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Acoustics — Determination and application of measurement uncertainties in building acoustics

Part 1: Sound insulation (ISO 12999-1:2014)

National foreword

This British Standard is the UK implementation of EN ISO 12999-1:2014. It supersedes BS EN 20140-2:1993, which is withdrawn.

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Foreword

This document (EN ISO 12999-1:2014) has been prepared by Technical Committee ISO/TC 43 "Acoustics" in collaboration with Technical Committee CEN/TC 126 “Acoustic properties of building elements and of buildings” the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by November 2014, and conflicting national standards shall be withdrawn at the latest by November 2014.

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

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Endorsement notice

The text of ISO 12999-1:2014 has been approved by CEN as EN ISO 12999-1:2014 without any modification.

Contents

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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 43, *Acoustics*, Subcommittee SC 2, *Building acoustics*.

This first edition of ISO 12999-1 cancels and replaces ISO 140-2:1991, which has been technically revised. It also incorporates the Technical Corrigendum ISO 140-2:1991/Cor 1:1993.

ISO 12999 consists of the following parts, under the general title *Acoustics — Determination and application of measurement uncertainties in building acoustics*:

— *Part 1: Sound insulation*

A part 2 dealing with sound absorption is under preparation.

Introduction

An assessment of uncertainties that is comprehensible and close to reality is indispensable for many questions in building acoustics. Whether a requirement is met, a laboratory delivers correct results or the acoustic properties of a product are better than the same properties of some other product can be decided only by adequately assessing the uncertainties associated with the quantities under consideration.

Uncertainties should preferably be determined following the principles of ISO/IEC Guide 98-3. This Guide specifies a detailed procedure for the uncertainty evaluation that is based upon a complete mathematical model of the measurement procedure. At the current knowledge, it seems to be impossible to formulate these models for the different quantities in building acoustics. Therefore, only the principles of such an uncertainty assessment are explained.

To come to uncertainties all the same, the concept of reproducibility and repeatability is incorporated which is the traditional way of uncertainty determination in building acoustics. This concept offers the possibility to state the uncertainty of a method and of measurements carried out according to the method, based on the results of inter-laboratory measurements.

Acoustics — Determination and application of measurement uncertainties in building acoustics —

Part 1:
Sound insulation

1 Scope

This part of ISO 12999 specifies procedures for assessing the measurement uncertainty of sound insulation in building acoustics. It provides for

- a detailed uncertainty assessment;
- a determination of uncertainties by inter-laboratory tests;
- an application of uncertainties.

Furthermore, typical uncertainties are given for quantities determined according to ISO 10140, ISO 140-4, ISO 140-5, ISO 140-7 and ISO 717 (all parts).

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 140-4, *Acoustics — Measurement of sound insulation in buildings and of building elements — Part 4: Field measurements of airborne sound insulation between rooms*

ISO 140-5, *Acoustics — Measurement of sound insulation in buildings and of building elements — Part 5: Field measurements of airborne sound insulation of façade elements and façades*

ISO 140-7, *Acoustics — Measurement of sound insulation in buildings and of building elements — Part 7: Field measurements of impact sound insulation of floors*

ISO 717 (all parts), *Acoustics — Rating of sound insulation in buildings and of building elements*

ISO 5725-1:1994, *Accuracy (trueness and precision) of measurement methods and results — Part 1: General principles and definitions*

ISO 5725-2:1994, *Accuracy (trueness and precision) of measurement methods and results — Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method*

ISO 10140 (all parts), *Acoustics — Laboratory measurement of sound insulation of building elements*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

NOTE Whenever applicable, they are equivalent to those given in ISO 5725-1, in the ISO/IEC Guide 98-3[1] and in ISO/IEC Guide 99.[2]

3.1
measurand
particular quantity subject to measurement, e.g. the airborne sound insulation of a particular window pane determined in accordance with ISO 10140

3.2
measurement result
value attributed to a measurand, obtained by following the complete set of instructions given in a measurement procedure

Note 1 to entry: The measurement result may be a frequency band level or a single number value determined according to the rating procedures of ISO 717 (all parts).

3.3
uncertainty
parameter, associated with the result of a measurement, that characterizes the dispersion of the values that can reasonably be attributed to the measurand

3.4
standard uncertainty
u
uncertainty of the result of a measurement expressed as a standard deviation

3.5
combined standard uncertainty
u_c
standard uncertainty of the result of a measurement when that result is obtained from the values of a number of other quantities, equal to the positive square root of a sum of terms, the terms being the variances or covariances of these other quantities weighted according to how the measurement result varies with changes in these quantities

3.6
expanded uncertainty
U
quantity defining an interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values that can reasonably be attributed to the measurand

3.7
coverage factor
k
numerical factor used as a multiplier of the combined standard uncertainty in order to obtain an expanded uncertainty

3.8
repeatability condition
condition of measurement that includes the same measurement procedure, same operators, same measuring system, same location (laboratory or usual building), and replicate measurements on the same object over a short period of time

3.9
repeatability standard deviation
σ_r
standard deviation of measurement results obtained under repeatability conditions

3.10
reproducibility condition
condition of measurement that includes different locations (laboratories or usual buildings), operators, measuring systems, and replicate measurements on the same or similar objects

3.11

reproducibility standard deviation

σ_R

standard deviation of measurement results obtained under reproducibility conditions

3.12

***in-situ* condition**

condition of measurement that includes the same location (laboratory or usual building), and replicate measurements on the same object by different operators using different measuring systems

3.13

***in-situ* standard deviation**

σ_situ

standard deviation of measurement results obtained under *in-situ* conditions

4 Detailed uncertainty budget

The derivation of a detailed uncertainty budget is desirable to find out which uncertainty contributions are the most important ones and how these contributions can be reduced. Furthermore, such a budget reflects the individual sound fields during the measurement. Consequently, the uncertainty is valid for an individual measurement result and not for a whole family of results. Annex C gives provisions on the derivation of such uncertainty budgets.

5 Uncertainty determination by inter-laboratory measurements

5.1 General

Standard deviations determined by inter-laboratory measurements may serve as an estimate for the standard uncertainty. The general concept and the procedure for determining these standard deviations are given in ISO 5725-1 and ISO 5725-2, respectively. As many operators and laboratories as possible should participate in such inter-laboratory measurements in order to obtain reliable results.

5.2 Measurement situations

In building acoustics, three different measurement situations are to be distinguished.

a) Situation A is that a building element is characterized by laboratory measurements. In this case, the measurand is defined by the relevant part of ISO 10140, including all additional requirements e.g. for the measurement equipment and especially for the test facilities. Therefore, all measurement results that are obtained in another test facility or building also comply with this definition. The standard uncertainty, thus, is the standard deviation of reproducibility as determined by inter-laboratory measurements.

b) Situation B is described by the case that different measurement teams come to the same location to carry out measurements. The location may be a usual building or a test facility. The measurand, thus, is a property of one particular element in one particular test facility or the property of a building. The main difference to situation A is that many aspects of the airborne and structure-borne sound fields involved remain constant since the physical construction is unchanged. The standard uncertainty obtained for this situation is called *in situ* standard deviation.

c) Situation C applies to the case when the measurement is simply repeated in the same location by the same operator using the same equipment. The location may be a usual building or a test facility. The standard uncertainty is the standard deviation of repeatability as determined by inter-laboratory measurements.

5.3 Measurement conditions

The acoustical measurement conditions for determining the different standard deviations shall correspond to the conditions given in the standardized measurement procedures. The test specimen shall not be remounted between repeated measurements.

Each laboratory shall use its normal measurement procedure when participating in an inter-laboratory measurement. No deviations from the test procedure laid down shall occur but repeating the measurements several times, the parameters left open in the measurement procedure shall be represented as well as possible. In particular, the set of microphone positions and source positions over which averaging is carried out for one measurement shall be selected anew, more or less randomly, for each repeated measurement. This is necessary to obtain a mean value and a standard deviation of repeatability that represent the situation correctly.

Before the inter-laboratory measurement is started, each participating laboratory shall report the exact details of its test procedure.

Additional requirements for carrying out inter-laboratory measurements for the test specimen chosen shall be laid down in detail. This refers in particular to the following items:

- quantities being measured and reported, rules for rounding numbers;
- number of repeated measurements required;
- calibration of the measurement equipment;
- mounting and sealing conditions of the test specimen, and curing time where appropriate.

5.4 Number of participating laboratories

The number of laboratories, p, shall, from a statistical point of view, be at least eight, but is preferable to exceed this number in order to reduce the number of replicate measurements required. The number, n, of measurements in each laboratory should be so chosen that $p(n - 1) \geq 35$. In addition, at least five test results are needed for each laboratory. If the number n of measurements is different among the participating laboratories, a mean number of measurements shall be calculated and used (see ISO 5725-2). The measurement results obtained shall not be pre-selected in any way by the participating laboratories before they are reported.

5.5 Stating the test results of inter-laboratory measurements

In order to simplify the evaluation of measurement results reported, it is strongly desirable to supply forms for filling in by the participants. For the statistical analysis, it is important to report special observations and/or any irregularities observed during the test.

5.6 Choice of test specimen

5.6.1 General

The kind of test specimen used for an inter-laboratory measurement depends not only on the quantity being tested (i.e. airborne sound reduction index, normalized impact sound pressure level) but specifically on the mounting and measurement conditions for which the standard deviation of repeatability and reproducibility are being obtained (e.g. walls, floors, windows). Effects influencing the measurement result, like ageing or a strong dependence on humidity or temperature, shall also be considered.

The choice of test specimen also depends on practical considerations. In general, three different approaches (see 5.6.2 to 5.6.4) depending on the type of measurement method and/or on the type of specimen can be appropriate.

5.6.2 Use of single test specimen — Same material circulated among participants

For checking the measurement procedure and the facilities in different laboratories, ideally, the same test specimen should be used by all participants in the inter-laboratory measurement and checked again by the first laboratory at the end of the inter-laboratory measurement.

In building acoustics, this procedure is often not feasible due to the long period of time required, the risk of damage or change of the test specimen and different sizes of test openings. However, the variability resulting from the use of more than one test specimen is avoided and the standard deviation of reproducibility thus obtained is characteristic for the test facility and measurement procedure alone.

5.6.3 Use of several test specimens taken from a production lot — Nominally identical material exchangeable among participants

In contrast to the procedure described in 5.6.2, all participants of the inter-laboratory measurement receive nominally identical test specimens, i.e. coming from the same production lot or of identical design and constructed by one manufacturer. This enables testing in parallel and reduces the risk of damage or of change due to the influence of time. However, the variability among the test specimens due to their heterogeneity is then inseparable from the variability of the measurement procedure, and forms an inherent part of the reproducibility standard deviation. For this reason it can be advantageous to check all test specimens for homogeneity with more precision at one laboratory before the inter-laboratory measurement and possibly also after its completion.

5.6.4 Use of several test specimens constructed *in situ* — Nominally identical material not exchangeable among participants

When the test specimens cannot be prefabricated and readily transported, they shall be constructed *in situ* by each participant according to close specifications. In this case, the variability among the test specimens due to their heterogeneity is even larger than for test specimens according to 5.6.3.

5.7 Laboratories with outlying measurement results

ISO 5725-2 provides statistical methods to test whether a result of a laboratory is an outlier in a statistical sense. If a result turns out to be an outlier, it is necessary to investigate what are the reasons for the discrepancy. A result shall be disqualified only in the case that an error has occurred, e.g. a wrong microphone sensitivity was used. Whenever the measurement procedure described in the standard has been applied correctly and all the requirements for the test facility, the measurement equipment and the mounting of the specimen are fulfilled, the measurement result shall be considered to be in conformity with the definition of the measurand. Such results shall not be disqualified even if they are outliers.

5.8 Verification of laboratory results by results of inter-laboratory tests

A laboratory x that has not taken part in an inter-laboratory test can verify the proper operation of its own test procedure using the test results and the test specimen from an inter-laboratory test. It is further recommended that a laboratory verify the proper operation of its own test procedure from time to time, especially whenever changes in the test procedure itself, the test facility or the instrumentation are made.

Laboratory x carries out n_x repeated measurements. The standard deviation of these measurements shall be smaller than the values given in Table 1.

Table 1 — Maximum standard deviation of repeatability

Frequency Hz	**Maximum standard deviation of repeatability** dB
50	4,0
63	3,5

Table 1 *(continued)*

Frequency Hz	**Maximum standard deviation of repeatability** dB
80	3,0
100	2,6
125	2,2
160	1,9
200	1,7
250	1,5
315	1,4
400	1,3
500	1,3
630	1,3
800	1,3
1 000	1,3
1 250	1,3
1 600	1,3
2 000	1,3
2 500	1,3
3 150	1,3
4 000	1,3
5 000	1,3

The average value of these measurements $\bar{y}_x$ is compared with the total average $\bar{\bar{y}}$ of the inter-laboratory test in each frequency band. The appropriate critical difference, δ_{Cr95}, for this case is as given in Formula (1):

$$\delta_{\mathrm{Cr95}}\left(\left|\bar{\bar{y}}-\bar{y}_x\right|\right)=2\sqrt{\sigma_R^2\left(1+\frac{1}{p}\right)-\sigma_r^2\left(1+\frac{1}{p}-\frac{1}{n_x}-\frac{1}{p^2}\sum_{i=1}^{p}\frac{1}{n_i}\right)} \tag{1}$$

where

σ_{R} and σ_{r}	were determined for each frequency band in the inter-laboratory test;
$\bar{\bar{y}}$	is the overall average of the inter-laboratory test;
$\bar{y}_x$	is the average of the test results of laboratory x;
p	is the number laboratories having participated in the inter-laboratory test;
n_i	is the number of test results of the ith laboratory;
n_x	is the number of test results of an additional laboratory x.

The results of laboratory *x* are in agreement with the results of the inter-laboratory test if the differences between the average of the test for the laboratory and the overall average of the inter-laboratory test are not exceeding the appropriate critical difference in more than 5 % of the frequency bands. In case of more exceedings, it is necessary to investigate what are the reasons for the discrepancy. A result is invalid only in the case that an error occurred, e. g. a wrong microphone sensitivity was used. Whenever the agreed measurement procedure has been applied correctly and all the requirements for the test facility, the measurement equipment and the mounting of the specimen are fulfilled, the measurement result shall be considered as a valid realization of the measurand.

6 Uncertainties associated with single-number values

The uncertainty associated with single-number values determined in accordance with ISO 717 (all parts) can be determined by two different methods.[3]

The first method is to treat the single-number value as the measurand. A value for the standard uncertainty can then be determined by inter-laboratory tests. This method has the disadvantage that the uncertainty of the single-number value depends then on the spectral shape of the one-third-octave band values that are the base for the calculation of the single-number value. Typical uncertainties determined in this way are given in Clause 8.

A second method for the determination of the uncertainty of single-number values is to apply the one-third-octave band uncertainties to the weighting procedure. Unfortunately, the unknown degree of correlation between the one-third-octave band results influences the uncertainty of the single-number value considerably. Such correlations can be caused by using the same microphone and source positions for all one-third-octave bands. Nevertheless, an upper limit for the uncertainty of the single-number value can be calculated by assuming a correlation coefficient of 1 between the one-third-octave band values. An example of such a calculation is given in Annex B.

7 Standard uncertainties for typical measurands

7.1 General

If uncertainty data are available for specific specimens, e.g. from an inter-laboratory test, these data shall be used. If no such data are available, uncertainties given in 7.2 to 7.4 shall be used in general. They are derived from inter-laboratory measurements according to ISO 5725-1 and ISO 5725-2 and represent average values derived from measurements on different types of test specimens including lightweight partition walls, heavyweight walls, glazings and windows.

7.2 also contains a quantity σ_{R95}. It is derived from the same round robins as σ_R but represents an average of the upper interval limits for the standard deviations of reproducibility with a coverage probability of 95 %. In the absence of uncertainty data for specific specimens, e.g. from an inter-laboratory test, these values shall be used for the declaration of product or system data.

7.2 Airborne sound insulation

Standard uncertainties for airborne sound insulation in one-third-octave bands are given in Table 2. Standard uncertainties for different single-number quantities are given in Table 3. The values apply to situations where the volume of the receiving room and the surface of the separating element are well defined. If this is not the case, standard uncertainties can be larger. The numbers given in Table 2 and Table 3 exclude receiving room volumes less than 25 m^3.

Table 2 — Standard uncertainties for airborne sound insulation in one third-octave bands

Frequency Hz	**Situation A** σ_{R95} dB	**Situation A** σ_R dB	**Situation B** σ_{situ} dB	**Situation C** σ_r dB
50	11,7	6,8	4,0	2,0
63	6,7	4,6	3,6	1,8
80	5,9	3,8	3,2	1,6
100	5,0	3,0	2,8	1,4
125	5,0	2,7	2,4	1,2

Table 2 *(continued)*

Frequency Hz	**Situation A** σ_{R95} dB	**Situation A** σ_R dB	**Situation B** σ_{situ} dB	**Situation C** σ_r dB
160	3,8	2,4	2,0	1,0
200	3,3	2,1	1,8	0,9
250	3,3	1,8	1,6	0,8
315	3,3	1,8	1,4	0,7
400	3,3	1,8	1,2	0,6
500	3,3	1,8	1,1	0,6
630	3,3	1,8	1,0	0,6
800	3,3	1,8	1,0	0,6
1 000	3,3	1,8	1,0	0,6
1 250	3,4	1,8	1,0	0,6
1 600	3,4	1,8	1,0	0,6
2 000	3,4	1,8	1,0	0,6
2 500	3,5	1,9	1,3	0,6
3 150	3,6	2,0	1,6	0,6
4 000	4,0	2,4	1,9	0,6
5 000	4,7	2,8	2,2	0,6

Table 3 — Standard uncertainties for single-number values in accordance with ISO 717-1

Descriptor	**Situation A** σ_{R95} dB	**Situation A** σ_R dB	**Situation B** σ_{situ} dB	**Situation C** σ_r dB
$R_w, R'_w, D_{nw}, D_{nT,w}$	2,0	1,2	0,9	0,4
$(R_w, R'_w, D_{nw}, D_{nT,w}) + C_{100-3150}$	2,1	1,3	0,9	0,5
$(R_w, R'_w, D_{nw}, D_{nT,w}) + C_{100-5000}$	2,1	1,3	1,1	0,5
$(R_w, R'_w, D_{nw}, D_{nT,w}) + C_{50-3150}$	2,1	1,3	1,0	0,7
$(R_w, R'_w, D_{nw}, D_{nT,w}) + C_{50-5000}$	2,1	1,3	1,1	0,7
$(R_w, R'_w, D_{nw}, D_{nT,w}) + C_{tr,100-3150}$	2,4	1,5	1,1	0,7
$(R_w, R'_w, D_{nw}, D_{nT,w}) + C_{tr,100-5000}$	2,4	1,5	1,1	0,7
$(R_w, R'_w, D_{nw}, D_{nT,w}) + C_{tr,50-3150}$	2,4	1,5	1,3	1,0
$(R_w, R'_w, D_{nw}, D_{nT,w}) + C_{tr,50-5000}$	2,4	1,5	1,0	1,0

7.3 Impact sound insulation

At present, there are no results available for impact sound insulation at reproducibility conditions (situation A). Standard uncertainties for impact sound insulation in one-third-octave bands are given in Table 4. Standard uncertainties for different single-number quantities are given in Table 5. The values apply to situations where the volume of the receiving room and the surface of the separating element are well defined. If this is not the case, standard uncertainties can be larger.

Table 4 — Standard uncertainties for impact sound insulation in one third-octave bands

Frequency Hz	**Situation B** dB	**Situation C** dB
50	3,2	1,5
63	2,8	1,4
80	2,4	1,3
100	2,0	1,2
125	1,6	1,1
160	1,4	1,0
200	1,3	0,9
250	1,2	0,8
315	1,2	0,8
400	1,2	0,8
500	1,2	0,8
630	1,2	0,8
800	1,2	0,8
1 000	1,2	0,8
1 250	1,3	0,8
1 600	1,4	0,8
2 000	1,5	0,8
2 500	1,7	1,0
3 150	1,9	1,2
4 000	2,1	1,4
5 000	2,3	1,6

Table 5 — Standard uncertainties for single-number values in accordance with ISO 717-2

Descriptor	**Situation A** dB	**Situation B** dB	**Situation C** dB
$L_{n,w}$, $L'_{n,w}$,$L'_{nT,w}$	1,5[a]	1,0	0,5
($L_{n,w}$, $L'_{n,w}$,$L'_{nT,w}$) + C_I	1,5[a]	1,0	0,6

[a] Indicated values are estimates.

7.4 Reduction of transmitted impact noise by floor coverings

At present, there are no results available for the reduction in impact sound pressure level at *in situ* and at repeatability conditions (situations B and C). Standard uncertainties for the reduction in impact sound pressure level in one-third-octave bands are given in Table 6. Standard uncertainties for different single-number quantities are given in Table 7.

Table 6 — Standard uncertainties for the reduction in impact sound pressure level in one-third-octave bands

Frequency Hz	**Situation A** dB
50	1,4

Table 6 *(continued)*

Frequency Hz	**Situation A** dB
63	1,3
80	1,2
100	1,1
125	1,0
160	1,0
200	1,0
250	1,0
315	1,0
400	1,1
500	1,2
630	1,3
800	1,6
1 000	1,9
1 250	2,2
1 600	2,5
2 000	2,8
2 500	3,2
3 150	3,6
4 000	4,0
5 000	4,4

Table 7 — Standard uncertainties for single-number values in accordance with ISO 717-2

Descriptor	**Situation A** dB
ΔL_w	1,1

8 Application of the uncertainties

For measurement results, the expanded uncertainty U shall be calculated by Formula (2):

$$U = k\,u \tag{2}$$

where

u is the standard uncertainty determined in accordance with Clause 5 or Clause 6 of this part of ISO 12999;

k is the coverage factor, the value of which depends on the distribution of the possible values of the measurand and on the confidence level.

For the purpose of ISO 10140, it is assumed that the values of the measurand follow a Gaussian distribution. The value of k can then be determined from Table 8. A minimum value of $k = 1$ shall be used. The chosen coverage factor shall be reported together with the information whether one-sided or two-sided intervals have been used.

Table 8 — Coverage factors for different confidence levels

Coverage factor k	Confidence level for two-sided test %	Confidence level for one-sided test %
1,00	68	84
1,28	80	90
1,65	90	95
1,96	95	97,5
2,58	99	99,5
3,29	99,9	99,95

A measurand, Y, shall then be stated as given in Formula (3):

$$Y = y \pm U \tag{3}$$

where

y	is the best estimate found by the measurement;
U	is the expanded uncertainty calculated for a given confidence level for the two-sided test.

EXAMPLE An airborne sound insulation would be designated as R = (35,1 ± 1,2) dB (k = 1, two-sided).

If the conformity with a requirement will be verified by a measurement, the coverage factor for one-sided tests shall be applied to calculate the expanded uncertainty, U. This value is then added to the best estimate y to check whether a measurement result is smaller than a requirement Y_{required} as given by Formula (4):

$$y + U < Y_{\text{required}} \tag{4}$$

The expanded uncertainty is subtracted from the best estimate, y, to check whether a measurement result is larger than a requirement Y_{required} as given by Formula (5):

$$y - U > Y_{\text{required}} \tag{5}$$

Annex A
(informative)

Example of handling uncertainties in building acoustics

A.1 General

This annex gives an example showing how uncertainties can be handled in building acoustics for airborne sound insulation.

A.2 From laboratory measurements to predicted values

The starting point is a determination of a weighted sound reduction index in a laboratory. The standard uncertainty of this measurement is the standard deviation of reproducibility. From this value, the input uncertainty for the prediction u_{input} can be determined with the standard deviation for the product homogeneity (σ_{product} – scatter of different nominally identical test specimens) and the number n of measurements carried out with this product in different laboratories.

$$u_{\text{input}} = \sqrt{\frac{\sigma_{\text{R}}^2 + \sigma_{\text{product}}^2}{n} + \sigma_{\text{product}}^2} \qquad \text{(A.1)}$$

Such an input uncertainty shall be calculated for all acoustic quantities used in the prediction.

The apparent sound reduction index of the building is then predicted from the acoustic properties of the building products e.g. by the method described in EN 12354-1. Since analytical expressions are used, the uncertainty of the predicted value can be calculated from the interaction of the input quantities and their uncertainties, u_{calc}, with an additional component, u_{reality}, accounting for the discrepancies between the reality and the calculation model[4] as given by Formula (A.2):

$$u_{\mathrm{pred}} = \sqrt{u_{\mathrm{calc}}^2 + u_{\mathrm{reality}}^2} \tag{A.2}$$

In a next step, the expanded uncertainty, U, is calculated by Formula (2) for an appropriate confidence level for the one-sided test. The requirement is met when the condition in Formula (A.3) is fulfilled:

$$R'_{\mathrm{w,pred}} - U > R'_{\mathrm{w,required}} \tag{A.3}$$

EXAMPLE The conditions

$$\sigma_{\mathrm{R}} = 1{,}2\,\mathrm{dB}$$

$$\sigma_{\mathrm{product}} = 1{,}0\,\mathrm{dB}$$

$$n = 1$$

yield the result

$$u_{\mathrm{input}} = 1{,}9\,\mathrm{dB}$$

The assumption that one building element determines the sound transmission leads to Formula (A.4):

$$u_{\mathrm{calc}} = u_{\mathrm{input}} \tag{A.4}$$

Formula (A.4) combined with the condition

$$u_{\mathrm{reality}} = 0{,}8\,\mathrm{dB}$$

yields the result

$$u_{\mathrm{pred}} = 2{,}0\,\mathrm{dB}$$

For the chosen confidence level of 84 % for the one-sided test, a coverage factor of 1 is obtained from Table 7. The expanded uncertainty thus is

$$U = 2{,}0\,\mathrm{dB}$$

It is necessary that this value be subtracted from the predicted apparent sound reduction index before it is compared to a requirement.

A.3 Experimental verification of a requirement

It shall now be determined whether or not the requirement for the airborne sound insulation is met in a building. The standard uncertainty of this measurement is the *in situ* standard deviation, which is 0,9 dB for the apparent weighted sound reduction index according to Table 2. A confidence level of 84 % is chosen as an example, which leads to a coverage factor of 1 and an expanded uncertainty of 0,9 dB. The requirement is met when the condition given as Formula (A.5) applies:

$$R'_{\text{w,meas}} - U > R'_{\text{w,required}} \tag{A.5}$$

It is not met when the condition given as Formula (A.6) applies:

$$R'_{\text{w,meas}} + U < R'_{\text{w,required}} \tag{A.6}$$

If no decision can be made, the uncertainty of the measurement can be reduced by further independent measurements, which means other persons measure with other equipment. Then the uncertainty is as given by Formula (A.7):

$$u = \frac{0{,}9}{\sqrt{m}}\ \text{dB} \tag{A.7}$$

where m is the number of independent measurements.

Annex B
(informative)

Example for the calculation of the uncertainty of single number values

B.1 Uncertainty of the sum of the weighted sound reduction index and the spectrum adaptation terms

The sum of the weighted sound reduction index and the spectrum adaptation terms, expressed in decibels, is calculated in accordance with ISO 717 (all parts) as given in Formula (B.1):

$$R_w + C = -10 \lg \sum_i 10^{\left(L_i - R_i\right)/10\,\mathrm{dB}}\ \mathrm{dB} \tag{B.1}$$

where

R_i is the measured sound reduction index in frequency band i, in dB;

L_i is the reference spectrum as defined in ISO 717 (all parts).

Regarding the one-third-octave band insulations as independent input quantities, the uncertainty under the assumption of no correlation between the input quantities is given by Formula (B.2) (see[3]):

$$u\left(R_w + C\right) = \sqrt{\sum_i \left(\frac{10^{\left(L_{i,j} - R_i\right)/10\,\mathrm{dB}}}{\sum_i 10^{\left(L_{i,j} - R_i\right)/10\,\mathrm{dB}}} \right)^2 u^2\left(R_i\right)} \tag{B.2}$$

Under the assumption of full positive correlation between the one-third-octave band insulations, the single-number value is determined twice. In the first case, all uncertainties are added to the measured sound insulations in the one-third-octave bands yielding the sum of the single-number value and the standard uncertainty as given in Formula (B.3):

$$R_w + C + u\left(R_w + C\right) = -10 \lg \sum_i 10^{\left(L_i - R_i + u\left(R_i\right)\right)/10\,\mathrm{dB}}\ \mathrm{dB} \tag{B.3}$$

In the second case, all uncertainties are subtracted from the measured sound insulations in the one-third-octave bands yielding the difference between the single-number value and the standard uncertainty as given in Formula (B.4):

$$R_w + C - u\left(R_w + C\right) = -10 \lg \sum_i 10^{\left(L_i - R_i - u\left(R_i\right)\right)/10\,\mathrm{dB}}\ \mathrm{dB} \tag{B.4}$$

Dividing the results from Formulae (B.4) and (B.3) by two yields the uncertainty as given in Formula (B.5):

$$u\left(R_\mathrm{w} + C\right) = \frac{R_\mathrm{w} + C + u\left(R_\mathrm{w} + C\right) - \left[R_\mathrm{w} + C - u\left(R_\mathrm{w} + C\right)\right]}{2} \tag{B.5}$$

This procedure is applicable to all the different reference spectra and frequency ranges defined in ISO 717 (all parts).

B.2 Uncertainty of the weighted sound reduction index

According to ISO 717-1, the weighted sound reduction index is calculated by shifting a reference curve by full decibel steps until the sum of all negative (or non-favourable) one-third-octave band differences is equal or smaller than 32 dB. The uncertainty of the weighted sound reduction index can be calculated under the assumption of full positive correlation between the one-third-octave band insulations by adding or subtracting the uncertainty in one-third-octave bands by analogy to B.1. The weighted sound reduction index is then calculated for both cases, the results being $R_\mathrm{w}+u(R_\mathrm{w})$ and $R_\mathrm{w}-u(R_\mathrm{w})$, respectively. The uncertainty of the weighted sound reduction index is, then, calculated from these results by analogy to Formula (B.5) as given in Formula (B.6):

$$u(R_\mathrm{w})=\frac{R_\mathrm{w}+u(R_\mathrm{w})-\left[R_\mathrm{w}-u(R_w)\right]}{2} \qquad \text{(B.6)}$$

To come to realistic uncertainties, a shift of the reference curve in 0,1 dB steps is required.

Under the assumption of no correlation between the one-third-octave band insulations, the uncertainty of the weighted sound reduction index can be calculated by a special linearization technique or by Monte-Carlo methods.[3]

B.3 Example

An example of a measured sound insulation is given in Table B.1. The uncertainties are from Table 2, situation A. The calculated single-number values and uncertainties are given in Table B.2.

Table B.1 — Example for a measured sound insulation and the associated uncertainties

Frequency Hz	R_i dB	u_i dB
50	39,5	6,8
63	40,3	4,6
80	41,6	3,8
100	43,1	3,0
125	43,3	2,7
160	43,1	2,4
200	42,5	2,1
250	44,7	1,8
315	48,0	1,8
400	50,5	1,8
500	53,2	1,8
630	55,9	1,8
800	58,1	1,8
1 000	60,0	1,8
1 250	62,2	1,8
1 600	63,7	1,8
2 000	65,4	1,8
2 500	66,8	1,9
3 150	68,4	2,0

Table B.1 *(continued)*

Frequency Hz	R_i dB	u_i dB
4 000	68,8	2,4
5 000	65,1	2,8

Table B.2 — Single-number values and uncertainties calculated from the values in Table B.2

	R_w dB	$R_w + C_{50–5\,000}$ dB	$R_w + C_{tr,\,50–5\,000}$ dB
Single-number value	57,4	56,4	51,1
Uncertainty for correlated one-third octave band insulations	1,9	2,1	2,6
Uncertainty for uncorrelated one-third octave band insulations	—	0,6	0,8

Annex C
(informative)

Detailed uncertainty budget

C.1 Influences on the result of building acoustic measurements

Measurement results in building acoustics are influenced by many parameters that can be arranged into groups corresponding to repeatability and reproducibility conditions. Uncertainty components listed below are thought to be of importance for most measurands in building acoustics. Nevertheless, other uncertainty components can arise under special circumstances.

The first group of uncertainty components comprises all the influences that occur under repeatability conditions. To these influences belong

- imperfect spatial and temporal averaging when determining averaged sound pressure levels;
- uncertainties in the background noise correction if the background noise is not stationary;
- uncertainties associated with the determination of room absorption, e.g. due to imperfect spatial averaging.

Effects of static pressure, humidity and temperature can be neglected here when the measurements are carried out within a short period of time wherein these quantities remain constant.

All influences leading to deviations between different laboratories are covered by the second group. These are uncertainties due to differences in the airborne or structure-borne sound fields involved that can be caused by

- different sizes or aspect ratios of the test openings;
- different loss factors of the test facilities;
- different room geometries;
- different boundary conditions;
- remaining flanking transmission.

Further uncertainty components of the second group are

- the measurement equipment including the calibration;
- effects of temperature, static pressure and humidity.

The sum of all uncertainty contributions from the first and the second group contain all influences covered by the term reproducibility conditions.

A third group of influences is made up of only one element. This is the product scatter of usual building elements. This uncertainty component is not handled within the scope of this part of ISO 12999 even though there are cases where it exceeds all the other components.

C.2 Calculation of the standard uncertainty of the measurand

The measurand Y is determined by N input quantities X_1, X_2, ..., X_N through a functional relationship f, as given by Formula (C.1):

$$Y = f\left(X_1, X_2, ...X_N\right) \tag{C.1}$$

A probability distribution (normal, rectangular, student-*t*, etc.) is associated with each of the input quantities. Its expectation (mean value) is the best estimate for the value of the input quantity and its standard deviation is a measure of the dispersion of values, termed uncertainty.

For the case of negligible correlation between the input quantities, the combined standard uncertainty of the estimate of the measurand y is given by Formula (C.2):

$$u_\text{c}\left(y\right) = \sqrt{\sum_{i=1}^{N}\left(\frac{\partial f}{\partial x_i}\right)^2 u^2\left(x_i\right)} \tag{C.2}$$

where

f is the function given in Formula (C.1);

$u(x_i)$ is the standard uncertainty of the estimate x_i representing the input quantity X_i.

At the current state of knowledge, the derivation of a functional relationship covering all effects mentioned in C.2 is not possible for all measurands in building acoustics, one reason being the unknown degree of correlation between input quantities.[3]

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