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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

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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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An ISO/PAS or ISO/TS is reviewed after three years in order to decide whether it will be confirmed for a further three years, revised to become an International Standard, or withdrawn. If the ISO/PAS or ISO/TS is confirmed, it is reviewed again after a further three years, at which time it must either be transformed into an International Standard or be withdrawn.

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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
$e_\mathrm{w}(T_\mathrm{d})$	water vapour partial pressure at T_d	Pa
f_w	enhancement factor, considered as a constant value equal to 1	—
$K_\mathrm{S,i}$	heat leakage coefficient between the indoor side compartment of the calorimeter and its surroundings	W·K^{-1}
$K_\mathrm{S,o}$	heat leakage coefficient between the outdoor side compartment of the calorimeter and its surroundings	W·K^{-1}
$K_\mathrm{S,p}$	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
$U(C_\mathrm{I})$	indirect contribution to expanded uncertainty	W
$u(C_\mathrm{I})$	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:

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

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

b) If the calibration correction is not applied:

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

NOTE 2 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:

$$T_m = \frac{\sum_{i=1}^{N} T_i}{N} \quad (3)$$

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:

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

where

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

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

