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Guidelines for the evaluation of uncertainty of measurement in air conditioner and heat pump cooling and heating capacity tests

Lignes directrices pour l'évaluation de l'incertitude de mesure lors des essais de puissance frigorifique et calorifique des climatiseurs et des pompes à chaleur

Reference number
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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In other circumstances, particularly when there is an urgent market requirement for such documents, a technical committee may decide to publish other types of document:

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Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TS 16491 was prepared by Technical Committee ISO/TC 86, *Refrigeration and air-conditioning*, Subcommittee SC 6, *Air-cooled air conditioners and air-to-air heat pumps*.

Introduction

This Technical Specification is intended to be a practical guide to assist laboratory personnel in evaluating the uncertainties in the measurement of the cooling and heating capacities of air conditioners and heat pumps. 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.

Guidelines for the evaluation of uncertainty of measurement in air conditioner and heat pump cooling and heating capacity tests

1 Scope

This Technical Specification gives guidance on the practical applications of the principles of performance measurement of air-cooled air-conditioners and air-to-air heat pumps as described in ISO 5151, ISO 13253, and ISO 15042.

2 Normative references

The following referenced documents are indispensable for the application 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/IEC Guide 99, *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement* (GUM:1995)

ISO 3534-1, *Statistics — Vocabulary and symbols — Part 1: General statistical terms and terms used in probability*

ISO 5151, *Non-ducted air conditioners and heat pumps — Testing and rating for performance*

ISO 13253, *Ducted air-conditioners and air-to-air heat pumps — Testing and rating for performance*

ISO 15042, *Multiple split-system air-conditioners and air-to-air heat pumps — Testing and rating for performance*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC Guide 99, ISO/IEC Guide 98-3, ISO 3534-1, ISO 5151, ISO 13253 and ISO 15042 apply.

NOTE The definitions of terms 3.1, 3.2, 3.3, 3.4 and 3.5 are taken from ISO/IEC Guide 99:2007, 2.39, 4.14, 2.53, 4.21 and 4.19, respectively, and they are repeated here for easy reference.

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

[SOURCE: ISO/IEC Guide 99:2007, 2.39]

3.2
resolution
smallest change in a quantity being measured that causes a perceptible change in the corresponding indication

[SOURCE: ISO/IEC Guide 99:2007, 4.14]

NOTE In the case of a digital instrument, this value corresponds to the value of the least significant digit of the reading of the instrument. This value might be different on the overall range of an instrument.

3.3
correction
modification applied to a measured quantity value to compensate for a known systematic effect

[SOURCE: ISO/IEC Guide 99:2007, 2.53, modified]

3.4
(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

[SOURCE: ISO/IEC Guide 99:2007, 4.21, modified]

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

[SOURCE: ISO/IEC Guide 99:2007, 4.19, modified]

3.6
uncertainty due to the lack of homogeneity
component specific to air temperature measurements where several probes are used simultaneously

NOTE In this case the air temperature value used in the calculation of heat power is the mean of the measurements of the different probes.

3.7 Type of error evaluation

3.7.1
type A evaluation of standard uncertainty
evaluation of standard uncertainty based on any valid statistical method for treating data

NOTE 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.

3.7.2
type B evaluation of standard uncertainty
evaluation of standard uncertainty that is usually based on scientific judgment using all the relevant information available

NOTE 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.

4 Symbols

For the purposes of this document, the symbols defined in ISO 5151, ISO 13253 and ISO 15042 and the following apply.

Symbol	Description	Unit
e	water vapour partial pressure	Pa
$e_w(T_d)$	water vapour partial pressure at T_d	Pa
f_w	enhancement factor, considered as a constant value equal to 1	—
$K_{S,i}$	heat leakage coefficient between the indoor side compartment of the calorimeter and its surroundings	W·K-1
$K_{S,o}$	heat leakage coefficient between the outdoor side compartment of the calorimeter and its surroundings	W·K-1
$K_{S,p}$	heat leakage coefficient between indoor side and outdoor side compartments of the calorimeter through the separating partition	W·K-1
m_a	dry air mass	kg
M_a	dry air mass molar	molar (kg·mol-1)
M_v	water vapour mass molar	molar (kg·mol-1)
N	number of sensors	—
N_T	number of values recorded during the acquisition time	—
p	atmospheric pressure	Pa
p_a	dry air partial pressure	Pa
p_w	water vapour partial pressure at wet-bulb temperature T_w	Pa
q_{iw}	water flow rate through the coil of the indoor side compartment of the calorimeter	kg/s
q_{ow}	water flow rate through the coil of the outdoor side compartment of the calorimeter	kg/s
R	perfect gas constant	—
T	air dry bulb temperature	°C
T_d	air dew point temperature	°C
T_i	value measured by the sensor i	—
T_m	mean value measured by N sensors	—
T_{iam}	air temperature in the indoor side compartment of the calorimeter	°C
T_{oam}	air temperature in the outdoor side compartment of the calorimeter	°C
T_{iscm}	air temperature in the surroundings of the indoor side compartment of the calorimeter	°C
T_{oscm}	air temperature in the surroundings of the outdoor side compartment of the calorimeter	°C
T_{iwi}	water inlet temperature to coil of the indoor side compartment of the calorimeter	°C
T_{iwo}	water outlet temperature to coil of the indoor side compartment of the calorimeter	°C
T_{owi}	water inlet temperature to coil of the outdoor side compartment of the calorimeter	°C
T_{owo}	water outlet temperature to coil of the outdoor side compartment of the calorimeter	°C
$U(C_I)$	indirect contribution to expanded uncertainty	W
$u(C_I)$	indirect contribution to standard uncertainty	W
V	dry air volume	m^3
δ	ratio of the water vapour mass molar to the dry air mass molar (0,62198)	—

5 Method of calculation

5.1 Calibration

This value is given in the calibration certificate.

This value is the calibration uncertainty which takes into account the reference instrument and the calibrated instrument. The calibration uncertainty shall be at a confidence level of at least 95 %.

5.2 Correction

This quantity concerns here the calibration correction.

If this calibration correction is applied on the raw measurement of the instrument through a modelisation curve, this term is the maximum difference between the correction model and the calibration results. If no correction is applied on the raw measurement of the instrument, this correction is linearly added to the expanded measurement uncertainty.

5.3 (Instrumental) drift

This value is calculated as the difference in successive calibration corrections.

5.4 Stability

The quantity is generally a mean of several instantaneous data measured in a given period of time. The uncertainty component due to stability is calculated as the standard deviation of the instantaneous measurements, and the standard uncertainty of the mean value is defined as this standard deviation divided by the square root of the number of recorded data.

5.5 Uncertainty due to the lack of homogeneity

The uncertainty component due to homogeneity is calculated as the standard deviation of the individual measurements, and the standard uncertainty of the mean value is defined as this standard deviation divided by the square root of the number of probes.

6 Explanatory notes useful in laboratory application

6.1 Uncertainty

No measurement of a real quantity can be exact; there is always some error involved in the measurement. Errors 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. The likely magnitude of this error in measurement is known as the uncertainty. 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 %).

6.2 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.

6.3 Evaluation of errors

Two types of error evaluation are recognized by ISO Guide 98-3. A type A evaluation involves statistical methods of evaluation of the errors, 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 errors in the measurement.

6.4 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 model of the measurement system must be 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 error to the final measurement error.

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 cooling capacity of an air-conditioner (in kilowatts, kW) will involve the measurement of temperatures (in degrees Celsius, °C) or temperature differences (in Kelvin, K). In these cases, it is necessary to determine weighting factors to describe the effect that errors 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 must be combined to give the overall uncertainty in the final measurement.

6.5 Uncertainty of measurements

6.5.1 Uncertainty of individual measurements

The uncertainty of measurement of each individual measurement shall 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 6.5.1 NOTE 1 and NOTE 2)	— (see 6.5.1 NOTE 1 and NOTE 2)	u_3 (see 6.5.1 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	$\sqrt{N_T}$	$\frac{S_5}{\sqrt{N_T}}$

[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:

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

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:

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

NOTE 2 It should be avoided that the uncertainty is enlarged with no correction. However, if the correction value is small compared to the uncertainty, there may be a case where correction is not needed. If the value of the calibration correction U_3 is entered in Equation (2), then $u_3 = 0$.

6.5.2 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 equation:

$$T_m = \frac{\sum_{i=1}^{N} T_i}{N} \tag{3}$$

The uncertainty of this mean value shall 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:

$$u(T_m) = \sqrt{\left(\frac{\sum_{i=1}^{N} u(T_i)}{N}\right)^2 + \left(\frac{s}{\sqrt{N}}\right)^2},$$

leading to:

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

where

$u(T_m)$ is the standard uncertainty on the mean value;

$U(T_m)$ is the expanded uncertainty on the mean value;

$u(T_i)$ is the standard measurement uncertainty of the sensor i, determined according to Table 1;

$U(T_i)$ 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 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 equation:

$$u_c^2(y) = \left(\sum_{i=1}^{N} c_i u(x_i) \right)^2$$

leads to, for the mean value, $u(T_m) = \left(\sqrt{\left(\sum_{i=1}^{N} u(T_i) \right)^2} \right) \Big/ N = \sqrt{\left(\sum_{i=1}^{N} u(T_i) \Big/ N \right)^2}$.

6.5.3 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:

$$u^2(V(m))$$

shall be replaced by:

$$\left[\left(\frac{\partial V}{\partial m} \Big| m_i \right)^2 \cdot u^2(m_i) + u_{smooth}^2(V(m)) \right] \quad (5)$$

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;

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

7 Evaluation of uncertainty — Calorimeter room method

This Clause describes general procedures and examples of the evaluation of uncertainties of total cooling capacity and heating capacity of a unit when tested using the calorimeter room method.

For calorimeter room method, the uncertainty is developed in absolute value because the equation of cooling/heating capacity is a sum of terms, which makes the expression of absolute uncertainty easier to write.

In the following clauses, the absolute standard uncertainty is determined, allowing to calculate both absolute and relative uncertainty as follows.

The expanded uncertainty is calculated as follows:

$$U\left(\phi_x\right) = 2 \times u_{\mathrm{c}}(\phi_x) \quad (6)$$

And the relative expanded uncertainty is obtained by dividing the expanded uncertainty by ϕ_x

where ϕ_x corresponds to:

— ϕ_{tci} in Equation (10),

— ϕ_{tco} in Equation (16),

— ϕ_{hi} in Equation (22), and

— ϕ_{ho} in Equation (27).

NOTE Similar calculation methods may be used to evaluate uncertainty of latent and/or sensible cooling capacity.

7.1 Cooling capacity test

7.1.1 Measured parameters affecting test result (in order of importance)

7.1.1.1 Cooling capacity measurement

— Heater power to calorimeter.

— Auxiliary power to calorimeter, including fans, lighting, etc.

— Humidifier input (this may be included in heater power).

— Indoor and outdoor wet-bulb temperature.

— Indoor and outdoor dry-bulb temperature.

— Calculation of losses through separating partition.

— Calculation of losses through other walls (will be more significant with calibrated-room method).

— Evaluation of losses between power measurement point and the boundary of calorimeter. These losses may occur where power measurements are made at a point remote from the calorimeter boundary leading to unknown losses between the measurement point and the calorimeter boundary due to cable resistance.

— Condensed water flow rate from calorimeter.

— Condensed water temperature from calorimeter.

— Water flow rate entering the calorimeter.

— Water temperature entering the calorimeter.

7.1.1.2 Total power input measurement

— Electrical power.

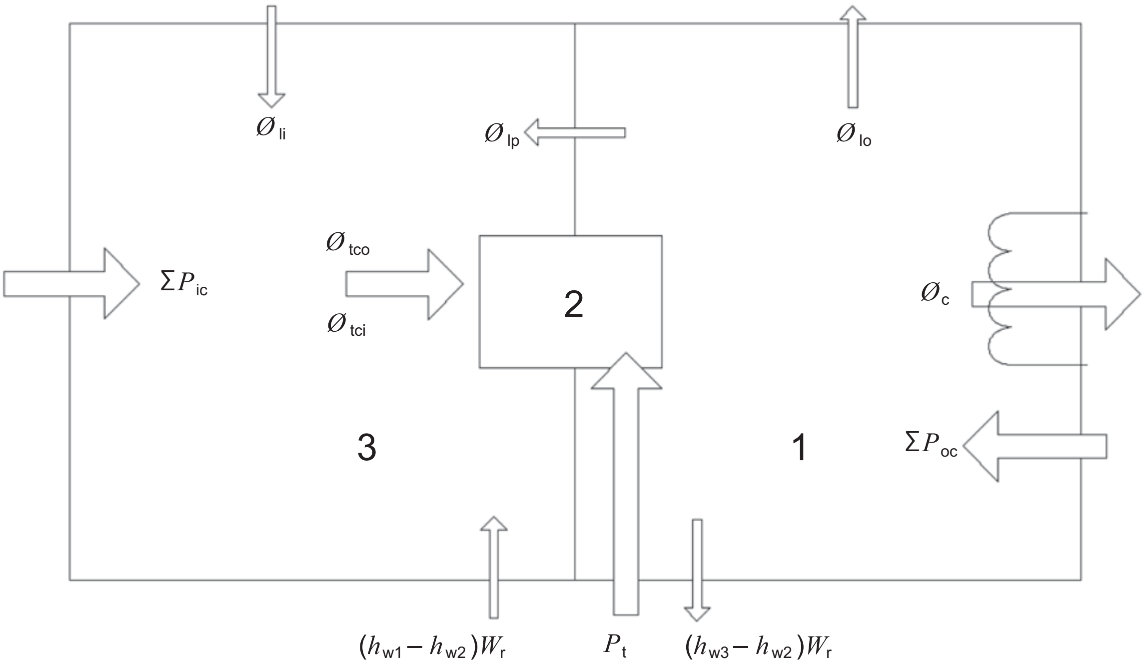
— Calculation of losses between measurement point and connection point of the unit under test. These losses may occur where power measurements are made at a point remote from the unit leading to unknown losses between the measurement point and the unit due to cable resistance.

7.1.2 Cooling capacity — Indoor side measurements

The total cooling capacity measured on the indoor side of the calorimeter is expressed as follows:

$$\phi_{\text{tci}} = \sum P_{\text{ic}} + \left(h_{\text{w1}} - h_{\text{w2}}\right) \cdot W_{\text{r}} + \phi_{\text{lp}} + \phi_{\text{li}} \tag{7}$$

according to the energy flows described in Figure 1.



Key

1 outdoor-side compartment

2 unit under test

3 indoor-side compartment

Figure 1 — Calorimeter energy flows — cooling mode

The definitions of the terms used are those given in ISO 5151.

Moreover, ϕ_{lp} is the heat leakage flow through the separating partition. This term is calculated as:

$$\phi_{\text{lp}} = K_{\text{S,p}} \cdot (T_{\text{oam}} - T_{\text{iam}}) \tag{8}$$

where $K_{\text{S,p}}$ is evaluated by calibration of the calorimeter room.

ϕ_{li} is the heat leakage flow through walls, floor, and ceiling out of the indoor-side compartment, calculated as:

$$\phi_{\text{li}} = K_{\text{S,i}} \cdot (T_{\text{iscm}} - T_{\text{iam}}) \tag{9}$$

where $K_{\text{S,i}}$ is evaluated by calibration of the calorimeter room.

7.1.2.1 Uncertainty calculation — General case

The combined standard uncertainty calculation is given by the general Equation (10).

As an example of calculation using Equation (10), Table A.1 is shown in Annex A.

$$\begin{aligned} u_{\text{c}}^2(\phi_{\text{tci}}) &= u^2(\Sigma P_{\text{ic}}) + W_{\text{r}}^2 u^2(h_{\text{w1}}) + W_{\text{r}}^2 u^2(h_{\text{w2}}) + (h_{\text{w1}} - h_{\text{w2}})^2 u^2(W_{\text{r}}) + \\ &(T_{\text{oam}} - T_{\text{iam}})^2 u^2(K_{\text{S,p}}) + (T_{\text{iscm}} - T_{\text{iam}})^2 u^2(K_{\text{S,i}}) + (K_{\text{S,p}})^2 u^2(T_{\text{oam}}) + \\ &(K_{\text{S,i}})^2 u^2(T_{\text{iscm}}) + (K_{\text{S,p}} + K_{\text{S,i}})^2 u^2(T_{\text{iam}}) + u^2(C_{\text{l}}) \end{aligned} \tag{10}$$

The term $u(C_{\text{l}})$ may be calculated according to Annex B. If the calculation is not made according to Annex B, a value of 1,5 % of the measured capacity shall be used for the standard uncertainty value $u(C_{\text{l}})$.

7.1.2.2 Uncertainty calculation — Specific cases

— In case individual power inputs for the different electrical components in the indoor side compartment are measured with different individual uncertainties, the term $u^2(\Sigma P_{\text{ic}})$ shall be replaced by a sum of individual terms:

$$u^2(\Sigma P_{\text{ic}}) = u^2(P_1) + u^2(P_2) + u^2(P_3) + \ldots \tag{11}$$

— In cases where a brine solution is used in the heat exchanger reconditioning system of the calorimeter room, an additional term due to the change of enthalpy of brine with temperature and density shall be included in Equation (10). When using water, this additional term is not required.

— In case of the use of additional auxiliary cooling and/or humidifying equipment, the corresponding uncertainty shall be added to the uncertainty measured using Equation (10).

7.1.3 Cooling capacity — Outdoor side measurements

The total cooling capacity measured on the outdoor side of the calorimeter is expressed as follows:

$$\phi_{\text{tco}} = \phi_{\text{c}} - \sum P_{\text{oc}} - P_{\text{t}} + (h_{\text{w3}} - h_{\text{w2}}) \cdot W_{\text{r}} + \phi_{\text{lp}} + \phi_{\text{lo}} \tag{12}$$

according to the energy flows described in Figure 1.

The definitions of the used terms are those given in ISO 5151.

Moreover, ϕ_{c} is the heat removed by the cooling coil in the outdoor side compartment, expressed as:

$$\phi_{\text{c}} = q_{\text{ow}} \cdot (h(T_{\text{owo}}) - h(T_{\text{owi}})) \tag{13}$$

And ϕ_{lp} is the heat leakage flow through the separating partition. This term is calculated as:

$$\phi_{\text{lp}} = K_{\text{S,p}} \cdot (T_{\text{oam}} - T_{\text{iam}}) \tag{14}$$

where $K_{S,p}$ is evaluated by calibration of the calorimeter room.

ϕ_{lo} is the heat leakage flow through walls, floor, and ceiling out of the outdoor side compartment. This term is calculated as:

$$\phi_{lo} = K_{S,o} \cdot (T_{oam} - T_{oscm}) \quad (15)$$

where $K_{S,o}$ is evaluated by calibration of the calorimeter room.

7.1.3.1 Uncertainty calculation — General case

The combined standard uncertainty calculation is given by the general equation:

$$\begin{aligned} u_c^2(\phi_{tco}) &= q_{ow}^2 \cdot u^2\left(h(T_{owo})\right) + q_{ow}^2 \cdot u^2\left(h(T_{owi})\right) + \left(h(T_{owo}) - h(T_{owi})\right)^2 \cdot u^2(q_{ow}) + \\ & u^2\left(\sum P_{oc}\right) + u^2(P_t) + W_r^2 u^2(h_{w3}) + W_r^2 u^2(h_{w2}) + (h_{w3} - h_{w2})^2 u^2(W_r) + \\ & (T_{oam} - T_{iam})^2 \cdot u^2(K_{S,p}) + (T_{oscm} - T_{oam})^2 \cdot u^2(K_{S,o}) + (K_{S,p} + K_{S,o})^2 \cdot u^2(T_{oam}) + \\ & (K_{S,p})^2 \cdot u^2(T_{iam}) + (K_{S,o})^2 \cdot u^2(T_{oscm}) + u^2(C_l) \end{aligned} \quad (16)$$

The term $u(C_l)$ may be calculated according to Annex B. If the calculation is not made according to Annex B, a value of 1,5 % of the measured capacity shall be used for the standard uncertainty value $u(C_l)$.

7.1.3.2 Uncertainty calculation — Specific cases

— In case individual power inputs for the different electrical components in the indoor side compartment are measured with different individual uncertainties, the term $u^2(\Sigma P_{oc})$ may be replaced by a sum of individual terms:

$$u^2(\sum P_{oc}) = u^2(P_1) + u^2(P_2) + u^2(P_3) + \ldots \quad (17)$$

— In cases where a brine solution is used in the heat exchanger reconditioning system of the calorimeter room, an additional term due to the change of enthalpy of brine with temperature and density shall be included in Equation (16). When using water, this additional term is not required.

7.2 Heating capacity test

7.2.1 Measured parameters affecting test result (in order of importance)

7.2.1.1 Heating capacity measurement

— coolant temperature difference

— coolant mass flow rate

— the specific heat of the coolant

— heater power

— auxiliary power to calorimeter, including fans, lighting, etc.

— outdoor wet-bulb temperature

— outdoor dry-bulb temperature

— indoor dry-bulb temperature

— indoor wet bulb temperature for units under test that evaporate moisture on the indoor side

— calculation of losses through the separating partition

— calculation of losses through other walls (will be more significant with calibrated-room method)

— calculation of losses between power measurement point and boundary of calorimeter. These losses may occur where power measurements are made at a point remote from the calorimeter boundary leading to unknown losses between the measurement point and the calorimeter boundary due to cable resistance.

7.2.1.2 Total power input measurement

— electrical power

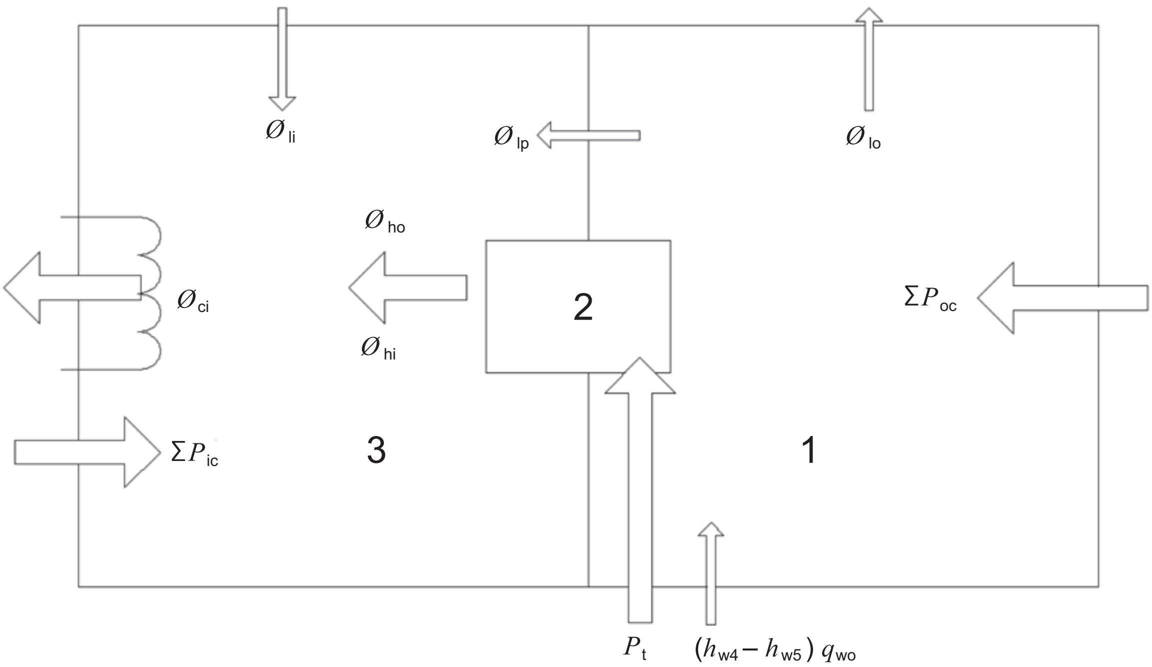
— calculation of losses between measurement point and connection point of the unit under test. These losses may occur where power measurements are made at a point remote from the unit leading to unknown losses between the measurement point and the unit due to cable resistance.

7.2.2 Heating capacity — Indoor side measurements

The total heating capacity measured on the indoor side of the calorimeter is expressed as follows:

$$\phi_{hi} = \phi_{ci} - \sum P_{ic} - \phi_{lp} - \phi_{li} \qquad (18)$$

according to the energy flows described in Figure 2.



Key

1 outdoor-side compartment

2 unit under test

3 indoor-side compartment

Figure 2 — Calorimeter energy flows — heating mode

The definitions of the used terms are those given in ISO 5151.

Moreover, ϕ_{ci} is the heat removed from the indoor side compartment, expressed as:

$$\phi_{ci} = q_{iw} \cdot \Delta H = q_{iw} \cdot \left(h(T_{iwo}) - h(T_{iwi}) \right) \tag{19}$$

And ϕ_{lp} is the heat leakage flow through the separating partition. This term is calculated as:

$$\phi_{lp} = K_{S,p} \cdot \left(T_{oam} - T_{iam} \right) \tag{20}$$

where $K_{S,p}$ is evaluated by calibration of the calorimeter room.

And ϕ_{li} is the heat leakage flow through walls, floor, and ceiling out of the indoor side compartment. This term is calculated as:

$$\phi_{li} = K_{S,i} \cdot \left(T_{iscm} - T_{iam} \right) \tag{21}$$

where $K_{S,i}$ is evaluated by calibration of the calorimeter room.

7.2.2.1 Uncertainty calculation — General case

The combined standard uncertainty calculation is given by the general Equation (22).

As an example of calculation using Equation (22), Table A.2 is shown in Annex A.

$$\begin{aligned} u_c^2\left(\phi_{hi}\right) &= \left(h\left(T_{iwo}\right) - h\left(T_{iwi}\right)\right)^2 \cdot u^2\left(q_{iw}\right) + q_{iw}^2 \cdot u^2\left(h\left(T_{iwo}\right)\right) + q_{iw}^2 \cdot u^2\left(h\left(T_{iwi}\right)\right) + \\ & u^2\left(\sum P_{ic}\right) + \left(T_{oam} - T_{iam}\right)^2 \cdot u^2\left(K_{S,p}\right) + \left(T_{iscm} - T_{iam}\right)^2 \cdot u^2\left(K_{S,i}\right) + \\ & \left(K_{S,p}\right)^2 \cdot u^2\left(T_{oam}\right) + \left(K_{S,i}\right)^2 \cdot u^2\left(T_{iscm}\right) + \left(K_{S,p} + K_{S,i}\right)^2 \cdot u^2\left(T_{iam}\right) + u^2\left(C_l\right) \end{aligned} \tag{22}$$

The term $u(C_l)$ may be calculated according to Annex B. If the calculation is not made according to Annex B, a value of 1,5 % of the measured capacity shall be used for the standard uncertainty value $u(C_l)$.

7.2.2.2 Uncertainty calculation — Specific cases

— In case individual power inputs for the different electrical components in the indoor side compartment are measured with different individual uncertainties, the term $u^2\left(\Sigma P_{ic}\right)$ may be replaced by a sum of individual terms:

$$u^2(\Sigma P_{ic}) = u^2\left(P_1\right) + u^2\left(P_2\right) + u^2(P_3) + \ldots \tag{23}$$

— In case of the use of a brine heat exchanger in the compensation system of the calorimeter room, an additional term due to the change of enthalpy of brine with temperature and density shall be included in Equation (22).

7.2.3 Heating capacity — Outdoor side measurements

The total heating capacity measured on the outdoor side of the calorimeter is expressed as follows:

$$\phi_{ho} = \sum P_{oc} + P_t + \left(h_{w4} - h_{w5}\right) \cdot q_{wo} - \phi_{lp} - \phi_{lo} \tag{24}$$

according to the energy flows described in Figure 2.

The definitions of the used terms are those given in ISO 5151.

Moreover, ϕ_{lp} is the heat leakage flow through the separating partition. This term is calculated as:

$$\phi_{\text{lp}} = K_{\text{S,p}} \cdot \left(T_{\text{oam}} - T_{\text{iam}}\right) \tag{25}$$

where $K_{\text{S,p}}$ is evaluated by calibration of the calorimeter room.

ϕ_{lo} is the heat leakage flow through walls, floor, and ceiling out of the outdoor side compartment. This term is calculated as:

$$\phi_{\text{lo}} = K_{\text{S,o}} \cdot \left(T_{\text{oam}} - T_{\text{oscm}}\right) \tag{26}$$

where $K_{\text{S,o}}$ is evaluated by calibration of the calorimeter room.

7.2.3.1 Uncertainty calculation — General case

The combined standard uncertainty calculation is given by the general Equation (27):

$$\begin{aligned} u_{\text{c}}^2\left(\phi_{\text{ho}}\right) = {} & u^2\left(\sum P_{\text{oc}}\right) + u^2\left(P_{\text{t}}\right) + \left(h_{\text{w4}} - h_{\text{w5}}\right)^2 \cdot u^2\left(q_{\text{wo}}\right) + q_{\text{wo}}^2 \cdot u^2\left(h_{\text{w4}}\right) + \\ & q_{\text{wo}}^2 \cdot u^2\left(h_{\text{w5}}\right) + \left(T_{\text{oam}} - T_{\text{iam}}\right)^2 \cdot u^2\left(K_{\text{S,p}}\right) + \left(T_{\text{oam}} - T_{\text{oscm}}\right)^2 \cdot u^2\left(K_{\text{S,o}}\right) + \\ & \left(K_{\text{S,p}}\right)^2 \cdot u^2\left(T_{\text{iam}}\right) + \left(K_{\text{S,o}}\right)^2 \cdot u^2\left(T_{\text{oscm}}\right) + \left(K_{\text{S,p}} + K_{\text{S,o}}\right)^2 \cdot u^2\left(T_{\text{oam}}\right) + u^2\left(C_{\text{l}}\right) \end{aligned} \tag{27}$$

The term $u(C_{\text{l}})$ may be calculated according to Annex B. If the calculation is not made according to Annex B, a value of 1,5 % of the measured capacity shall be used for the standard uncertainty value $u(C_{\text{l}})$.

In case of the use of a brine heat exchanger in the compensation system of the calorimeter room, an additional term due to the change of enthalpy of brine with temperature and density shall be included in Equation (27).

7.2.3.2 Uncertainty calculation — Specific cases

— In case individual power inputs for the different electrical components in the indoor side compartment are measured with different individual uncertainties, the term $u^2\left(\Sigma P_{\text{oc}}\right)$ may be replaced by a sum of individual terms:

$$u^2(\Sigma P_{\text{oc}}) = u^2\left(P_1\right) + u^2\left(P_2\right) + u^2(P_3) + \ldots \tag{28}$$

— In case of the use of a brine heat exchanger in the compensation system of the calorimeter room, an additional term due to the change of enthalpy of brine with temperature and density shall be included in Equation (27).

— In case of the use of additional auxiliary cooling and/or humidifying equipment, the corresponding uncertainty shall be added to the uncertainty measured using Equation (27).

8 Evaluation of uncertainty — Air enthalpy method

This clause describes general procedures and examples of the evaluation of uncertainties of total cooling capacity and heating capacity of a unit when tested using the air enthalpy method.

For the air enthalpy method, the cooling/heating capacity is expressed as the product of terms, which makes the expression of the uncertainty easier to write in relative value.

In the following clauses, the relative standard uncertainty is determined, allowing to calculate both relative and absolute uncertainty.

The relative expanded uncertainty is obtained by multiplying the relative standard uncertainty $u(\phi_x)/\phi_x$ by 2.

The expanded uncertainty is calculated as follows:

$$U(\phi_x) = 2 \times \left[\frac{u(\phi_x)}{\phi_x} \right] \times \phi_x = 2 \times u(\phi_x) \tag{29}$$

where ϕ_x corresponds to:

— ϕ_{tci} in Equations (33) and (35)

— ϕ_{thi} in Equations (39) and (41)

NOTE Similar calculation methods may be used to evaluate uncertainty of latent and/or sensible cooling capacity.

8.1 Cooling capacity test

According to ISO 5151 and ISO 13253, the total cooling capacity measured by the air enthalpy method is expressed as follows:

$$\phi_{\text{tci}} = \frac{q_{\text{vi}}\left(h_{\text{a1}} - h_{\text{a2}}\right)}{v'_{\text{n}}\left(1 + W_{\text{n}}\right)} = \frac{q_{\text{vi}}\left(h_{\text{a1}} - h_{\text{a2}}\right)}{v_{\text{n}}} \tag{30}$$

When $v_{\text{n}} = \dfrac{\delta \cdot R \cdot T}{M_{\text{v}}\left(p - e\right)}$, Equation (30) is expressed as follows:

$$\phi_{\text{tci}} = q_{\text{vi}}\left(h_{\text{a1}} - h_{\text{a2}}\right) \cdot \frac{M_{\text{v}}}{\delta \cdot R \cdot T} \cdot \left(p - e\right) \tag{31}$$

NOTE According to the equation of state for dry air: $p_{\text{a}}V = \dfrac{m_{\text{a}}R \cdot T}{M_{\text{a}}}$ and $\delta = \dfrac{M_{\text{v}}}{M_{\text{a}}}$, v_{n} is expressed as follows:

$$v_{\text{n}} = \frac{V}{m_{\text{a}}} = \frac{R \cdot T}{M_{\text{a}} p_{\text{a}}} = \frac{\delta \cdot R \cdot T}{M_{\text{v}} p_{\text{a}}} = \frac{\delta \cdot R \cdot T}{M_{\text{v}}\left(p - e\right)}$$

The calculation of the uncertainty of measurement of the total cooling capacity depends on the way the specific volume of air v'_{n} and the specific humidity of air W_{n} are determined from the following measurements of the air:

— dry bulb and wet bulb temperatures

— dry bulb and dew point temperatures

8.1.1 Uncertainty calculation with measurement of wet bulb temperature

When wet bulb temperature of the air is measured, $e = p_{\text{w}}$, Equation (31) is expressed as follows:

$$\phi_{\text{tci}} = q_{\text{vi}}\left(h_{\text{a1}} - h_{\text{a2}}\right) \cdot \frac{M_{\text{v}}}{\delta \cdot R \cdot T} \cdot \left(p - p_{\text{w}}\right) \tag{32}$$

The relative combined standard uncertainty calculation is given by the general Equation (33).

As an example of calculation using Equation (33), Table A.3 is shown in Annex A.

$$\left(\frac{u(\phi_{\text{tci}})}{\phi_{\text{tci}}}\right)^2 = \left(\frac{u(q_{\text{vi}})}{q_{\text{vi}}}\right)^2 + \left(\frac{u(h_{\text{a1}})}{(h_{\text{a1}}-h_{\text{a2}})}\right)^2 + \left(\frac{u(h_{\text{a2}})}{(h_{\text{a1}}-h_{\text{a2}})}\right)^2 + \left(\frac{u(T)}{T}\right)^2 + \left(\frac{u(p)}{p-p_{\text{w}}}\right)^2 + \left(\frac{u(p_{\text{w}})}{p-p_{\text{w}}}\right)^2 + \left(\frac{u(C_{\text{l}})}{\phi_{\text{tci}}}\right)^2 \quad (33)$$

The term $u(C_{\text{l}})$ may be calculated according to Annex B. If the calculation is not made according to Annex B, a value of 1,5 % of the measured capacity shall be used for the standard uncertainty value $u(C_{\text{l}})$.

8.1.2 Uncertainty calculation with measurement of dew point temperature

When dew point temperature of the air is measured, $e = f_{\text{w}} \cdot e_{\text{w}}(T_{\text{d}})$, Equation (31) is expressed as follows:

$$\phi_{\text{tci}} = q_{\text{vi}}\left(h_{\text{a1}}-h_{\text{a2}}\right)\cdot\frac{M_{\text{v}}}{\delta\cdot R\cdot T}\cdot\left(p-f_{\text{w}}.e_{\text{w}}\left(T_{\text{d}}\right)\right) \quad (34)$$

where the relative combined standard uncertainty calculation is given by the general Equation (35):

$$\left(\frac{u(\phi_{\text{tci}})}{\phi_{\text{tci}}}\right)^2 = \left(\frac{u(q_{\text{vi}})}{q_{\text{vi}}}\right)^2 + \left(\frac{u(h_{\text{a1}})}{(h_{\text{a1}}-h_{\text{a2}})}\right)^2 + \left(\frac{u(h_{\text{a2}})}{(h_{\text{a1}}-h_{\text{a2}})}\right)^2 + \left(\frac{u(T)}{T}\right)^2 + \left(\frac{u(p)}{p-f_{\text{w}}\cdot e_{\text{w}}(T_{\text{d}})}\right)^2 + \left(\frac{e_{\text{w}}(T_{\text{d}})\cdot u(f_{\text{w}})}{p-f_{\text{w}}\cdot e_{\text{w}}(T_{\text{d}})}\right)^2 + \left(\frac{f_{\text{w}}\cdot u(e_{\text{w}}(T_{\text{d}}))}{p-f_{\text{w}}\cdot e_{\text{w}}(T_{\text{d}})}\right)^2 + \left(\frac{u(C_{\text{l}})}{\phi_{\text{tci}}}\right)^2 \quad (35)$$

The term $u(C_{\text{l}})$ may be calculated according to Annex B. If the calculation is not made according to Annex B, a value of 1,5 % of the measured capacity shall be used for the standard uncertainty value $u(C_{\text{l}})$.

8.2 Heating capacity test

According to ISO 5151 and ISO 13253, the heating capacity measured by the air enthalpy method is expressed as follows:

$$\phi_{\text{thi}} = \frac{q_{\text{vi}}\left(c_{\text{pa2}}t_{\text{a2}}-c_{\text{pa1}}t_{\text{a1}}\right)}{v'_{\text{n}}\left(1+W_{\text{n}}\right)} = \frac{q_{\text{vi}}\left(c_{\text{pa2}}t_{\text{a2}}-c_{\text{pa1}}t_{\text{a1}}\right)}{v_{\text{n}}} \quad (36)$$

When $v_{\text{n}} = \dfrac{\delta\cdot R\cdot T}{M_{\text{v}}\left(p-e\right)}$, Equation (36) is expressed as follows:

$$\phi_{\text{thi}} = q_{\text{vi}}\left(c_{\text{pa2}}t_{\text{a2}}-c_{\text{pa1}}t_{\text{a1}}\right)\cdot\frac{M_{\text{v}}}{\delta\cdot R\cdot T}\cdot\left(p-e\right) \quad (37)$$

NOTE According to the equation of state for dry air: $p_{\text{a}}V = \dfrac{m_{\text{a}}R\cdot T}{M_{\text{a}}}$ and $\delta = \dfrac{M_{\text{v}}}{M_{\text{a}}}$, v_{n} is expressed as follows:

$$v_{\text{n}} = \frac{V}{m_{\text{a}}} = \frac{R\cdot T}{M_{\text{a}}p_{\text{a}}} = \frac{\delta\cdot R\cdot T}{M_{\text{v}}p_{\text{a}}} = \frac{\delta\cdot R\cdot T}{M_{\text{v}}\left(p-e\right)}$$

The calculation of the uncertainty of measurement of the heating capacity depends on the way the specific volume of air v'_{n} and the specific humidity of air W_{n} are determined from the following measurements of the air:

— dry bulb and wet bulb temperatures

— dry bulb and dew point temperatures

8.2.1 Uncertainty calculation with measurement of wet bulb temperature

When wet bulb temperature of the air is measured, $e = p_{w}$, Equation (37) is expressed as follows:

$$\phi_{thi} = q_{vi}\left(c_{pa2}t_{a2} - c_{pa1}t_{a1}\right)\cdot\frac{M_{v}}{\delta\cdot R\cdot T}\cdot\left(p - p_{w}\right) \tag{38}$$

The relative combined standard uncertainty calculation is given by the general Equation (39).

As an example of calculation using Equation (39), Table A.4 is shown in Annex A.

$$\begin{aligned}\left(\frac{u(\phi_{thi})}{\phi_{thi}}\right)^2 &= \left(\frac{u(q_{vi})}{q_{vi}}\right)^2 + \left(\frac{t_{a2}\cdot u(c_{pa2})}{\left(c_{pa2}t_{a2} - c_{pa1}t_{a1}\right)}\right)^2 + \left(\frac{c_{pa2}\cdot u(t_{a2})}{\left(c_{pa2}t_{a2} - c_{pa1}t_{a1}\right)}\right)^2 + \\ &\left(\frac{t_{a1}\cdot u(c_{pa1})}{\left(c_{pa2}t_{a2} - c_{pa1}t_{a1}\right)}\right)^2 + \left(\frac{c_{pa1}\cdot u(t_{a1})}{\left(c_{pa2}t_{a2} - c_{pa1}t_{a1}\right)}\right)^2 + \left(\frac{u(T)}{T}\right)^2 + \\ &\left(\frac{u(p)}{p - p_{w}}\right)^2 + \left(\frac{u(p_{w})}{p - p_{w}}\right)^2 + \left(\frac{u(C_{l})}{\phi_{thi}}\right)^2\end{aligned} \tag{39}$$

The term $u(C_{l})$ may be calculated according to Annex B. If the calculation is not made according to Annex B, a value of 1,5 % of the measured capacity shall be used for the standard uncertainty value $u(C_{l})$.

8.2.2 Uncertainty calculation with measurement of dew point temperature

When dew point temperature of the air is measured, $e = f_{w}\cdot e_{w}(T_{d})$, Equation (37) is expressed as follows:

$$\phi_{thi} = q_{vi}\left(c_{pa2}t_{a2} - c_{pa1}t_{a1}\right)\cdot\frac{M_{v}}{\delta\cdot R\cdot T}\cdot\left(p - f_{w}\cdot e_{w}(T_{d})\right) \tag{40}$$

The relative combined standard uncertainty calculation is given by the general equation:

$$\begin{aligned}\left(\frac{u(\phi_{thi})}{\phi_{thi}}\right)^2 &= \left(\frac{u(q_{vi})}{q_{vi}}\right)^2 + \left(\frac{t_{a2}\cdot u(c_{pa2})}{\left(c_{pa2}t_{a2} - c_{pa1}t_{a1}\right)}\right)^2 + \left(\frac{c_{pa2}\cdot u(t_{a2})}{\left(c_{pa2}t_{a2} - c_{pa1}t_{a1}\right)}\right)^2 + \\ &\left(\frac{t_{a1}\cdot u(c_{pa1})}{\left(c_{pa2}t_{a2} - c_{pa1}t_{a1}\right)}\right)^2 + \left(\frac{c_{pa1}\cdot u(t_{a1})}{\left(c_{pa2}t_{a2} - c_{pa1}t_{a1}\right)}\right)^2 + \left(\frac{u(T)}{T}\right)^2 + \left(\frac{u(p)}{p - f_{w}\cdot e_{w}(T_{d})}\right)^2 + \\ &\left(\frac{e_{w}(T_{d})\cdot u(f_{w})}{p - f_{w}\cdot e_{w}(T_{d})}\right)^2 + \left(\frac{f_{w}\cdot u(e_{w}(T_{d}))}{p - f_{w}\cdot e_{w}(T_{d})}\right)^2 + \left(\frac{u(C_{l})}{\phi_{thi}}\right)^2\end{aligned} \tag{41}$$

The term $u(C_{l})$ may be calculated according to Annex B. If the calculation is not made according to Annex B, a value of 1,5 % of the measured capacity shall be used for the standard uncertainty value $u(C_{l})$.

8.3 Uncertainty of measurement on the air volume flow rate

According to ISO 5151 and ISO 13253, the air volume flow rate measured by using a single nozzle is expressed as follows:

$$q_{\mathrm{v}} = C_{\mathrm{d}} A \sqrt{2 p_{\mathrm{v}} v'_{\mathrm{n}}} \tag{42}$$

The calculation of the relative combined standard uncertainty of measurement shall be made as follows:

$$\left(\frac{u\left(q_{\mathrm{v}}\right)}{q_{\mathrm{v}}}\right)^2 = \left(\frac{u\left(C_{\mathrm{d}}\right)}{C_{\mathrm{d}}}\right)^2 + \left(\frac{u\left(A\right)}{A}\right)^2 + \left(\frac{u\left(p_{\mathrm{v}}\right)}{2 P_{\mathrm{v}}}\right)^2 + \left(\frac{u\left(v'_{\mathrm{n}}\right)}{2 v'_{\mathrm{n}}}\right)^2 \tag{43}$$

Annex A
(normative)

Uncertainty budget sheets

The following four budget sheets, presented as tables, are given in this annex as an example of uncertainty calculations.

Table A.1 — Uncertainty budget sheet for cooling capacity by the calorimeter method

Table A.2 — Uncertainty budget sheet for heating capacity by the calorimeter method

Table A.3 — Uncertainty budget sheet for cooling capacity by the air enthalpy method

Table A.4 — Uncertainty budget sheet for heating capacity by the air enthalpy method

These budget sheets are only an example of the 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.

Table A.1 — Uncertainty budget sheet for cooling capacity of indoor side measurements by the calorimeter method

Input quantity and/or source of uncertainty	Symbol	Uncertainty of each factor				Value of standard uncertainty $u(x_i)$	Calculation of the uncertainty for cooling capacity		
		Evaluation basis	Uncertainty	Probability distribution	Divisor		Sensitivity coefficient c_i	$c_i u(x_i)$ (W)	
Power input to the indoor-side compartment	$\sum P_{ic}$	Uncertainty calculation result of the quantity	25,0 W (0,5 % of $\sum P_{ic}$)	Normal 2	2	12,5 W	1	12,5 W	12,5
Specific enthalpy of water supplied to indoor-side compartment	h_{w1}	Same as above	419 J/kg (for 0,1 °C)	Rectangular	1,73	242 J/kg	W_r = 0,28 × 10^−3^ kg/s	(0,28 × 10^{-3} kg/s) × (242 J/kg) = 0,07 J/s = 0,07 W	0,1
Specific enthalpy of condensed moisture leaving indoor-side compartment	h_{w2}	Same as above	418 J/kg (for 0,1 °C)	Rectangular	1,73	242 J/kg	W_r = 0,28 × 10^{-3} kg/s	(0,28 × 10^{-3} kg/s) × (242 J/kg) = 0,07 J/s = 0,07 W	0,1
Water vapour rate condensed by the equipment	W_r	Same as above	0,28 × 10^{-4} kg/s (10 % of W_r)	Rectangular	1,73	0,16x10^{-4} kg/s	$(h_{w1} - h_{w2})$ = 5,45 × 10^{4} J/kg	(5,45 × 10^{4} J/kg) × (0,16 × 10^{-4} kg/s) = 0,9 J/s = 0,9 W	0,9
Heat leakage coefficient between indoor side and outdoor side compartments of the calorimeter through the separating partition	$K_{S,p}$	Same as above	0,80 W·K^{-1} (20 % of $K_{S,p}$)	Rectangular	1,73	0,46 W·K^{-1}	$(T_{oam} - T_{iam})$ = 35,0 – 27,0 = 8,0 K	(8,0 K) × (0,46 W·K^{-1}) = 3,7 W	3,7
Heat leakage coefficient between the indoor side compartment of the calorimeter and its surroundings	$K_{S,i}$	Same as above	4,0 W·K^{-1} (20 % of K_{Si})	Rectangular	1,73	2,31 W·K^{-1}	$(T_{iscm} - T_{iam})$ = 27,5 – 27,0 = 0,5 K	(0,5 K) × (2,31 W·K^{-1}) = 1,2 W	1,2
Air temperature in the outdoor side compartment of the calorimeter	T_{oam}	Same as above	0,2 K	Normal 2	2	0,1 K	$K_{S,p}$ = 4,0 W·K^{-1}	(4,0 W·K^{-1}) × (0,1 K) = 0,4 W	0,4
Air temperature in the indoor side compartment of the calorimeter	T_{iam}	Same as above	0,2 K	Normal 2	2	0,1 K	$(K_{S,p} + K_{S,i})$ = 4,0 + 20,0 = 24,0 W·K^{-1}	(24,0 W·K^{-1}) × (0,1 K) = 2,4 W	2,4

Input quantity and/or source of uncertainty	Symbol	Uncertainty of each factor				Value of standard uncertainty $u(x_i)$	Calculation of the uncertainty for cooling capacity		
		Evaluation basis	Uncertainty	Probability distribution	Divisor		Sensitivity coefficient c_i	$c_i u(x_i)$ (W)	
Air temperature in the surroundings of the indoor side compartment of the calorimeter	T_{iscm}	Same as above	0,2 K	Normal 2	2	0,1 K	K_{Si} = 20,0 W·K^{-1}	(20,0 W·K^{-1}) × (0,1 K) = 2,0 W	2,0
Indirect contribution	C_l	Default value	78 W (1,5% of ϕ_{tci})	Normal 1	1	78 W	1	78 W	78
NOTE 1 ISO 5151 requires uncertainty equal to or less than 5 % in calorimeter method. NOTE 2 Normal 1 indicates coverage factor k = 1, and Normal 2 indicates coverage factor k = 2.					Combined standard uncertainty $u_c(\phi_{tci}) = \sqrt{\sum_{i=1}^{n} [c_i u(x_i)]^2}$			79,2 W	
					Expanded uncertainty $U = k \cdot u_c(\phi_{tci})$ Coverage factor k = 2 [Relative expanded uncertainty (%)] ϕ_{tci} = 5 200 W			158,4 W k = 2 (3,0 % of ϕ_{tci})	

Table A.2 — Uncertainty budget sheet for heating capacity of indoor side measurements by the calorimeter method

Input quantity and/or source of uncertainty	Symbol	Uncertainty of each factor				Value of standard uncertainty $u(x_i)$	Calculation of the uncertainty for cooling capacity		
		Evaluation basis	Uncertainty	Probability distribution	Divisor		Sensitivity coefficient c_i	$c_i u(x_i)$ (W)	
Water flow rate through the coil of the indoor side compartment of the calorimeter	q_{iw}	Uncertainty calculation result of the quantity	0,184 $\times 10^{-2}$ kg/s (1,0 % of q_{iw})	Normal 2	2	0,092 $\times 10^{-2}$ kg/s	$h(T_{iwo}) - h(T_{iwi})$ = 3,70 $\times 10^4$ J/kg	(3,70 $\times 10^4$ J/kg) $\times$ (0,092 $\times 10^{-2}$ kg/s) = 34,0 W	34,0
Specific enthalpy of water leaving coil of the indoor side compartment of the calorimeter	$h(T_{iwo})$	Same as above	419 J/kg (for 0,1 °C)	Rectangular	1,73	242 J/kg	q_{iw} = 0,184 kg/s	(0,184 kg/s) $\times$ (242 J/kg) = 44,5 J/s = 44,5 W	44,5
Specific enthalpy of water entering coil of the indoor side compartment of the calorimeter	$h(T_{iwi})$	Same as above	420 J/kg (for 0,1 °C)	Rectangular	1,73	242 J/kg	q_{iw} = 0,184 kg/s	(0,184 kg/s) $\times$ (242 J/kg) = 44,5 J/s = 44,5 W	44,5
Power input to the indoor-side compartment	$\sum P_{ic}$	Uncertainty calculation result of the quantity	10,0 W (0,5 % of $\sum P_{ic}$)	Normal 2	2	5,0 W	1	5,0 W	5,0
Heat leakage coefficient between indoor side and outdoor side compartments of the calorimeter through the separating partition	$K_{S,p}$	Same as above	0,80 W·K^{-1} (20 % of $K_{S,p}$)	Rectangular	1,73	0,46 W·K^{-1}	$(T_{oam} - T_{iam})$ = 20,0 – 7,0 = 13,0 K	(13,0 K) $\times$ (0,46 W·K^{-1}) = 6,0 W	6,0
Heat leakage coefficient between the indoor side compartment of the calorimeter and its surroundings	$K_{S,i}$	Same as above	4,0 W·K^{-1} (20 % of $K_{S,i}$)	Rectangular	1,73	2,31 W·K^{-1}	$(T_{iscm} - T_{iam})$ = 20,5 – 20,0 = 0,5 K	(0,5 K) $\times$ (2,31 W·K^{-1}) = 1,2 W	1,2
Air temperature in the outdoor side compartment of the calorimeter	T_{oam}	Same as above	0,2 K	Normal 2	2	0,1 K	$K_{S,p}$ = 4,0 W·K^{-1}	(4,0 W·K^{-1}) $\times$ (0,1 K) = 0,4 W	0,4
Air temperature in the indoor side compartment of the calorimeter	T_{iam}	Same as above	0,2 K	Normal 2	2	0,1 K	$(K_{S,p} + K_{S,i})$ = 4,0 + 20,0 = 24,0 W·K^{-1}	(24,0 W·K^{-1}) $\times$ (0,1 K) = 2,4 W	2,4

Input quantity and/or source of uncertainty	Symbol	Uncertainty of each factor				Value of standard uncertainty $u(x_i)$	Calculation of the uncertainty for cooling capacity		
		Evaluation basis	Uncertainty	Probability distribution	Divisor		Sensitivity coefficient c_i	$c_i u(x_i)$ (W)	
Air temperature in the surroundings of the indoor side compartment of the calorimeter	T_{iscm}	Same as above	0,2 K	Normal 2	2	0,1 K	$K_{S,i}$ = 20,0 W·K^{-1}	(20,0 W·K^{-1}) × (0,1 K) = 2,0 W	2,0
Indirect contribution	C_l	Default value	80 W (1,5 % of ϕ_{hi})	Normal 1	1	80 W	1	80 W	80,0
					Combined standard uncertainty $u_c(\phi_{hi}) = \sqrt{\sum_{i=1}^{n}[c_i u(x_i)]^2}$			107,7 W	
					Expanded uncertainty $U = k \cdot u_c(\phi_{hi})$ Coverage factor k = 2 [Relative expanded uncertainty (%)] ϕ_{hi} = 5 300 W			215,4 W k = 2 (4,1 % of ϕ_{hi})	

NOTE 1 ISO 5151 requires uncertainty equal to or less than 5 % in calorimeter method.

NOTE 2 Normal 1 indicates coverage factor k = 1, and Normal 2 indicates coverage factor k = 2.

Table A.3 — Uncertainty budget sheet for cooling capacity by the air enthalpy method

Input quantity and/or source of uncertainty	Symbol	Uncertainty of each factor				Value of standard uncertainty $u(x_i)$	Relative standard uncertainty $\frac{p_i u(x_i)}{\|x_i\|}$ of each factor	
		Evaluation basis	Uncertainty	Probability distribution	Divisor			
Indoor air volume flow rate	q_{vi}	Uncertainty calculation result of the quantity	$0{,}88 \times 10^{-2}$ m³/s (4,8 % of q_{vi})	Normal 2	2	$0{,}44 \times 10^{-2}$ m³/s	$\frac{u(q_{vi})}{q_{vi}} = \frac{0{,}44 \times 10^{-2}\ (\text{m}^3/\text{s})}{0{,}185\ (\text{m}^3/\text{s})} = 2{,}38 \times 10^{-2}$	2,38 %
Specific enthalpy of air entering the indoor side	h_{a1}	Same as above	$0{,}66 \times 10^3$ (J/kg of dry air) (for 0,2 °C wet bulb)	Normal 2	2	$0{,}33 \times 10^3$ (J/kg of dry air)	$\frac{u(h_{a1})}{(h_{a1} - h_{a2})} = \frac{0{,}33 \times 10^3\ (\text{J/kg of dry air})}{54{,}26 \times 10^3\ (\text{J/kg of dry air}) - 31{,}04 \times 10^3\ (\text{J/kg of dry air})} = 1{,}4 \times 10^{-2}$	1,42 %
Specific enthalpy of air leaving the indoor side	h_{a2}	Same as above	$0{,}50 \times 10^3$ (J/kg of dry air) (for 0,2 °C wet bulb)	Normal 2	2	$0{,}25 \times 10^3$ (J/kg of dry air)	$\frac{u(h_{a2})}{(h_{a1} - h_{a2})} = \frac{0{,}25 \times 10^3\ (\text{J/kg of dry air})}{54{,}26 \times 10^3\ (\text{J/kg of dry air}) - 31{,}04 \times 10^3\ (\text{J/kg of dry air})} = 1{,}08 \times 10^{-2}$	1,08 %
Air dry bulb temperature	T	Same as above	0,2 K	Normal 2	2	0,1 K	$\frac{u(T)}{T} = \frac{0{,}1\ (\text{K})}{287{,}0\ (\text{K})} = 0{,}035 \times 10^{-2}$	0,04 %
Atmospheric pressure	p	Same as above	1 000 Pa (1,0 % of p)	Normal 2	2	500 Pa	$\frac{u(p)}{p - p_w} = \frac{500{,}0\ \text{Pa}}{(1000{,}0 \times 10^2\ \text{Pa}) - (13{,}0 \times 10^2\ \text{Pa})} = 0{,}51 \times 10^{-2}$	0,51 %
Water vapour partial pressure at wet-bulb temperature T_w	p_w	Same as above	30,0 Pa (2,3 % of p_w)	Normal 2	2	15,0 Pa	$\frac{u(p_w)}{p - p_w} = \frac{15{,}0\ \text{Pa}}{(1000{,}0 \times 10^2\ \text{Pa}) - (13{,}0 \times 10^2\ \text{Pa})} = 0{,}02 \times 10^{-2}$	0,02 %
Indirect contribution	C_l	Default value	78 W (1,5 % of ϕ_{tci})	Normal 1	1	78 W	$\frac{u(C_l)}{\phi_{tci}} = \frac{78 (\text{W})}{5\,200\ (\text{W})} = 1{,}50 \times 10^{-2}$	1,50 %
NOTE 1 ISO 5151 requires uncertainty equal to or less than 10 % in air enthalpy method. NOTE 2 Normal 1 indicates coverage factor k = 1, and Normal 2 indicates coverage factor k = 2.							Relative combined standard uncertainty $\frac{u(\phi_{tci})}{\|\phi_{tci}\|} = \sqrt{\sum_{i=1}^{n} \left[\frac{p_i u(x_i)}{\|x_i\|} \right]^2} = 3{,}4 \times 10^{-2}$	3,4 %
							Relative expanded uncertainty $U = k \frac{u(\phi_{tci})}{\phi_{tci}} = 6{,}8 \times 10^{-2}$ Coverage factor k = 2, ϕ_{tci} = 5 200 W	6,8 % k = 2

Table A.4 — Uncertainty budget sheet for heating capacity by the air enthalpy method

Input quantity and/or source of uncertainty	Symbol	Uncertainty of each factor				Value of standard uncertainty $u(x_i)$	Relative standard uncertainty $\frac{p_i u(x_i)}{\lvert x_i \rvert}$ of each factor	
		Evaluation basis	Uncertainty	Probability distribution	Divisor			
Indoor air volume flow rate	q_{vi}	Uncertainty calculation result of the quantity	$0{,}88 \times 10^{-2}$ m³/s (4,8 % of q_{vi})	Normal 2	2	$0{,}44 \times 10^{-2}$ m³/s	$\frac{u(q_{vi})}{q_{vi}} = \frac{0{,}44 \times 10^{-2}\ (\text{m}^3/\text{s})}{0{,}185\ (\text{m}^3/\text{s})} = 2{,}38 \times 10^{-2}$	2,38 %
Specific heat of moist air entering the indoor side	c_{pa2}	Same as above	2,0 J/kg °C	Normal 2	2	1,0 J/kg °C	$\frac{t_{a2} \cdot u(c_{pa2})}{(c_{pa2} \cdot t_{a2} - c_{pa1} \cdot t_{a1})} = \frac{(45{,}0\ °\text{C}) \times (1{,}0\ \text{J/kg}\ °\text{C})}{(1{,}02 \times 10^3\ \text{J/kg}\ °\text{C}) \times (45{,}0\ °\text{C}) - (1{,}02 \times 10^3\ \text{J/kg}\ °\text{C}) \times (20{,}0\ °\text{C})} = (45{,}0\ \text{J/kg})/(2{,}55 \times 10^4\ \text{J/kg}) = 0{,}18 \times 10^{-2}$	0,18 %
Temperature of air leaving the indoor side, dry bulb	t_{a2}	Same as above	0,2 °C	Normal 2	2	0,1 °C	$\frac{c_{pa2} \cdot u(t_{a2})}{(c_{pa2} \cdot t_{a2} - c_{pa1} \cdot t_{a1})} = \frac{(1{,}02 \times 10^3\ \text{J/kg}\ °\text{C}) \times (0{,}1\ °\text{C})}{2{,}55 \times 10^4\ \text{J/kg}} = 0{,}4 \times 10^{-2}$	0,40 %
Specific heat of moist air entering the indoor side	c_{pa1}	Same as above	2,0 J/kg °C	Normal 2	2	1,0 J/kg °C	$\frac{t_{a1} \cdot u(c_{pa1})}{(c_{pa2} \cdot t_{a2} - c_{pa1} \cdot t_{a1})} = \frac{(20{,}0\ °\text{C}) \times (1{,}0\ \text{J/kg}\ °\text{C})}{2{,}55 \times 10^4\ \text{J/kg}} = 0{,}08 \times 10^{-2}$	0,08 %
Temperature of air entering the indoor side, dry bulb	t_{a1}	Same as above	0,2 °C	Normal 2	2	0,1 °C	$\frac{c_{pa1} \cdot u(t_{a1})}{(c_{pa2} \cdot t_{a2} - c_{pa1} \cdot t_{a1})} = \frac{(1{,}02 \times 10^3\ \text{J/kg}\ °\text{C}) \times (0{,}1\ °\text{C})}{2{,}55 \times 10^4\ \text{J/kg}} = 0{,}4 \times 10^{-2}$	0,40 %
Air dry bulb temperature	T	Same as above	0,2 K	Normal 2	2	0,1 K	$\frac{u(T)}{T} = \frac{0{,}1\ (\text{K})}{318{,}0\ (\text{K})} = 0{,}03 \times 10^{-2}$	0,03 %
Atmospheric pressure	p	Same as above	1 000 Pa (1,0 % of p)	Normal 2	2	500 Pa	$\frac{u(p)}{p - p_w} = \frac{500{,}0\ \text{Pa}}{(1000{,}0 \times 10^2\ \text{Pa}) - (13{,}0 \times 10^2\ \text{Pa})} = 0{,}51 \times 10^{-2}$	0,51 %
Water vapour partial pressure at wet-bulb temperature T_w	p_w	Same as above	30,0 Pa (2,3 % of p_w)	Normal 2	2	15,0 Pa	$\frac{u(p_w)}{p - p_w} = \frac{15{,}0\ \text{Pa}}{(1000{,}0 \times 10^2\ \text{Pa}) - (13{,}0 \times 10^2\ \text{Pa})} = 0{,}02 \times 10^{-2}$	0,02 %

Input quantity and/or source of uncertainty	Symbol	Uncertainty of each factor				Value of standard uncertainty $u(x_i)$	Relative standard uncertainty $\frac{p_i u(x_i)}{\lvert x_i \rvert}$ of each factor	
		Evaluation basis	Uncertainty	Probability distribution	Divisor			
Indirect contribution	C_l	Default value	78 W (1,5 % of ϕ_{thi})	Normal 1	1	78 W	$\frac{u(C_l)}{\phi_{thi}} = \frac{78(\text{W})}{5\ 300\ (\text{W})} = 1{,}50 \times 10^{-2}$	1,50 %
NOTE 1 ISO 5151 requires uncertainty equal to or less than 10 % in air enthalpy method.							Relative combined standard uncertainty $\frac{u(\phi_{thi})}{\lvert \phi_{thi} \rvert} = \sqrt{\sum_{i=1}^{n} \left[\frac{p_i u(x_i)}{\lvert x_i \rvert} \right]^2} = 2{,}92 \times 10^{-2}$	2,92 %
NOTE 2 Normal 1 indicates coverage factor k = 1, and Normal 2 indicates coverage factor k = 2.							Relative expanded uncertainty $U = k \frac{u(\phi_{thi})}{\phi_{thi}} = 5{,}8 \times 10^{-2}$ Coverage factor k = 2, ϕ_{thi} = 5 300 W	5,8 % k = 2

Annex B
(informative)

Determination of indirect contribution to uncertainty, $U(C_I)$

This annex contains information on measurements that contribute to the uncertainty of measurement of capacity which are not directly included in the capacity equations. The uncertainties introduced into the measurement of capacity by these measurements shall be combined into an expanded uncertainty value, $U(C_I)$, having a normal distribution with a coverage factor of 2. Therefore, the value of $u(C_I)$ to be used in Equations (10), (16), (22), (27), (33), (35), (39) and (41) shall be equal to $U(C_I)/2$.

The measurements that contribute to the uncertainty of measurement of capacity include at least (listed in order of importance):

- indoor wet bulb measurement for cooling capacity tests;
- outdoor wet bulb measurement for heating capacity tests;
- all other temperature measurements not already directly taken into account in the uncertainty equations;
- variations from set points:
  - indoor and outdoor-side air temperatures,
  - air flow rates,
  - voltage of the electrical supply to the unit under test,
  - frequency of the electrical supply to the unit under test;
- location of temperature and pressure measurements;
- heat losses in the air duct between the unit under test and the temperature measuring point (air-enthalpy test method);
- properties of fluids (air, water, brine, refrigerant);
- length and configuration of refrigerant connecting tubing;
- voltage wave form of the electrical supply to the unit under test.

Bibliography

[1] M3003: Edition 2, UKAS, *The expression of uncertainty and confidence in measurement*

[2] JAB NOTE 6: 2006, *Evaluation of uncertainty of measurement (Electrical testing/refrigerating & air conditioning testing)*

[3] R. R. Cook, National Association of Testing Authorities, Australia, 2002: *Assessment of uncertainties of measurement for calibration and testing laboratories*

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