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T1 : Acoustique

T2 : Mesurage des paramètres acoustiques des salles

T3 : Partie 2: Durée de réverbération des salles ordinaires

E : Acoustics - Measurement of room acoustic parameters - Part 2: Reverberation time in ordinary rooms

D : Akustik - Messung von Parametern der Raumakustik - Teil 2: Nachhallzeit in gewöhnlichen Räumen

Avant-projet de norme française homologuée

Remplace la norme homologuée NF EN ISO 3382 de mai 2000.

Correspondance

Analyse

Modifications

EUROPEAN STANDARD

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Will supersede EN ISO 3382:2000

English Version

Acoustics - Measurement of room acoustic parameters - Part 2: Reverberation time in ordinary rooms (ISO/DIS 3382-2:2006)

Acoustique - Mesurage des paramètres acoustiques des salles - Partie 2: Durée de réverbération des salles ordinaires (ISO/DIS 3382-2:2006)

Akustik - Messung von Parametern der Raumakustik - Teil 2: Nachhallzeit in gewöhnlichen Räumen (ISO/DIS 3382-2:2006)

This draft European Standard is submitted to CEN members for parallel enquiry. It has been drawn up by the Technical Committee CEN/TC 126.

If this draft becomes a European Standard, CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

This draft European Standard was established by CEN in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Management Centre has the same status as the official versions.

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Recipients of this draft are invited to submit, with their comments, notification of any relevant patent rights of which they are aware and to provide supporting documentation.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: rue de Stassart, 36 B-1050 Brussels

Ref. No. prEN ISO 3382-2:2006: E

Foreword

This document (prEN ISO 3382-2:2006) 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 document is currently submitted to the parallel Enquiry.

This document will supersede EN ISO 3382:2000.

Endorsement notice

The text of ISO 3382-2:2006 has been approved by CEN as prEN ISO 3382-2:2006 without any modifications.

DRAFT INTERNATIONAL STANDARD ISO/DIS 3382-2

ISO/TC **43**/SC **2** Secretariat: **DIN**

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Acoustics — Measurement of room acoustic parameters —

Part 2: **Reverberation time in ordinary rooms**

Acoustique — Mesurage des paramètres acoustiques des salles —

Partie 2: Durée de réverbération des salles ordinaires

ICS 91.120.20

ISO/CEN PARALLEL ENQUIRY
The CEN Secretary-General has advised the ISO Secretary-General that this ISO/DIS covers a subject of interest to European standardization. **In accordance with the ISO-lead mode of collaboration as defined in the Vienna Agreement, consultation on this ISO/DIS has the same effect for CEN members as would a CEN enquiry on a draft European Standard.** Should this draft be accepted, a final draft, established on the basis of comments received, will be submitted to a parallel two-month FDIS vote in ISO and formal vote in CEN.

In accordance with the provisions of Council Resolution 15/1993 this document is circulated in the English language only.

Conformément aux dispositions de la Résolution du Conseil 15/1993, ce document est distribué en version anglaise seulement.

To expedite distribution, this document is circulated as received from the committee secretariat. ISO Central Secretariat work of editing and text composition will be undertaken at publication stage.

Pour accélérer la distribution, le présent document est distribué tel qu'il est parvenu du secrétariat du comité. Le travail de rédaction et de composition de texte sera effectué au Secrétariat central de l'ISO au stade de publication.

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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.

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 3382-2 was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 2.

It has been agreed with the Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 2, *Building acoustics* that this document should form a new Part 2 of ISO 3382. The existing International Standard ISO 3382:1997, *Acoustics – Measurement of the reverberation time of rooms with reference to other acoustical parameters* should be made Part 1. In this way it will be clear that the two standards are closely related but that they cover different applications. Part 1 contains the technical details of the measurement technique and the information for room acoustic measurements in performance spaces, including the measurement of other room acoustic parameters. Part 2 will not repeat the technical details of Part 1, but it deals with the measurement of reverberation time, only, in any kind of room.

ISO 3382 consists of the following parts, under the general title *Acoustics — Measurement of room acoustic parameters:*

— *Part 1: Performance rooms;*

— *Part 2: Reverberation time in ordinary rooms.*

The Annexes A, B and C are for information only.

Introduction

The reverberation time is important in many kinds of rooms and there are several purposes for measuring the reverberation time. The sound pressure level from noise sources, the intelligibility of speech and the privacy in a room are strongly dependent on the reverberation time. Examples of relevant rooms are living rooms, stairways, workshops, industrial halls, classrooms, offices, restaurants, exhibition areas, sports halls and railway and airport terminals. Another reason for measuring the reverberation time is for the correction term for room absorption inherent in many acoustic measurements. Examples of this are sound insulation measurements according to the ISO 140 series and sound power measurements according to the ISO 3740 series.

In some countries building codes specify the required reverberation times in classrooms and other categories of room. However, in the vast majority of rooms it is left for the design team to specify and design for a reverberation time that is reasonable for the purpose of a room. It is the hope that the present standard may contribute to the general understanding and acceptance of the importance of reverberation time for the quality and usability of rooms.

The standard specifies three levels of measurement accuracy: survey, engineering and precision. The main difference concerns the number of measurement positions and thus the time required for the measurements. Annex A contains some additional information about the measurement uncertainty of the reverberation time. By introducing the option of a survey measurement it is the hope that reverberation time will be measured more often in rooms where it is relevant. It seems obvious that even a very simple measurement is much better than no measurement.

Two different evaluation ranges are defined in the standard, 20 dB and 30 dB. However, a preference has been given to the 20 dB evaluation range for several reasons:

- The subjective evaluation of reverberation is related to the early part of the decay.
- For the estimation of the steady state sound level in a room from its reverberation time, it is appropriate to use the early part of the decay.
- The signal-to-noise ratio is often a problem in field measurements, and it is often difficult or impossible to get a evaluation range of more than 20 dB. This requires a signal-to-noise level of at least 35 dB.

The traditional measuring technique is based on visual inspection of every single decay curve. With modern measuring equipment the decay curves are normally not displayed and this may introduce a risk that abnormal decay curves are used for the determination of the reverberation time. For this reason Annex B introduces two new measures that quantify the degree of non-linearity and the degree of curvature of the decay curve. These measures may be used to give warnings when the decay curve is not linear, and consequently the result should be dismissed or marked as less reliable.

The use of rotating microphones during the measurement of decay curves has been considered by the working group, and this procedure is found to be without a clear physical meaning and thus it is not accepted in this standard.

Two other standards for reverberation time measurement already exist: ISO 3382 for auditoriums and performance spaces and ISO 354 for absorption coefficient measurements in a reverberation room. Neither of these standards is suited for measurements in rooms like those mentioned above. Thus the present standard is assumed to fill a gap among the measuring standards for acoustic properties of buildings.

Acoustics — Measurement of room acoustic parameters — Part 2: Reverberation time in ordinary rooms

1 Scope

This International Standard specifies methods for the measurement of reverberation time in rooms. It specifies the measurement procedure, the apparatus needed, the required number of measurement positions, and the method for evaluating the data and presenting the test report.

The measurement results may be used for correction of other acoustic measurements, e.g. sound pressure level from sound sources or measurements of sound insulation. The results may also be used for comparison with requirements for reverberation time in rooms. This standard is not applicable for concert halls and other performance spaces.

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 140 (all parts), *Acoustics — Measurement of sound insulation in buildings and of building elements*

ISO 10052, *Acoustics — Field measurements of airborne and impact sound insulation and of service equipment sound — Survey method*

ISO/FDIS 18233, *Acoustics – Application of new measurement methods in building acoustics*

ISO/CD 3382-1:2005, *Acoustics - Measurement of room acoustic parameters - Part 1: Performance spaces*

IEC 60268-1:1985, *Sound system equipment – Part 1: General*

IEC 61260, *Electro acoustics — Octave-band filters and fractional-octave-band filters*

3 Terms and definitions

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

3.1
decay curve
decay of sound pressure level as a function of time at one point of the room after the source of sound has ceased

NOTE 1 This decay can be either measured after the actual cut-off of a continuous sound source in the room or derived from the reverse-time integrated squared impulse response of the room, see clause 5.

NOTE 2 The decay directly obtained after non-continuous excitation of a room (e.g. by recording a gunshot with a level recorder) is not recommended for accurate evaluation of the reverberation time. This method should only be used for survey purposes following the procedure for survey measurements.

3.2
interrupted noise method
method of obtaining decay curves by direct recording of the decay of sound pressure level after exciting a room with broadband or band limited noise and turning it off

3.3
integrated impulse response method
method of obtaining decay curves by reverse-time integration of squared impulse responses

3.4
impulse response
plot as a function of time of the sound pressure received in a room as a result of an acoustical excitation of the room by a Dirac delta signal

NOTE It is impossible in practice to create and radiate true Dirac delta functions but short transient sounds (e.g. from gunshots) may offer close enough approximations for practical measurement. An alternative measurement technique, however, is to use a period of maximum-length sequence type signal or other deterministic, flat-spectrum signal like a sine sweep and transform the measured response back to an impulse response.

3.5
reverberation time
T
time, expressed in seconds, that would be required for the sound pressure level to decrease by 60 dB

NOTE The range to be evaluated is defined by the times at which the decay curve first reaches 5 dB and 25 dB below the initial level, respectively. A value for T based on the decay rate over an extended dynamic range of 30 dB is also allowable provided the results are appropriately labelled. In the case of ambiguity the measure for T using the decay between 5 dB and 35 dB should be labelled T_{30}. Using 5 dB and 25 dB, the result should be labelled T_{20}.

3.6
large room volume
a room volume over 300 m^2

4 Measurement conditions

4.1 General

In many commonly encountered rooms the number of people present may have a strong influence on the reverberation time. Preferably reverberation time measurements should be made in a room containing no people. However, it may normally be allowed to represent an unoccupied state of the room with up to two persons present in the room, unless something else is demanded by the requirements. If the measuring result is used for correction of a measured sound pressure level the number of persons present in the room should be the same for that measurement.

In large rooms the attenuation by the air may contribute significantly to the sound absorption at high frequencies. For precision measurements the temperature and relative humidity of the air in the room shall normally be measured.

NOTE The contribution from air absorption is of minor importance if the reverberation time is shorter than 1,5 s at 2 kHz and shorter than 0,8 s at 4 kHz. In this case it is not necessary to measure the temperature and relative humidity.

4.2 Equipment

4.2.1 Sound source

For precision measurements the sound source should be as close to omni-directional as possible (see ISO/CD 3382-1, A.3.1). The sound source should not be strongly directional for any level of accuracy. For the survey and engineering measurements any loudspeaker which is not strongly directional may be used. It shall produce a sound pressure level sufficient to provide decay curves with the required minimum dynamic range without contamination by background noise.

4.2.2 Microphones and analysis equipment

Omni-directional microphones shall be used to detect the sound pressure and the output may be taken either

— directly to an amplifier, filter set and a system for displaying decay curves or analysis equipment for deriving the impulse responses; or

— to a signal recorder for later analysis.

4.2.2.1 Microphone and filters

The microphone should be as small as possible and preferably have a maximum diaphragm diameter of 14 mm. Microphones with diameters up to 27 mm are allowed, if they are of the pressure response type or of the free field response type but supplied with a random incidence corrector. The octave or one-third-octave filters shall conform to IEC 61260.

4.2.2.2 Apparatus for forming decay record of level

The apparatus for forming (and displaying and/or evaluating) the decay record shall use any of the following:

a) exponential averaging, with continuous curve as output;

b) exponential averaging, with successive discrete sample points from the continuous average as output;

c) linear averaging, with successive discrete linear averages as output (in some cases with small pauses between performance of averages).

The averaging time, i.e. time constant of an exponential averaging device shall be less than, but as close as possible to $T/30$. Similarly, the averaging time of a linear averaging device shall be less than $T/12$. Here T is the reverberation time being measured.

In apparatus where the decay record is formed as a succession of discrete points, the time interval between points on the record shall be less than 1,5 times the averaging time of the device.

In all cases where the decay record is to be evaluated visually, adjust the time scale of the display so that the slope of the record is as close as possible to 45°.

NOTE 1 The averaging time of an exponential averaging device is equal to 4,34 (=10 lg e) divided by the decay rate in decibels per second of the device.

NOTE 2 Commercial level recorders, in which sound pressure level is recorded graphically as a function of time, are usually equivalent to exponential averaging devices.

NOTE 3 When an exponential averaging device is used there is little advantage in setting the averaging time very much less than $T/30$. When a linear averaging device is used there is no advantage in setting the interval between points at very much less than $T/12$. In some sequential measuring procedures it is feasible to set the averaging time appropriately for each frequency band. In other procedures this is not feasible, and an averaging time or interval chosen as above with reference to the shortest reverberation time in any band has to serve for measurements in all bands.

4.2.2.3 Overload

No overloading shall be allowed in any stage of the measuring apparatus. Where impulsive sound sources are used, peak-level indicating devices shall be used for checking against overloading.

4.3 Measurement positions

4.3.1 General

The number of measurement positions is chosen in order to achieve an appropriate coverage in the room (see Table 1). The numbers in the table are minimum values. In rooms with a complicated geometry more measurement positions should be used. A distribution of microphone-positions shall be chosen which anticipates the major influences likely to cause differences in reverberation time throughout the room.

Table 1 — Minimum number of positions and measurements

	Survey	Engineering[c]	Precision
Source-microphone combinations	2	6	12
Source positions	≥ 1	≥ 2	≥ 2
Microphone positions	≥ 2	≥ 2	≥ 3
Number of decays in each position (interrupted noise method)	1	2	3

[a] For the interrupted noise method uncorrelated sources may be used simultaneously.

[b] For the interrupted noise method and when the result is used for a correction term a rotating microphone boom may be used instead of multiple microphone positions.

[c] For the interrupted noise method and when the result is used for a correction term to other engineering-level measurements, only one source position and three microphone positions are required.

For the interrupted noise method the total number of decays is normally obtained by a number of repeated decays in each position. However, it is also allowed to take a new position for each decay, provided that the total number of decays is as prescribed.

Source positions may be chosen as the normal position according to the use of the room. In small rooms such as domestic rooms and when no normal positions exist, one source position should be in a corner of the room. Microphone positions shall be at least half a wavelength apart, i.e. a minimum distance of around 2 m for the usual frequency range. The distance from any microphone position to the nearest reflecting surface, including the floor, shall be at least a quarter of a wavelength, i.e. normally around 1 m. Symmetric positions should be avoided.

NOTE It is essential that the microphone positions are not too close together. Otherwise the number of independent positions is less than the actual number of measurement positions. The minimum numbers given in Table 1 are the numbers of independent positions.

No microphone position shall be too close to any source position in order to avoid too strong influence from the direct sound. The minimum distance d_{min}, in metres, can be calculated from:

$$d_{\text{min}} = 2\sqrt{\frac{V}{cT}} \quad (1)$$

where

V is the volume, in cubic metres;

c is the speed of sound, in metres per second;

T is an estimate of the expected reverberation time, in seconds.

4.3.2 Survey method

The survey method is appropriate for the assessment of the amount of the room absorption for noise control purposes, and survey measurements of the airborne and impact sound insulation. It should be used for measurements in ISO 10052. Survey measurements are made in octave bands, only. The nominal accuracy is assumed to be better than 10% for octave bands, see Annex A.

Make measurements of the reverberation time for at least one source-position. Find the average of results from at least two microphone-positions, see Table 1.

4.3.3 Engineering method

The engineering method is appropriate for verification of building performance for comparison with specifications of reverberation time or room absorption. It should be used for measurements in all parts of ISO 140 with remarks to reverberation time measurements. The nominal accuracy is assumed to be better than 5% in octave bands and better than 10% in one-third octave bands, see Annex A.

Make measurements of the reverberation time for at least two source positions. At least 6 independent source-microphone positions are required, see Table 1.

4.3.4 Precision method

The precision method is appropriate where high measurement accuracy is required. The nominal accuracy is assumed to be better than 2,5% in octave bands and better than 5% in one-third octave bands, see Annex A.

Make measurements of the reverberation time for at least two source positions. At least 12 independent source-microphone positions are required, see Table 1.

5 Measurement procedures

5.1 General

Two methods of measuring the reverberation time are described in this standard: the interrupted noise method and the integrated impulse response method. Both methods have the same expectation value. The frequency range depends on the purpose of the measurements. Where there is no requirement for specific frequency bands, the frequency range should cover at least 250 Hz to 2 000 Hz for the survey method. For the engineering and precision methods the frequency range should cover at least 125 Hz to 4 000 Hz in octave bands, or 100 Hz to 5 000 Hz in one-third octave bands.

5.2 Interrupted noise method

5.2.1 Excitation of the room

A loudspeaker source shall be used and the signal fed into the loudspeaker shall be derived from broadband random or pseudo-random electrical noise. When using a pseudo-random noise, it shall be randomly ceased, not using a repeated sequence. The source shall be able to produce a sound pressure level sufficient to ensure a decay curve starting at least 35 dB above the background noise in the corresponding frequency band. If T_{30} is to be measured it is necessary to create a level at least 45 dB above the background level.

For measurements in octave bands the bandwidth of the signal shall be greater or equal to one octave and for measurements in one-third-octave bands the bandwidth of the signal shall be greater or equal to one-third octave. The spectrum shall be reasonably flat within the actual octave band to be measured. Alternatively, the broadband noise spectrum may be shaped to provide a pink spectrum of steady-state reverberant sound in the enclosure from 88 Hz to 5 657 Hz. Thus the frequency range covers the one-third-octave bands with mid-band frequencies from 100 Hz to 5 kHz or octave bands from 125 Hz to 4 kHz.

For the engineering and precision methods, the duration of excitation of the room needs to be sufficient for the sound field to have achieved a steady state before the source is switched off. Thus it is essential for the noise to be radiated for a minimum period of $T/2$ seconds. In large volumes the duration of the excitation shall be at least a few seconds.

For the survey method it is allowed to use a short excitation or an impulse signal as an alternative to the interrupted noise signal. However, in that case the measuring accuracy is less than stated in 4.3.1.

5.2.2 Averaging of measurements

The number of microphone positions used will be determined by the accuracy required. However, in view of the randomness inherent in the source signal, it is necessary to average over a number of measurements at each position in order to achieve an acceptable measurement uncertainty (see 7.1). The averaging can be made in two different ways, either

- find the individual reverberation times for all the decay curves and take the mean value, or
- make an ensemble average of the squared sound pressure decays and find the reverberation time of the resulting decay curve. The individual decays are superposed with their beginnings synchronised. The discrete squared sound pressure sample values are summed for each time interval increment of the decays and the sequence of these sums is used as a single overall ensemble decay from which T is then evaluated. It is important that the sound power emitted by the source is kept the same for all measurements. This is the preferred method.

5.3 Integrated impulse response method

5.3.1 General

The impulse response from a source position to a receiver position in a room is a well-defined quantity, which can be measured in a variety of ways (e.g. using pistol shots, spark gap impulses, noise bursts, chirps or m-sequences as signals). It is not the aim of this standard to exclude any other method that can yield the correct impulse response.

5.3.2 Excitation of the room

The impulse response can be measured directly using an impulse source such as a pistol shot or any other source that is not reverberant itself as long as its spectrum is broad enough to meet the requirements of 5.2.1. The impulse source shall be able to produce a peak sound pressure level sufficient to ensure a decay curve starting at least 35 dB above the background noise in the corresponding frequency band. If T_{30} is to be measured it is necessary to create a level at least 45 dB above the background level.

Special sound signals may be used which yield the impulse response only after special processing of the recorded microphone signal, see ISO/FDIS 18233:2005. This can provide an improved signal-to-noise ratio. Sine sweeps or pseudo-random noise (e.g. maximum-length sequences) may be used if the requirements for the spectrum and directional characteristics of the source are fulfilled. Because of the improvement in signal-to-noise ratio, the dynamic requirements on the source can be considerably lower than those set in the previous paragraph. If time averaging is used it is necessary to verify that the averaging process does not alter the measured impulse response. Using these measuring techniques the frequency filtering is often inherent in the signal analysis, and it is sufficient that the excitation signal covers the frequency bands to be measured.

5.3.3 Integration of the impulse response

Generate for each octave band or third octave band the decay curve by a backward integration of the squared, filtered impulse response. For further details see ISO/CD 3382-1:2005.

NOTE In the limit of an infinite number of measurements with interrupted noise, the ensemble averaged decay curve will be identical with that of a single integrated squared impulse response.

6 Evaluation of decay curves

For the determination of T_{20} the evaluated range for the decay curves is from 5 dB to 25 dB below the steady state level. For the integrated impulse response method the steady state level is the total level of the integrated impulse response. Within the evaluation range a least-squares fit line shall be computed for the curve or, in the case of decay curves plotted directly by level recorder, a straight line shall be fitted manually as closely as possible to the decay curve. The formula for the least square method is given in Annex C. Other algorithms that provide similar results may be used. The slope of the straight line gives the decay rate *d* in decibels per second, from which the reverberation time is calculated as T_{20} = 60/*d*. For the determination of T_{30} the evaluation range is from 5 dB to 35 dB.

If the technique used for determining the reverberation time is based on evaluating traces plotted out by a level recorder, then a visual "best fit" line may be substituted for a computed regression line but this will not be as reliable as a regression analysis.

In order to specify a reverberation time, it is essential that the decay curves follow approximately a straight line. If the curves are wavy or bent this may indicate a mixture of modes with different reverberation times and thus the result may be unreliable. Two indicators of non-linear decay curves are proposed in Annex B

7 Measurement uncertainty

7.1 Interrupted noise method

Due to the random nature of the excitation signal, the measurement uncertainty of the interrupted noise method strongly depends on the number of averages performed. Ensemble averaging and the averaging of individual reverberation times have the same dependencies on the number of averages. The standard deviation of the measurement result T_{20} or T_{30}, respectively, can be estimated from

$$\sigma(T_{20}) = 0{,}88 \times T_{20} \sqrt{\frac{1 + 1{,}90/n}{N\,B\,T_{20}}} \tag{2}$$

$$\sigma(T_{30}) = 0{,}55 \times T_{30} \sqrt{\frac{1 + 1{,}52/n}{N\,B\,T_{30}}} \tag{3}$$

where

n is the number of decays measured in each position;

N is the number of independent measurement positions (combinations of source and receiver positions);

B is the bandwidth, in Hz.

The equations (2) and (3) are based on certain assumptions concerning the averaging device. Further information is given in Annex A.

For an octave filter $B = 0{,}71 \times f_c$, and for one-third-octave filter $B = 0{,}23 \times f_c$, where f_c is the mid-band frequency of the filter in Hz. Octave band measurements give a better measurement accuracy than one-third-octave measurements with the same number of measurement positions.

7.2 Integrated impulse response method

The measurement uncertainty using the integrated impulse response method is of the same order of magnitude as that using an average of n = 10 measurements in each position with the interrupted noise method. No additional averaging is necessary to increase the statistical measurement accuracy for each position.

7.3 Lower limits for reliable results caused by filter and detector

In the case of very short reverberation times the decay curve can be influenced by the filter and the detector. Using traditional forward analysis the lower limits for reliable results shall be:

$$B\,T > 16 \quad \text{and} \tag{4}$$

$$T > 2\,T_{\text{det}} \tag{5}$$

where

B is the filter bandwidth in Hz;

T_{det} is the reverberation time of the averaging detector.

NOTE Very short reverberation times may be analysed using the time reversal technique described in ISO/CD 3382-1:2005. In that case the lower limits for reliable results are $B\,T > 4$ and $T > T_{\text{det}}/4$.

8 Spatial averaging

The results measured for the range of source and microphone positions can be combined either for separate identified areas or for the room as a whole to give spatial average values. This spatial averaging shall be achieved by either of the following procedures:

a) Arithmetic averaging of the reverberation times. The spatial average is given by taking the mean of the individual reverberation times for all the independent source and microphone positions. The standard deviation may be determined to provide a measure of accuracy and the spatial variance of the reverberation time.

b) Ensemble averaging of the decay curves. The individual decays are superposed with their beginnings synchronised, see 5.2.2.

9 Statement of results

9.1 Tables and curves

The evaluated reverberation times for each frequency of measurement shall be stated in a table. The result may also be plotted in the form of a graph.

In the case of a graph either straight lines connecting the points or a bar graph should be used. The abscissa shall present frequency on a logarithmic scale, whilst the ordinate shall use either a linear time scale with an origin of zero, or a logarithmic scale. The nominal mid-band frequencies for octave bands according to IEC 61260 should be marked on the frequency axis.

In the table and graph it shall be clearly stated whether T_{20} or T_{30} is used for the reverberation time.

9.2 Test report

The test report shall state that the measurements were made in conformity with this International Standard. It shall include:

a) name and place of the room tested;

b) sketch plan of the room, with an indication of the scale;

c) volume of the room;

NOTE If the room is not completely enclosed, an explanation shall be given of how the stated volume is defined.

d) condition of the room (furniture, number of persons present etc.);

e) temperature and relative humidity in the room during the measurement (precision method, only);

f) type of sound source;

g) description of the sound signal used;

h) degree of precision (survey, engineering or precision) including details of the source and microphone positions, preferably shown on a plan together with an indication of the heights of the positions;

i) description of measuring apparatus and the microphones;

j) method used for evaluation of the decay curves, either computed least squares best fit or a visual best fit (clause 6);

k) method used for averaging the result in each position (5.2.2);

l) method used for averaging the result over the positions (Clause 8);

m) table with the measuring results;

n) date of measurement and name of the measuring organisation.

Annex A
(informative)

Measurement uncertainty

A.1 General

The measurement uncertainty of decay rate measurements has been studied in [1] and [2].

The decay rate d in dB/s is related to the reverberation time T, in s, by : $d = 60/T$. The ensemble variance in one position is $\mathrm{var_e}(d)$. The measurements can be repeated in the same position and n denotes the number of decays measured in each position. The spatial variance is $\mathrm{var_s}(d)$. The number of independent measurement positions is denoted N.

The variance of the grand average $\bar{d}$ is

$$\mathrm{var}(\bar{d}) = \frac{1}{N}\mathrm{var_s}(d) + \frac{1}{N\,n}\mathrm{var_e}(d) \tag{A.1}$$

The relative variance of the reverberation time is

$$\frac{\mathrm{var}(\bar{T})}{\bar{T}^2} = \frac{\mathrm{var}(\bar{d})}{\bar{d}^2} \tag{A.2}$$

Thus, the estimated relative standard deviation of the average reverberation time (also known as the standard uncertainty) is

$$\frac{\sigma(\bar{T})}{\bar{T}} = \sqrt{\frac{\mathrm{var}(\bar{d})}{\bar{d}^2}} = \frac{1}{\sqrt{N}}\sqrt{\frac{\mathrm{var_s}(d)}{d^2} + \frac{\mathrm{var_e}(d)}{n\,d^2}} \tag{A.3}$$

A.2 The interrupted noise method

In [1] the ensemble variance and the spatial variance were derived for the case of measurements using the interrupted noise method. By inserting the results from [1] equations (2.55) and (2.56) in (A.3) we get

$$\frac{\sigma(\bar{T})}{\bar{T}} = G\sqrt{\frac{1 + H/n}{N\,B\,T}} \tag{A.4}$$

where

B is the bandwidth, in Hz;

G and H are constants that depend on the evaluation range D;

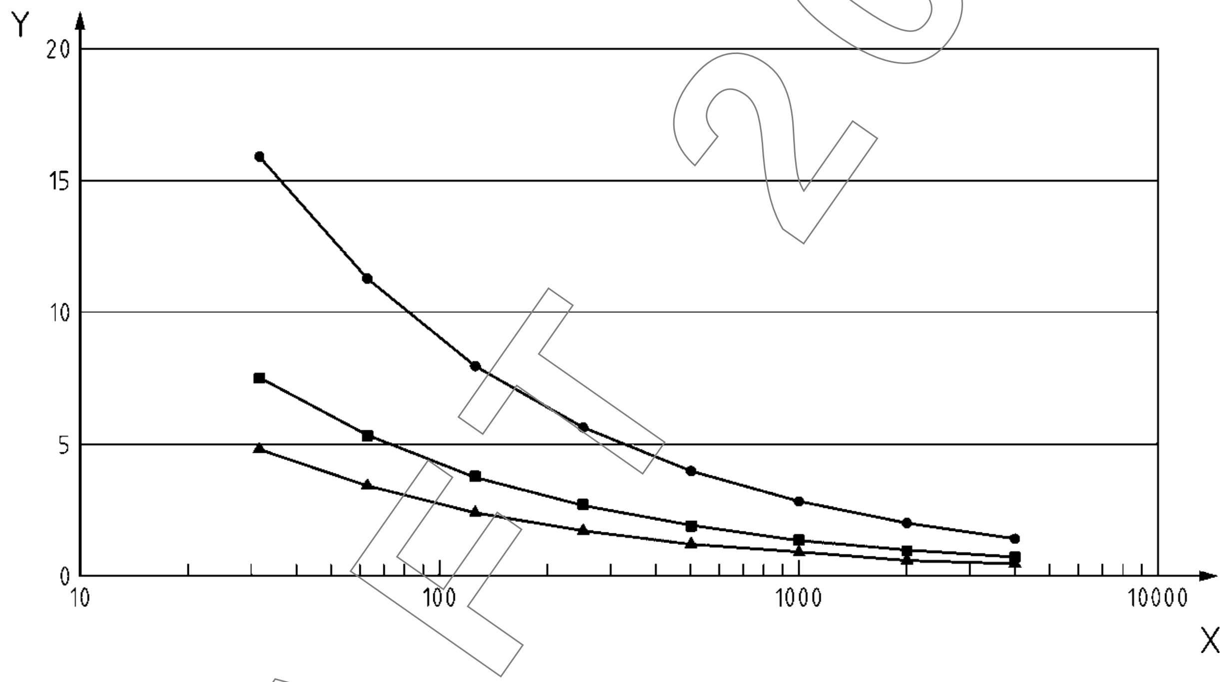
$\gamma = T / T_{\mathrm{det}}$ is the ratio of measured reverberation time and the reverberation time inherent in the measuring apparatus.

T_{det} is the reverberation time of the averaging detector. For some typical values of D and γ the values of the constants G and H can be taken from Table A.1.

The equations (2) and (3) in the main body of the standard are taken for the parameter $\gamma = 5$.

Table A.1 — Values of the constants G and H

Evaluation range, D dB	G %	H $\gamma = 3$	H $\gamma = 5$	H $\gamma = 10$
10	175	2,67	3,32	3,87
20	88	1,72	1,90	2,04
30	55	1,42	1,52	1,59



Key

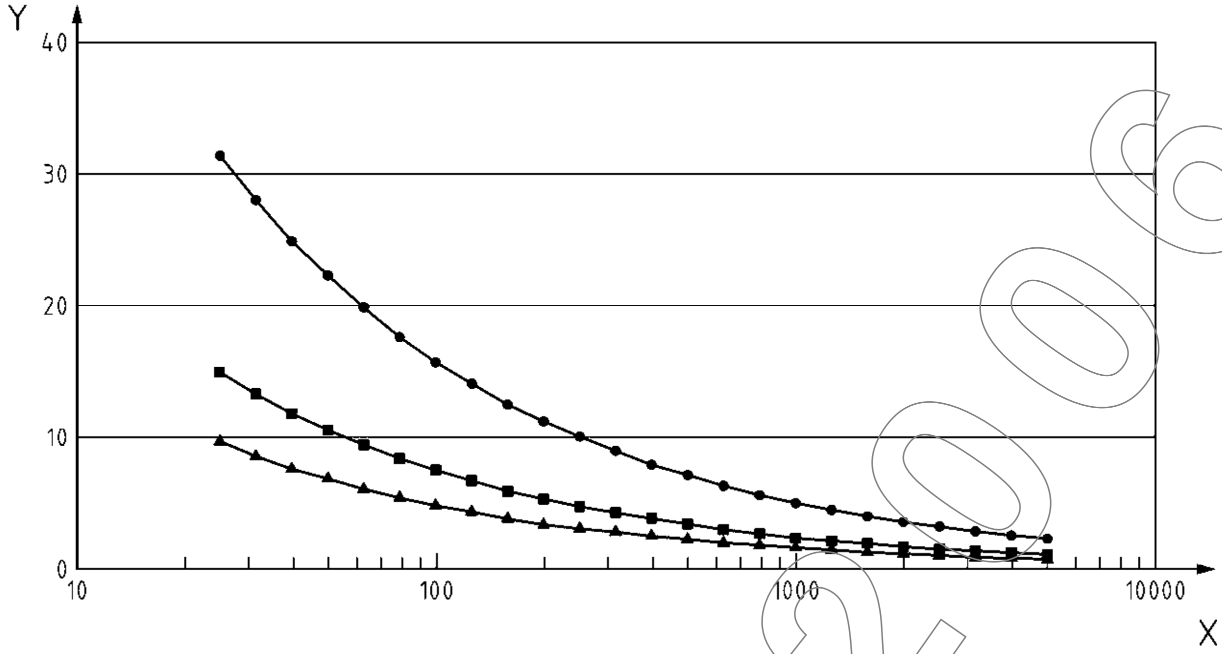
—●— Survey

—■— Engineering

—▲— Precision

x Frequency x Reverberation Time
y Standard deviation, $s(T_{20})/T_{20}$, %

Figure A.1 — The relative standard deviation for measurements of T_{20} in octave bands as a function of the centre frequency multiplied by the reverberation time. The curves represent survey-, engineering- and precision method



Key

—●— Survey

—■— Engineering

—▲— Precision

x Frequency x Reverberation Time
y Standard deviation, $s(T_{20})/T_{20}$, %

Figure A.2 — The relative standard deviation for measurements of T20 in third octave bands as a function of the centre frequency multiplied by the reverberation time. The curves represent survey-, engineering- and precision method.

A.3 The integrated impulse response method

For the integrated impulse response method the ensemble variance is theoretically $\mathrm{var}_e(d) = 0$. This corresponds to the averaging of an infinite number of excitations in the same position, if the interrupted noise method had been used, see [2]. For the estimation of the standard deviation of a measurement result equation (A.4) may be used with a value of n = 10.

Annex B
(informative)

Evaluation of non-linear decay curves

B.1 General

The measurement of reverberation time is based on the assumption that within the evaluation range a straight line can approximate the slope of the decay curve. It can be useful to have some information about the extent to which this assumption is actually fulfilled. Two such indicators are proposed in this annex.

B.2 The degree of non-linearity

If the evaluation of the decay curve is made by a least-squares fit of a straight line, the following non-linearity parameter may be calculated. Let L_i be the level in dB of sample number i, $L_{est,i}$ is the estimate value of sample number i from the linear regression, and the mean value of the samples is

$$L_{mean} = \frac{1}{m}\sum_{i=1}^{m} L_i \tag{B.1}$$

The square of the correlation coefficient is

$$r^2 = \frac{\sum_{i=1}^{m}(L_{est,i} - L_{mean})^2}{\sum_{i=1}^{m}(L_i - L_{mean})^2} \tag{B.2}$$

The squared correlation coefficient can have any value between 0 and 1 and a perfectly straight decay curve corresponds to $r^2 = 1$. The non-linearity parameter ξ is introduced as the permillage deviation from perfect linearity

$$\xi = 1000\,(1 - r^2)\ ‰ \tag{B.3}$$

Typical values of ξ are 0 ‰ to 5 ‰. Values higher than 10 ‰ indicate a decay curve, which is far from being a straight line and the value of the reverberation time estimated from the decay curve may be suspicious. These values apply to ensemble-averaged curves and integrated impulse response curves; higher values may occur for individual decay curves.

B.3 The degree of curvature

The decay curve measured in a room will often be slightly bent. The initial part of the decay is typically a little steeper than the late part of the decay. The reason for this is that the decay represents a mixture of decaying modes with different decay rates. If the absorption is not evenly distributed on the surfaces of the room the modes may have very different decay rates. Obviously, a bent decay curve means that the reverberation time evaluated from the measurement depends on which part of the decay curve is used. Consequently the result is less reliable than if the decay curve is not bent.

The curvature parameter C is based on the two evaluation ranges of 20 dB and 30 dB and it is introduced as the percentage deviation from a perfectly straight line

$$C = 100 \times \left(\frac{T_{30}}{T_{20}} - 1 \right) \% \qquad \text{(B.4)}$$

Typical values of C are 0% to 5%. Values higher than 10% indicate a decay curve, which is far from being a straight line and the value of the reverberation time estimated from the decay curve may be suspicious. Negative values should not occur and they may indicate an error in the measurement.

Annex C
(informative)

Formulas for the least square fit method

C.1 Algorithm

The reverberation time may be evaluated by using linear regression analysis and the least-squares fit procedure. This means that the decay curve is approximated by a straight line

$$L_{\text{est},i} = a + b\,t_i \quad \text{(dB)} \tag{C.1}$$

where

a is the intercept of the straight line, in dB,

b is the slope estimate, in dB/s,

t_i is the time of sample number *I*, in s.

According to the least-squares fit procedure the intercept and slope estimates shall be determined as follows

$$a = L_{\text{mean}} - b\,t_{\text{mean}} \tag{C.2}$$

$$b = \frac{\sum_{i=1}^{m} (t_i\,L_i) - m\,t_{\text{mean}}\,L_{\text{mean}}}{\sum_{i=1}^{m} (t_i^2) - m\,t_{\text{mean}}^2} \tag{C.3}$$

where

$$L_{\text{mean}} = \frac{1}{m}\sum_{i=1}^{m} L_i \quad \text{, in dB;} \tag{C.4}$$

$$t_{\text{mean}} = \frac{1}{m}\sum_{i=1}^{m} t_i \quad \text{, in s.} \tag{C.5}$$

The estimate of the reverberation time is

$$T = -60/b \quad \text{, in s} \tag{C.6}$$

Bibliography

[1] J.L. Davy, I.P. Dunn & P. Dubout. The Variance of Decay rates in Reverberation Rooms. Acustica **43** (1979) pp. 12-25.

[2] J.L. Davy. The Variance of Impulse Decays. Acustica **44** (1980) pp. 51-56.

