

When moisture transfer is not of interest (sensible-only ventilators) or does not occur, the substitution described in ISO 16494:2014, 8.7.3 can be made.

$$u(EW_{\text{sensible}})^2 = \left(u(P_{\text{in}}) \times (COE_{\text{sensible}} - 1)\right)^2 + \left(P_{\text{in}} \times u(COE_{\text{sensible}})\right)^2 \quad (45)$$

# Annex A
(informative)

# Uncertainty budget sheets

The following (18) budget sheets, presented as tables, are given in this annex as an example of uncertainty calculations using an uncertainty budget sheet approach.

— Table A.1 — Uncertainty budget sheet for air volume flow rate $\boldsymbol{Q}$

— Table A.2 — Uncertainty budget sheet for air mass flow rate $\boldsymbol{qm}_{i}$

— Table A.3 — Uncertainty budget sheet for static pressure differential(s) $\boldsymbol{ps}_{2\text{-}1}$, $\boldsymbol{ps}_{4\text{-}3}$

— Table A.4— Uncertainty budget sheet for unit exhaust air transfer ratio $\boldsymbol{UEATR}$

— Table A.5 — Uncertainty budget sheet for net supply airflow $\boldsymbol{Q}_{\mathrm{SANet}}$

— Table A.6 — Uncertainty budget sheet for net supply mass airflow $\boldsymbol{qm}_{\mathrm{2,net}}$

— Table A.7 — Uncertainty budget sheet for power value of moving air $\boldsymbol{P}_{\mathrm{vma}}$

— Table A.8 — Uncertainty budget sheet for gross effectiveness, sensible $\boldsymbol{\varepsilon}_{\mathrm{sensible}}$

— Table A.9 — Uncertainty budget sheet for gross effectiveness, latent $\boldsymbol{\varepsilon}_{\mathrm{latent}}$

— Table A.10 — Uncertainty budget sheet for gross effectiveness, total $\boldsymbol{\varepsilon}_{\mathrm{total}}$

— Table A.11 — Uncertainty budget sheet for coefficient of energy, ducted ventilator, total $\boldsymbol{COE}_{\mathrm{ducted}}$

— Table A.12 — Uncertainty budget sheet for coefficient of energy, ducted ventilator, sensible $\boldsymbol{COE}_{\mathrm{ducted,sensible}}$

— Table A.13 — Uncertainty budget sheet for coefficient of energy, unducted ventilator, total $\boldsymbol{COE}_{\mathrm{unducted}}$

— Table A.14 — Uncertainty budget sheet for coefficient of energy, unducted ventilator, sensible $\boldsymbol{COE}_{\mathrm{unducted,sensible}}$

— Table A.15 — Uncertainty budget sheet for effective work, total $\boldsymbol{EW}$

— Table A.16 — Uncertainty budget sheet for effective work, sensible $\boldsymbol{EW}_{\mathrm{sensible}}$

— Table A.17 — Uncertainty budget sheet for airflow rate from test *i*, used to determine net supply airflow for unducted ventilators using the attenuation method $\boldsymbol{Q}_{i}$

— Table A.18 — Uncertainty budget sheet for net supply airflow $\boldsymbol{Q}_{\mathrm{SANet}}$ for unducted ventilators using the attenuation method

In the normative sections of this document, most of the numbered formulae for determination of uncertainty yield the absolute uncertainty $u(Q)$.

The following budget sheets yield first the relative uncertainty $u(Y)/Y$, and the absolute uncertainty $u(Q)$ is calculated by multiplying the value of $Q$ by $u(Y)/Y$.

Alternate forms of the formulae which yield the relative uncertainty $u(Y)/Y$ are shown in the tables and are labelled as “(rel)”.

These budget sheets are only an example of the budget sheet method of calculation for guidance. Laboratories may use appropriate data depending on the test methods and instrumentation used. For minimum uncertainty in test results it is essential that an appropriate method is adopted for each test.

If the functional relationship is a product or quotient, i.e. the output quantity is obtained from only the multiplication or division of the input quantities, this can be transformed to a linear addition by the use of relative values.

In all cases of the general form $Y = c\, X_1^{p1} X_2^{p2} \ldots X_N^{pN}$ in which the exponents $p_\mathrm{i}$ are known positive or negative numbers having negligible uncertainties, then the combined standard relative uncertainty $u(Y)/Y$ can be calculated from the relative standard uncertainty of all of the sources of uncertainty as follows (see ISO/IEC Guide 98-3:2008, 5.1.6):

$$\frac{u(Y)}{|Y|} = \sqrt{\sum_{i=}^{n} \left[ \frac{p_\mathrm{i} u(x_\mathrm{i})}{|x_\mathrm{i}|} \right]^2} \tag{A.1}$$



 

**Table A.1 — Uncertainty budget sheet for air volume flow rate $Q$**

| Input quantity and/or source of uncertainty | Symbol | Units of measurement | Measured value | Uncertainty of each factor | | | | Relative standard uncertainty of each value | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Expanded uncertainty | Probability distribution | Divisor | Standard uncertainty $u(x_i)$ | $\frac{p_i u(x_i)}{\lvert x_i \rvert}$ | |
| Nozzle Coefficient | $C_D$ | — | 0,909 | 0,001 | Normal | 2 | 0,000 5 | $\frac{u(C_D)}{\lvert C_D \rvert}$ | 0,055 % |
| Nozzle Area | $A$ | m$^2$ | 0,005 | 0,000 1 | Normal | 2 | 0,000 05 | $\frac{u(A)}{\lvert A \rvert}$ | 1,00 % |
| Nozzle Pressure | $Pv$ | Pa | 124,6 | 2,5 | Normal | 2 | 1,25 | $\frac{u(P_v)}{\lvert 2P_v \rvert}$ | 0,502 % |
| Specific Volume | $v'_n$ | m$^3$/kg | 0,868 8 | 0,011 | Normal | 2 | 0,005 5 | $\frac{u(V'_n)}{\lvert 2V'_n \rvert}$ | 0,317 % |
| **Air volume flow rate** | **$Q$** | **m3/s** | **0,065 0** | **← calculated value per Formula (7)** | | | | | |
| Formula (7) | $Q = C_D\, A \sqrt{2\, P_v\, v'_n}$ | | | | | By uncertainty budget | | Combined standard relative uncertainty $u(Y)/Y$ | 1,16 % |
| | | | | | | | | Expanded absolute uncertainty $U(Q)$ | 0,001 55 |
| | | | | | | | | Expanded relative uncertainty U$(Y)/Y$ | 2,32 % |
| (rel) | $\left(\frac{u(Q)}{Q}\right)^2 = \left(\frac{u(C_D)}{C_D}\right)^2 + \left(\frac{u(A)}{A}\right)^2 + \left(\frac{u(P_v)}{2P_v}\right)^2 + \left(\frac{u(v'_n)}{2v'_n}\right)^2$ | | | | | By formula at left | | Combined standard relative uncertainty $u(Y)/Y$ | 1,16 % |
| | | | | | | | | Expanded relative uncertainty $U(Y)/Y$ | 2,32 % |
| | | | | | | | | *For expanded uncertainty, coverage factor $k$ = 2* | |

**Table A.2 — Uncertainty budget sheet for air mass flow rate $qm_i$**

| Input quantity and/or source of uncertainty | Symbol | Units of measurement | Uncertainty of each factor | | | | Value of standard uncertainty $u(x_i)$ | Relative standard uncertainty of each value | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Measured value | Expanded uncertainty | Probability distribution | Divisor | | $\frac{p_i u(x_i)}{\lvert x_i \rvert}$ | |
| Air volume flow rate | $Q_i$ | m³/s | 0,066 9 | 0,001 55 | Normal | 2 | 0,000 775 | $\frac{u(Q_i)}{\lvert Q_i \rvert}$ | 1,16 % |
| Air density as tested | $\rho_i$ | kg/m³ | 1,151 | ,015 | Normal | 2 | 0,007 5 | $\frac{u(\rho_i)}{\lvert \rho_i \rvert}$ | 0,65 % |
| **Air mass flow rate** | $qm_i$ | **kg/s** | **0,077 0** | **← calculated value per Formula (10)** | | | | | |
| Formula (10) | $qm_i = Q_i \rho_i$ | | | | | By uncertainty budget | | Combined standard relative uncertainty $u(Y)/Y$ | 1,33 % |
| | | | | | | | | Expanded absolute uncertainty $U(Q)$ | 0,002 05 |
| | | | | | | | | Expanded relative uncertainty $U(Y)/Y$ | 2,66 % |
| (rel) | $\left(\frac{u(qm_i)}{qm_i}\right)^2 = \left(\frac{u(Q_i)}{Q_i}\right)^2 + \left(\frac{u(\rho_i)}{\rho_i}\right)^2$ | | | | | By formula at left | | Combined standard relative uncertainty $u(Y)/Y$ | 1,33 % |
| | | | | | | | | Expanded relative uncertainty $U(Y)/Y$ | 2,66 % |
| | | | | | | | | *For expanded uncertainty, coverage factor k = 2* | |

**Table A.3 — Uncertainty budget sheet for static pressure differential $ps_{2\text{-}1}$**

| Input quantity and/or source of uncertainty | Symbol | Units of measurement | Uncertainty of each Factor | | | | Value of standard uncertainty $u(x_i)$ | Standard uncertainty of each value | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Measured value | Expanded uncertainty | Probability distribution | Divisor | | $u_c^2(y)=\left(\sum_{i=1}^{N} c_i u(x_i)\right)^2$ | |
| Inlet pressure | $ps_1$ | Pa | −20 | 2,5 | Normal | 2 | 1,250 | $u(ps_1)$ | 1,250 |
| Outlet pressure | $ps_2$ | Pa | 30 | 2,5 | Normal | 2 | 1,250 | $u(ps_2)$ | 1,250 |
| **Static pressure differential** | $ps_{2\text{-}1}$ | **Pa** | **50** | **← calculated value per Formula (12)** | | | | | |
| Formula (12) | $ps_{2-1}=\left\|ps_2-ps_1\right\|$ (see ISO/IEC Guide 98-3:2008, 5.1.5) | | | | | By uncertainty budget | | Combined standard uncertainty $u_c(Q)$ | 1,768 |
| | | | | | | | | Expanded absolute uncertainty $U(Q)$ | 3,535 |
| | | | | | | | | *For expanded uncertainty, coverage factor $k = 2$* | |

**Table A.4 — Uncertainty budget sheet for unit exhaust air transfer ratio *UEATR***

| Input quantity and/or source of uncertainty | Symbol | Units of measurement | Uncertainty of each factor: Measured value | Uncertainty of each factor: Expanded uncertainty | Uncertainty of each factor: Probability distribution | Uncertainty of each factor: Divisor | Value of standard uncertainty $u(x_i)$ | Relative standard uncertainty of each value: $\frac{p_i u(x_i)}{\lvert x_i \rvert}$ | |
|---|---|---|---|---|---|---|---|---|---|
| Tracer gas concentration entering supply air(station 1) | $C_1$ | $10^6$ | 84 | 1 | Normal | 2 | 0,5 | $\left\lvert 1-\frac{(C_2-C_1-u(C_1))(C_3-C_1)}{(C_3-C_1-u(C_1))(C_2-C_1)} \right\rvert$ | 1,3 % |
| Tracer gas concentration entering supply air(station 2) | $C_2$ | $10^6$ | 121 | 1 | Normal | 2 | 0,5 | $\left\lvert \frac{u(C_2)}{C_2-C_1} \right\rvert$ | 1,4 % |
| Tracer gas concentration entering supply air(station 3) | $C_3$ | $10^6$ | 824 | 1 | Normal | 2 | 0,5 | $\left\lvert 1-\frac{(C_3-C_1)}{(C_3-C_1-u(C_3))} \right\rvert$ | 0,07 % |
| **Unit Exhaust Air Transfer Rate** | ***UEATR*** | **%** | **5,0** | **← calculated value per Formula (16)** | | | | | |
| Formula (16) | $UEATR = \frac{C_2-C_1}{C_3-C_1} \times 100\rvert$ | | | | | By uncertainty budget | | Combined standard relative uncertainty $u(Y)/Y$ | 1,9 % |
| | | | | | | | | Expanded absolute uncertainty $U(Q)$ | 0,19 |
| | | | | | | | | Expanded relative uncertainty $U(Y)/Y$ | 3,8 % |
| (rel) | $\left(\frac{u(UEATR)}{UEATR}\right)^2 = \left(\frac{u(C_2)}{C_2-C_1}\right)^2 + \left(1-\frac{(C_2-C_1-u(C_1))(C_3-C_1)}{(C_3-C_1-u(C_1))(C_2-C_1)}\right)^2 + \left(1-\frac{(C_3-C_1)}{(C_3-C_1-u(C_3))}\right)^2$ | | | | | By formula at left | | Combined standard relative uncertainty u(Y)/Y | 1,9 % |
| | | | | | | | | Expanded relative uncertainty $U(Y)/Y$ | 3,8 % |
| | | | | | | | | *For expanded uncertainty, coverage factor k = 2* | |

**Table A.5 — Uncertainty budget sheet for net supply airflow $Q_{SANet}$**

| Input quantity and/or source of uncertainty | Symbol | Units of measurement | Uncertainty of each factor | | | | Value of standard uncertainty $u(x_i)$ | Relative standard uncertainty of each value | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Measured value | Expanded uncertainty | Probability distribution | Divisor | | $\frac{p_i u(x_i)}{\lvert x_i \rvert}$ | |
| Supply airflow | $Q_{SA}$ | m³/s | 0,066 9 | 0,001 6 | Normal | 2 | 0,001 | $\frac{u(Q_{SA})}{\lvert Q_{SA} \rvert}$ | 1,17 % |
| UEATR | *UEATR* | % | 5,000 | 0,019 0 | Normal | 2 | 0,010 | $\frac{u(UEATR)}{\lvert 100-UEATR \rvert}$ | 0,010 0 % |
| **Net supply airflow** | $Q_{SANET}$ | m³/s | **0,064** | **← calculated value per Formulae (18) and (19)** | | | | | |
| Formula (18) Formula (19) | $Q_{SANet} = \frac{NSAR}{100} \times Q_{SA}$ *where* $NSAR = 100 - EATR$ | | | | | By uncertainty budget | Combined standard relative uncertainty $u(Y)/Y$ | | 1,17 % |
| | | | | | | | Expanded absolute uncertainty $U(Q)$ | | 0,001 48 |
| | | | | | | | Expanded relative uncertainty $U(Y)/Y$ | | 2,33 % |
| (rel) | $\left(\frac{u(Q_{SA,Net})}{Q_{SA,Net}}\right)^2 = \left(\frac{u(UEATR)}{100-UEATR}\right)^2 + \left(\frac{u(Q_{SA})}{Q_{SA}}\right)^2$ | | | | | By formula at left | Combined standard relative uncertainty $u(Y)/Y$ | | 1,17 % |
| | | | | | | | Expanded relative uncertainty $U(Y)/Y$ | | 2,33 % |
| | | | | | | | *For expanded uncertainty, coverage factor k = 2* | | |

**Table A.6 — Uncertainty budget sheet for net supply mass airflow $qm_{2,net}$**

<table>
<tr><th rowspan="2">Input quantity and/or source of uncertainty</th><th rowspan="2">Symbol</th><th rowspan="2">Units of measurement</th><th colspan="4">Uncertainty of each Factor</th><th rowspan="2">Value of standard uncertainty $u(x_i)$</th><th colspan="2">Relative standard uncertainty of each value</th></tr>
<tr><th>Measured value</th><th>Expanded uncertainty</th><th>Probability distribution</th><th>Divisor</th><th colspan="2">$\frac{p_i u(x_i)}{\lvert x_i \rvert}$</th></tr>
<tr><td>Supply airflow</td><td>$qm_2$</td><td>kg/s</td><td>0,077 0</td><td>0,002 04</td><td>Normal</td><td>2</td><td>0,001 02</td><td>$\frac{u(qm_2)}{qm_2}$</td><td>1,32 %</td></tr>
<tr><td>UEATR</td><td>$UEATR$</td><td>%</td><td>5,0</td><td>0,186</td><td>Normal</td><td>2</td><td>0,093</td><td>$\frac{u(UEATR)}{100-UEATR}$</td><td>0,097 9</td></tr>
<tr><td>Net supply mass flow rate</td><td>$qm_{2,net}$</td><td>kg/s</td><td>0,075 1</td><td colspan="6">← calculated value per Formula (28)</td></tr>
<tr><td rowspan="3">Formula (28)</td><td colspan="5" rowspan="3">$qm_{2,\mathrm{net}} = qm_2\left(1-\frac{UEATR}{100}\right)$</td><td colspan="2" rowspan="3">By uncertainty budget</td><td>Combined standard relative uncertainty $u(Y)/Y$</td><td>1,32 %</td></tr>
<tr><td>Expanded absolute uncertainty $U(Q)$</td><td>0,001 93</td></tr>
<tr><td>Expanded relative uncertainty $U(Y)/Y$</td><td>2,64 %</td></tr>
<tr><td rowspan="3">(rel)</td><td colspan="5" rowspan="3">$\left(\frac{u(qm_{2,\mathrm{net}})}{qm_{2,\mathrm{net}}}\right)^2 = \left(\frac{u(qm_2)}{qm_2}\right)^2 + \left(\frac{u(UEATR)}{100-UEATR}\right)^2$</td><td colspan="2" rowspan="3">By formula at left</td><td>Combined standard relative uncertainty u(Y)/Y</td><td>2,68 %</td></tr>
<tr><td>Expanded relative uncertainty $U(Y)/Y$</td><td>5,36 %</td></tr>
<tr><td colspan="2">For expanded uncertainty, coverage factor k = 2</td></tr>
</table>

**Table A.7 — Uncertainty budget sheet for power value of moving air $P_{vma}$**

| Input quantity and/or source of uncertainty | Symbol | Units of measurement | Uncertainty of each factor | | | | Value of standard uncertainty $u(x_i)$ | Relative standard uncertainty of each value | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Measured value | Expanded uncertainty | Probability distribution | Divisor | | $\frac{p_i u(x_i)}{\lvert x_i \rvert}$ | |
| Static pressure at entering supply air (station 1) | $ps_1$ | Pa | −20 | 2,5 | Normal | 2 | 1,250 0 | $\frac{u(ps_n)}{\sum_{n=1}^{4} \lvert ps_n + pv_n \rvert}$ | 1,25 % |
| Static pressure at leaving supply air (station 2) | $ps_2$ | Pa | 30 | 2,5 | Normal | 2 | 1,250 0 | | 1,25 % |
| Static pressure at entering exhaust air (station 3) | $ps_3$ | Pa | −20 | 2,5 | Normal | 2 | 1,250 0 | | 1,25 % |
| Static pressure at leaving exhaust air (station 4) | $ps_4$ | Pa | 30 | 2,5 | Normal | 2 | 1,250 0 | | 1,25 % |
| Velocity pressure at entering supply air (station 1) | $pv_1$ | Pa | 10 | 2,5 | Normal | 2 | 1,250 0 | $\frac{u(pv_n)}{\sum_{n=1}^{4} \lvert ps_n + pv_n \rvert}$ | 1,25 % |
| Velocity pressure at leaving supply air (station 2) | $pv_2$ | Pa | 10 | 2,5 | Normal | 2 | 1,250 0 | | 1,25 % |
| Velocity pressure at entering exhaust air (station 3) | $pv_3$ | Pa | 10 | 2,5 | Normal | 2 | 1,250 0 | | 1,25 % |
| Velocity pressure at leaving exhaust air (station 4) | $pv_4$ | Pa | 10 | 2,5 | Normal | 2 | 1,250 0 | | 1,25 % |

**Table A.7** *(continued)*

| Input quantity and/or source of uncertainty | Symbol | Units of measurement | Uncertainty of each factor | | | | Value of standard uncertainty $u(x_i)$ | Relative standard uncertainty of each value | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Measured value | Expanded uncertainty | Probability distribution | Divisor | | $\frac{p_i u(x_i)}{\lvert x_i \rvert}$ | |
| The net supply mass flow rate at station 2 | $qm_{2,net}$ | kg/s | 0,075 1 | 0,001 0 | Normal | 2 | 0,000 5 | $\frac{u(qm_{2,net})}{qm_{2,net}}$ | 0,67 % |
| Specific volume at leaving supply air (station 2 | $v_s$ | m³/kg | 0,820 | 0,010 | Normal | 2 | 0,005 0 | $\frac{u(v_s)}{v_s}$ | 0,61 % |
| **Power value of moving Air** | $\boldsymbol{P_{vma}}$ | **J/s** | **12,320 1** | ←**calculated value per Formula (29)** | | | | | |
| Formula (29) | $P_{vma} = \left( \sum_{n=1}^{4} \lvert ps_n + pv_n \rvert \right) 2qm_{2,net} v_s$ | | | | | By uncertainty budget | | Combined standard relative uncertainty $u(Y)/Y$ | 3,65 % |
| | | | | | | | | Expanded absolute uncertainty $U(Q)$ | 0,899 0 |
| | | | | | | | | Expanded relative uncertainty $U(Y)/Y$ | 7,30 % |
| **(rel)** | **Formula for relative uncertainty not provided because $u(P_{vma})$ *is used only in calculation of COE.*** | | | | | | | *For expanded uncertainty, coverage factor k = 2* | |

**Table A.8 — Uncertainty budget sheet for gross effectiveness, sensible $\varepsilon_{\text{sensible}}$**

| Input quantity and/or source of uncertainty | Symbol | Units of measurement | Uncertainty of each factor | | | | Value of standard uncertainty $u(x_i)$ | Relative standard uncertainty of each value | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Measured value | Expanded uncertainty | Probability distribution | Divisor | | $\frac{p_i u(x_i)}{\lvert x_i \rvert}$ | |
| Dry-bulb temperature at entering supply air (station 1) | $T_1$ | K | 308,2 | 0,100 0 | Normal | 2 | 0,050 0 | $1-\left\lvert\frac{(T_1-T_2-u(T_1))(T_1-T_3)}{(T_1-T_3-u(T_1))(T_1-T_2)}\right\rvert$ | 0,21 % |
| Dry-bulb temperature at leaving supply air (station 2) | $T_2$ | K | 300,2 | 0,100 0 | Normal | 2 | 0,050 0 | $\frac{u(T_2)}{\lvert T_1-T_2\rvert}$ | 0,63 % |
| Dry-bulb temperature at entering exhaust air (station 3) | $T_3$ | K | 296,2 | 0,100 0 | Normal | 2 | 0,050 0 | $1-\left\lvert\frac{(T_1-T_3)}{T_1-T_3-u(T_3)}\right\rvert$ | 0,42 % |
| **Gross effectiveness, sensible** | $e_{\text{sensible}}$ | % | **0,667** | **← calculated value per Formula (25)** | | | | | |
| Formula (25)[a] | $\varepsilon_{\text{sensible}}=\frac{T_1-T_2}{T_1-T_3}$ | | | | | By uncertainty budget | Combined standard relative uncertainty $u(Y)/Y$ | | 0,78 % |
| | | | | | | | Expanded absolute uncertainty $U(Q)$ | | 0,010 4 |
| | | | | | | | Expanded relative uncertainty $U(Y)/Y$ | | 1,56 % |
| (rel) | $\left(\frac{u(\varepsilon_{\text{sensible}})}{\varepsilon_{\text{sensible}}}\right)^2=\left(1-\frac{(T_1-T_2-u(T_1))(T_1-T_3)}{(T_1-T_3-u(T_1))(T_1-T_2)}\right)^2+\left(\frac{u(T_2)}{T_1-T_2}\right)^2+\left(1-\frac{(T_1-T_3)}{(T_1-T_3-u(T_3))}\right)^2$ | | | | | By formula at left | Combined standard relative uncertainty $u(Y)/Y$ | | 0,78 % |
| | | | | | | | Expanded relative uncertainty $U(Y)/Y$ | | 1,56 % |
| | | | | | | | *For expanded uncertainty, coverage factor k = 2* | | |

[a] "T" is substituted here for "x" to indicate these calculations are for sensible effectiveness.

**Table A.9 — Uncertainty budget sheet for gross effectiveness, latent $\varepsilon_{latent}$**

| Input quantity and/or source of uncertainty | Symbol | Units of measurement | Uncertainty of each factor | | | | Value of standard uncertainty $u(x_i)$ | Relative standard uncertainty of each value | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Measured value | Expanded uncertainty | Probability distribution | Divisor | | $\frac{p_i u(x_i)}{\lvert x_i \rvert}$ | |
| Absolute humidity ratio at entering supply air (station 1) | $W_1$ | $kg_w/kg_{da}$ | 0,017 9 | 0,000 1 | Normal | 2 | 0,000 05 | $1-\left\lvert\frac{(W_1-W_2-u(W_1))(W_1-W_3)}{(W_1-W_3-u(W_1))(W_1-W_2)}\right\rvert$ | 0,40 % |
| Absolute humidity ratio at leaving supply air (station 2) | $W_2$ | $kg_w/kg_{da}$ | 0,013 0 | 0,000 1 | Normal | 2 | 0,000 05 | $\frac{u(W_2)}{\lvert W_1-W_2\rvert}$ | 1,02 % |
| Absolute humidity ratio at entering exhaust air (station 3) | $W_3$ | $kg_w/kg_{da}$ | 0,009 9 | 0,000 1 | Normal | 2 | 0,000 05 | $1-\left\lvert\frac{(W_1-W_3)}{(W_1-W_3-u(W_3))}\right\rvert$ | 0,63 % |
| **Gross effectiveness, latent** | $e_{latent}$ | % | **0,613** | **← calculated value per Formula (25)** | | | | | |
| Formula (25)[a] | $\varepsilon_{latent}=\frac{W_1-W_2}{W_1-W_3}$ | | | | | By uncertainty budget | | Combined standard relative uncertainty $u(Y)/Y$ | 1,26 % |
| | | | | | | | | Expanded absolute uncertainty $U(Q)$ | 0,015 5 |
| | | | | | | | | Expanded relative uncertainty $U(Y)/Y$ | 2,53 % |
| (rel) | $\left(\frac{u(\varepsilon_{latent})}{\varepsilon_{latent}}\right)^2=\left(1-\frac{(W_1-W_2-u(W_1))(W_1-W_3)}{(W_1-W_3-u(W_1))(W_1-W_2)}\right)^2+\left(\frac{u(W_2)}{W_1-W_2}\right)^2+\left(1-\frac{(W_1-W_3)}{(W_1-W_3-u(W_3))}\right)^2$ | | | | | By formula at left | | Combined standard relative uncertainty $u(Y)/Y$ | 1,26 % |
| | | | | | | | | Expanded relative uncertainty $U(Y)/Y$ | 2,53 % |
| | | | | | | | | *For expanded uncertainty, coverage factor k = 2* | |

[a] "W" is substituted here for "x" to indicate these calculations are for latent effectiveness.

**Table A.10 — Uncertainty budget sheet for gross effectiveness, total $\varepsilon_{total}$**

| Input quantity and/or source of uncertainty | Symbol | Units of measurement | Uncertainty of each factor | | | | Value of standard uncertainty $u(x_i)$ | Relative standard uncertainty of each value | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Measured value | Expanded uncertainty | Probability distribution | Divisor | | $\frac{p_i u(x_i)}{\lvert x_i \rvert}$ | |
| Enthalpy at entering supply air (station 1) | $h_1$ | $kJ/kg_{da}$ | 81,100 0 | 0,250 0 | Normal | 2 | 0,125 0 | $1-\left\lvert\frac{(h_1-h_2-u(h_1))(h_1-h_3)}{(h_1-h_3-u(h_1))(h_1-h_2)}\right\rvert$ | 0,30 % |
| Enthalpy at leaving supply air (station 2) | $h_2$ | $kJ/kg_{da}$ | 62,600 0 | 0,250 0 | Normal | 2 | 0,125 0 | $\frac{u(h_2)}{\lvert h_1-h_2\rvert}$ | 0,68 % |
| Enthalpy at entering exhaust air (station 3 | $h_3$ | $kJ/kg_{da}$ | 48,300 0 | 0,250 0 | Normal | 2 | 0,125 0 | $1-\left\lvert\frac{(h_1-h_3)}{(h_1-h_3-u(h_3))}\right\rvert$ | 0,38 % |
| **Gross effectiveness, total** | $e_{total}$ | **%** | **0,564 0** | **← calculated value per Formula (25)** | | | | | |
| Formula (25)[a] | $\varepsilon_{total}=\frac{h_1-h_2}{h_1-h_3}$ | | | | | By uncertainty budget | | Combined standard relative uncertainty $u(Y)/Y$ | 0,83 % |
| | | | | | | | | Expanded absolute uncertainty $U(Q)$ | 0,009 4 |
| | | | | | | | | Expanded relative uncertainty $U(Y)/Y$ | 1,66 % |
| (rel) | $\left(\frac{u(\varepsilon_{total})}{\varepsilon_{total}}\right)^2=\left(1-\frac{(h_1-h_2-u(h_1))(h_1-h_3)}{(h_1-h_3-u(h_1))(h_1-h_2)}\right)^2+\left(\frac{u(h_2)}{h_1-h_2}\right)^2+\left(1-\frac{(h_1-h_3)}{(h_1-h_3-u(h_3))}\right)^2$ | | | | | By formula at left | | Combined standard relative uncertainty $u(Y)/Y$ | 0,83 % |
| | | | | | | | | Expanded relative uncertainty $U(Y)/Y$ | 1,66 % |
| | | | | | | | | *For expanded uncertainty, coverage factor k = 2* | |

[a] "h" is substituted here for "x" to indicate these calculations are for total effectiveness.

**Table A.11 — Uncertainty budget sheet for coefficient of energy, ducted ventilator, total $COE_{ducted}$**

| Input quantity and/or source of uncertainty | Symbol | Units of measurement | Uncertainty of each factor | | | | Value of standard uncertainty $u(x_i)$ | Relative standard uncertainty of each value | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Measured value | Expanded uncertainty | Probability distribution | Divisor | | $\frac{p_i u(x_i)}{\lvert x_i \rvert}$ | |
| Net supply airflow rate | $qm_{2,net}$ | kg/s | 0,075 1 | 0,001 0 | Normal | 2 | 0,000 5 | $\frac{u(qm_{2,net})\lvert h_2 - h_1 \rvert 1\,000}{qm_{2,net}\lvert h_2 - h_1 \rvert 1\,000 + P_{vma}}$ | 0,69 % |
| Enthalpy at leaving supply air (station 2) | $h_2$ | kJ/kg of dry air | 81,100 0 | 0,250 0 | Normal | 2 | 0,125 0 | $\frac{qm_{2,net} u(h_1) 1\,000}{qm_{2,net}\lvert h_2 - h_1 \rvert 1\,000 + P_{vma}}$ | 0,67 % |
| Enthalpy at entering supply air (station 1) | $h_1$ | kJ/kg of dry air | 62,600 0 | 0,250 0 | Normal | 2 | 0,125 0 | $\frac{qm_{2,net} u(h_2) 1\,000}{qm_{2,net}\lvert h_2 - h_1 \rvert 1\,000 + P_{vma}}$ | 0,67 % |
| Power value of moving air | $P_{vma}$ | (W) | 12,316 4 | 0,073 0 | Normal | 2 | 0,036 5 | $\frac{u(P_{vma})}{qm_{2,net}\lvert h_2 - h_1 \rvert 1\,000 + P_{vma}}$ | 0,003 % |
| Power input to unit | $P_{in}$ | W | 110,000 | 1,10 | Normal | 2 | 0,550 0 | $\frac{u(P_{in}) P_{in}}{P_{in}^{\ 2} - u(P_{in}) P_{in}}$ | 0,50 % |
| **Coefficient of energy, total, ducted** | ***COE*** | **W/W** | **12,746 2** | **← calculated value per Formula (27)** | | | | | |
| Formula (27) | $COE_{DUCTED} = \frac{(\lvert qm_{2,net}(h_2 - h_1)\rvert \times 1\,000) + P_{vma}}{P_{in}}$ | | | | | By uncertainty budget | | Combined standard relative uncertainty $u(Y)/Y$ | 1,28 % |
| | | | | | | | | Expanded absolute uncertainty $U(Q)$ | 0,325 3 |
| | | | | | | | | Expanded relative uncertainty $U(Y)/Y$ | 2,55 % |

**Table A.11** *(continued)*

<table>
<tr>
<td rowspan="3">(rel)</td>
<td rowspan="3">$\left(\frac{U\left(COE_{\text{ducted}}\right)}{COE_{\text{ducted}}}\right)^2 = \left(\frac{u\left(qm_{2,\text{net}}\right)\left|h_2 - h_1\right|1\,000}{qm_{2,\text{net}}\left|h_2 - h_1\right|1\,000 + P_{\text{vma}}}\right)^2 +$<br>$\left(\frac{qm_{2,\text{net}}u\left(h_1\right)1\,000}{qm_{2,\text{net}}\left|h_2 - h_1\right|1\,000 + P_{\text{vma}}}\right)^2 + \left(\frac{qm_{2,\text{net}}u\left(h_2\right)1\,000}{qm_{2,\text{net}}\left|h_2 - h_1\right|1\,000 + P_{\text{vma}}}\right)^2 +$<br>$\left(\frac{u\left(P_{\text{vma}}\right)}{qm_{2,\text{net}}\left|h_2 - h_1\right|1\,000 + P_{\text{vma}}}\right)^2 + \left(\frac{u\left(P_{\text{in}}\right)P_{\text{in}}}{P_{\text{in}}{}^2 - u\left(P_{\text{in}}\right)P_{\text{in}}}\right)^2$</td>
<td rowspan="3">By formula at left</td>
<td>Combined standard relative uncertainty $u(Y)/Y$</td>
<td>1,28 %</td>
</tr>
<tr>
<td>Expanded relative uncertainty $U(Y)/Y$</td>
<td>2,55 %</td>
</tr>
<tr>
<td colspan="2">For expanded uncertainty, coverage factor k = 2</td>
</tr>
</table>

**Table A.12 — Uncertainty budget for coefficient of energy, ducted ventilator, sensible $COE_{\text{ducted,sensible}}$**

| Input quantity and/or source of uncertainty | Symbol | Units of measurement | Uncertainty of each factor | | | | Value of standard uncertainty $u(x_i)$ | Relative standard uncertainty of each value | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Measured value | Expanded uncertainty | Probability distribution | Divisor | | $\frac{p_i u(x_i)}{\lvert x_i \rvert}$ | |
| Net supply airflow rate | $qm_{2,\text{net}}$ | kg/s | 0,075 1 | 0,001 0 | Normal | 2 | 0,000 5 | $\frac{u(qm_{2,\text{net}})C_p(T_2-T_1)\times 1\,000}{qm_{2,\text{net}}(T_2-T_1)\times 1\,000+P_{\text{vma}}}$ | 0,68 % |
| Specific heat of air | $C_p$ | kJ/kgK | 1,005 | 0,001 0 | Normal | 2 | 0,000 5 | $\frac{qm_{2,\text{net}}u(C_p)(T_2-T_1)\times 1\,000}{qm_{2,\text{net}}C_p(T_2-T_1)\times 1\,000+P_{\text{vma}}}$ | 0,05 % |
| Drybulb temperature at entering supply air (station 1 | $T_1$ | K | 300,200 0 | 0,100 0 | Normal | 2 | 0,050 0 | $\frac{qm_{2,\text{net}}u(T)1\,000}{\lvert qm_{2,\text{net}}C_p(T_2-T_1)\times 1\,000+P_{\text{vma}}\rvert}$ | 0,61 % |
| Drybulb temperature at leaving supply air (station 2) | $T_2$ | K | 308,200 0 | 0,100 0 | Normal | 2 | 0,050 0 | $\frac{qm_{2,\text{net}}u(T_1)1\,000}{\lvert qm_{2,\text{net}}C_p(T_2-T_1)\times 1\,000+P_{\text{vma}}\rvert}$ | 0,61 % |
| Power value of moving air | $P_{\text{vma}}$ | W | 12,316 4 | 0,073 0 | Normal | 2 | 0,036 5 | $\frac{u(P_{\text{vma}})}{\lvert qm_{2,\text{net}}C_p(T_2-T_1)\times 1\,000+P_{\text{vma}}\rvert}$ | 0,01 % |
| Power input to unit | $P_{\text{in}}$ | W | 110, | 1,100 0 | Normal | 2 | 0,550 0 | $\frac{u(P_{\text{in}})P_{\text{in}}}{P_{\text{in}}^{\;2}-u(P_{\text{in}})P_{\text{in}}}$ | 0,50 % |
| **Coefficient of energy, ducted, sensible** | $COE_{\text{ducted,sensible}}$ | **W/W** | **5,602 7** | **← calculated value per Formula (27)** | | | | | |
| Formula (27)[a] | $COE_{\text{DUCTED,sensible}} = \frac{(\lvert qm_{2,\text{net}}C_p(T_2-T_1)\rvert\times 1\,000)+P_{\text{vma}}}{P_{\text{in}}}$ | | | | | By Uncertainty Budget | | Combined standard relative uncertainty $u(Y)/Y$ | 1,21 % |
| | | | | | | | | Expanded absolute uncertainty $U(Q)$ | 0,135 7 |
| | | | | | | | | Expanded relative uncertainty $U(Y)/Y$ | 2,42 % |

[a] "$C_p(T_2-T_1)$" is substituted here for "$(h_2-h_1)$" to provide calculations for sensible effectiveness.

**Table A.12** *(continued)*

| | | | | |
|---|---|---|---|---|
| (rel) | $\left(\frac{u\left(COE_{\text{ducted,sensible}}\right)}{COE_{\text{ducted,sensible}}}\right)^2 = \left(\frac{u\left(qm_{2,\text{net}}\right)C_\text{p}\left(T_2-T_1\right)\times 1\,000}{qm_{2,\text{net}}\left(T_2-T_1\right)\times 1\,000+P_\text{vma}}\right)^2+\left(\frac{qm_{2,\text{net}}u\left(T_1\right)1\,000}{qm_{2,\text{net}}C_\text{p}\left(T_2-T_1\right)\times 1\,000+P_\text{vma}}\right)^2+\left(\frac{qm_{2,\text{net}}u\left(T\right)1\,000}{qm_{2,\text{net}}C_\text{p}\left(T_2-T_1\right)\times 1\,000+P_\text{vma}}\right)^2+\left(\frac{u\left(P_\text{vma}\right)}{qm_{2,\text{net}}C_\text{p}\left(T_2-T_1\right)\times 1\,000+P_\text{vma}}\right)^2+\left(\frac{u\left(P_\text{in}\right)P_\text{in}}{P_\text{in}^{\;2}-u\left(P_\text{in}\right)P_\text{in}}\right)^2+\left(\frac{qm_{2,\text{net}}\,u\left(C_\text{p}\right)\left(T_2-T_1\right)\times 1\,000}{qm_{2,\text{net}}\,C_\text{p}\left(T_2-T_1\right)\times 1\,000+P_\text{vma}}\right)^2$ | By formula at left | Combined standard relative uncertainty $u(Y)/Y$ | 1,21 % |
| | | | Expanded relative uncertainty $U(Y)/Y$ | 2,42 % |
| | | | *For expanded uncertainty, coverage factor k = 2* | |

[a] "$C_p(T_2$-$T_1)$" is substituted here for "$(h_2$-$h_1)$" to provide calculations for sensible effectiveness.

**Table A.13 — Uncertainty budget sheet for coefficient of energy, total, unducted ventilator $COE_{\text{unducted}}$**

| Input quantity and/or source of uncertainty | Symbol | Units of measurement | Uncertainty of each factor | | | | Value of standard uncertainty $u(x_i)$ | Relative standard uncertainty of each value | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Measured value | Expanded uncertainty | Probability distribution | Divisor | | $\frac{p_i u(x_i)}{\lvert x_i \rvert}$ | |
| Net supply airflow rate | $qm_{2,\text{net}}$ | kg/s | 0,075 1 | 0,004 4 | Normal | 2 | 0,000 5 | $= \frac{u(qm_{2,\text{net}})\lvert h_2 - h_1 \rvert 1\,000}{qm_{2,\text{net}} \lvert h_2 - h_1 \rvert 1\,000}$ | 0,70 % |
| Enthalpy at leaving supply air (station 2) | $h_2$ | kJ/kg$_{\text{da}}$ | 81,1 | 1,622 | Normal | 2 | 0,125 0 | $= \frac{qm_{2,\text{net}} u(h_1) 1\,000}{qm_{2,\text{net}} \lvert h_2 - h_1 \rvert 1\,000}$ | 0,68 % |
| Enthalpy at entering supply air (station 1) | $h_1$ | kJ/kg$_{\text{da}}$ | 62,6 | 1,252 | Normal | 2 | 0,125 0 | $= \frac{qm_{2,\text{net}} u(h_2) 1\,000}{qm_{2,\text{net}} \lvert h_2 - h_1 \rvert 1\,000}$ | 0,68 % |
| Power input to unit | $P_{\text{in}}$ | W | 110 | 1,10 | Normal | 2 | 0,550 0 | $= \frac{u(P_{\text{in}}) P_{\text{in}}}{P_{\text{in}}^2 - u(P_{\text{in}}) P_{\text{in}}}$ | 0,50 % |
| **Coefficient of energy, unducted, total** | ***COE*** | **W/W** | **12,634 2** | **← calculated value per Formula (36)** | | | | | |
| Formula (36) | $COE_{\text{unducted}} = \frac{\left(\lvert qm_{2,\text{net}} (h_2 - h_1) \rvert \times 1\,000\right)}{P_{\text{in}}}$ | | | | | By uncertainty budget | | Combined standard relative uncertainty $u(Y)/Y$ | 1,29 % |
| | | | | | | | | Expanded absolute uncertainty $U(Q)$ | 0,324 8 |
| | | | | | | | | Expanded relative uncertainty $U(Y)/Y$ | 2,58 % |
| (rel) | $\left(\frac{U(COE_{\text{unducted}})}{COE_{\text{unducted}}}\right)^2 = \left(\frac{u(qm_{2,\text{net}})\lvert h_2 - h_1 \rvert 1\,000}{qm_{2,\text{net}} \lvert h_2 - h_1 \rvert 1\,000}\right)^2 + \left(\frac{qm_{2,\text{net}} u(h_1) 1\,000}{qm_{2,\text{net}} \lvert h_2 - h_1 \rvert 1\,000}\right)^2 + \left(\frac{qm_{2,\text{net}} u(h_2) 1\,000}{qm_{2,\text{net}} \lvert h_2 - h_1 \rvert 1\,000}\right)^2 + \left(\frac{u(P_{\text{in}}) P_{\text{in}}}{P_{\text{in}}^2 - u(P_{\text{in}}) P_{\text{in}}}\right)^2$ | | | | | By formula at left | | Combined standard relative uncertainty $u(Y)/Y$ | 1,29 % |
| | | | | | | | | Expanded relative uncertainty $U(Y)/Y$ | 2,58 % |
| | | | | | | | | *For expanded uncertainty, coverage factor k = 2* | |