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Acoustics — Measurement of room acoustic parameters —

Part 1: Performance spaces

Acoustique — Mesurage des paramètres acoustiques des salles —

Partie 1: Salles de spectacles

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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 3382-1 was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 2, *Building acoustics*.

This first edition of ISO 3382-1, together with ISO 3382-2 and ISO 3382-3, cancels and replaces ISO 3382:1997, of which it constitutes a technical revision. Annex A has been extended with information on JND (just noticeable difference), recommended frequency averaging and by the addition of a new parameter for LEV (listener envelopment). A new Annex C has been added with parameters for the acoustic conditions on the orchestra platform.

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

— *Part 1: Performance spaces*

— *Part 2: Reverberation time in ordinary rooms*

Open plan spaces are to form the subject of a future part 3.

Introduction

The reverberation time of a room was once regarded as the predominant indicator of its acoustical properties. While reverberation time continues to be regarded as a significant parameter, there is reasonable agreement that other types of measurements, such as relative sound pressure levels, early/late energy ratios, lateral energy fractions, interaural cross-correlation functions and background noise levels, are needed for a more complete evaluation of the acoustical quality of rooms.

This part of ISO 3382 establishes a method for obtaining reverberation times from impulse responses and from interrupted noise. The annexes introduce the concepts and details of measurement procedures for some of the newer measures, but these do not constitute a part of the formal specifications of this part of ISO 3382. The intention is to make it possible to compare reverberation time measurements with higher certainty and to promote the use of and consensus in measurement of the newer measures.

Annex A presents measures based on squared impulse responses: a further measure of reverberation (early decay time) and measures of relative sound levels, early/late energy fractions and lateral energy fractions in auditoria. Within these categories, there is still work to be done in determining which measures are the most suitable to standardize upon; however, since they are all derivable from impulse responses, it is appropriate to introduce the impulse response as the basis for standard measurements. Annex B introduces binaural measurements and the head and torso simulators (dummy heads) required to make binaural measurements in auditoria. Annex C introduces the support measures that have been found useful for evaluating the acoustic conditions from the musicians' point of view.

Acoustics — Measurement of room acoustic parameters —

Part 1:
Performance spaces

1 Scope

This part of ISO 3382 specifies methods for the measurement of reverberation time and other room acoustical parameters in performance spaces. It describes the measurement procedure, the apparatus needed, the coverage required, and the method of evaluating the data and presenting the test report. It is intended for the application of modern digital measuring techniques and for the evaluation of room acoustical parameters derived from impulse responses.

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.

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

IEC 61672-1, *Electroacoustics — Sound level meters — Part 1: Specifications*

3 Terms and definitions

For the purposes of this part of ISO 3382, the following terms and definitions apply.

3.1
decay curve
graphical representation of the decay of the sound pressure level in a room as a function of time after the sound source has stopped

[ISO 354:2003, 3.1]

NOTE 1 It is possible to measure this decay either 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 ought only be used for survey purposes. The decay of the impulse response in a room is in general not a simple exponential decay, and thus the slope is different from that of the integrated impulse response.

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

[ISO 354:2003, 3.3]

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

[ISO 354:2003, 3.4]

3.4
impulse response
temporal evolution of the sound pressure observed at a point in a room as a result of the emission of a Dirac impulse at another point in the room

[ISO 354:2003, 3.5]

NOTE It is impossible in practice to create and radiate true Dirac delta functions, but short transient sounds (e.g. from gunshots) can offer close enough approximations for practical measurement. An alternative measurement technique, however, is to use a period of maximum-length sequence (MLS) 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
⟨room acoustic parameters⟩ duration required for the space-averaged sound energy density in an enclosure to decrease by 60 dB after the source emission has stopped

NOTE 1 The reverberation time is expressed in seconds.

NOTE 2 T can be evaluated based on a smaller dynamic range than 60 dB and extrapolated to a decay time of 60 dB. It is then labelled accordingly. Thus, if T is derived from the time at which the decay curve first reaches 5 dB and 25 dB below the initial level, it is labelled T_{20}. If decay values of 5 dB to 35 dB below the initial level are used, it is labelled T_{30}.

3.6 States of occupancy

3.6.1
unoccupied state
state of a room prepared for use and ready for speakers or for performers and audience, but without these persons being present, and in the case of concert halls and opera houses, preferably with the performers' chairs, music stands and percussion instruments, etc.

3.6.2
studio state
⟨rooms for speech and music⟩ state of a room occupied by performers or speakers only and without an audience (for example, during rehearsals or sound recordings) and with the number of performers and other persons such as technicians corresponding to the usual number

3.6.3
occupied state
state of an auditorium or theatre when 80 % to 100 % of the seats are occupied

NOTE Reverberation time measured in a room will be influenced by the number of people present and the above states of occupancy are defined for measurement purposes.

4 Measurement conditions

4.1 General

The measurements of reverberation time may be made with the room in any or all states of occupancy. Where the room has adjustable components for providing variable acoustical conditions, it can be relevant to carry out separate measurements with these components in each of their normal settings. The temperature and relative humidity of the air in the room should be measured to an accuracy of ± 1 °C and ± 5 %, respectively.

An accurate description of the state of occupancy of the room is of decisive importance in assessing the results obtained by measuring the reverberation time. Extraordinary occupancies (such as that which would be created in a concert hall by a larger than usual orchestra or the additional presence of a choir or standees) shall be noted with the results.

In theatres, a distinction shall be made between “safety curtain up” and “safety curtain down”, between “orchestra pit open” and “orchestra pit closed”, and also between “orchestra seated on the stage”, with and without concert enclosure. In all of these cases, measurement can be useful. If the safety curtain is up, the amount of furnishing of the stage is of importance and shall be described.

Where variable components involve active (i.e. electronic) techniques, the effects of these should be measured, too, but as certain types of electronic reverberation enhancement systems create non-time-stationary conditions in the room, a unique impulse response will not exist and caution should be exercised in using synchronous averaging during the course of making measurements.

4.2 Equipment

4.2.1 Sound source

The sound source shall be as close to omnidirectional as possible (see Table 1). It shall produce a sound pressure level sufficient to provide decay curves with the required minimum dynamic range, without contamination by background noise. In the case of measurements of impulse responses using pseudo-random sequences, the required sound pressure level might be quite low because a strong improvement of the signal-to-noise ratio by means of synchronous averaging is possible. In the case of measurements which do not use a synchronous averaging (or other) technique to augment the decay range, a source level will be required that gives at least 45 dB above the background level in the corresponding frequency band. If only T_{20} is to be measured, it is sufficient to create a level at least 35 dB above the background level.

Table 1 lists the maximum acceptable deviations from omnidirectionality when averaged over “gliding” 30° arcs in a free sound field. In case a turntable cannot be used, measurements per 5° should be performed, followed by “gliding” averages, each covering six neighbouring points. The reference value shall be determined from a 360° energetic average in the measurement plane. The minimum distance between source and microphone shall be 1,5 m during these measurements.

Table 1 — Maximum deviation of directivity of source in decibels for excitation with octave bands of pink noise and measured in free field

Frequency, hertz	125	250	500	1 000	2 000	4 000
Maximum deviation, decibels	± 1	± 1	± 1	± 3	± 5	± 6

4.2.2 Microphones, recording and analysis equipment

4.2.2.1 General

Omnidirectional 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.

4.2.2.2 Microphone and filters

The measurement equipment shall meet the requirements of a type 1 sound level meter according to IEC 61672-1. The octave or one-third-octave filters shall conform with IEC 61260. The microphone should be as small as possible and preferably have a maximum diaphragm diameter of 13 mm. Microphones with diameters up to 26 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 yielding a flat frequency response at random incidence.

4.2.2.3 Recording device

If the sound decay is initially recorded on magnetic tape or a digital recording device, automatic gain control or other circuits for dynamic optimization of signal-to-noise ratio shall not be used. The recording time of each decay shall be sufficiently long to enable determination of the final background level following the decay; five seconds plus the expected reverberation time is recommended as a minimum.

The recording device shall have the following characteristics for the particular combination of record and playback speeds used.

a) The frequency response shall be flat over the frequency range of measurement with a smaller tolerance than ± 3 dB.

b) The dynamic range shall be sufficient to allow the required minimum decay curve range. In the case of interrupted noise decays, the recorder shall be capable of providing a signal-to-noise ratio of at least 50 dB in every frequency band concerned.

c) The ratio of the playback speed to the record speed shall be within ± 2 % of $10^{0,1 \times n}$, where n is an integer including zero.

NOTE If speed translation is used on playback, the corresponding frequency translation will then be a whole number of standard one-third-octave band spacings or, if n is a multiple of three, of octave band spacings.

Where a tape recorder is used, then in respect of the speed of response of the apparatus for forming a record of the decay of sound pressure level with time (see 4.2.2.4), T refers to the effective reverberation time of the signal being played back. This will differ from the true reverberation time of the enclosure only if the playback speed differs from the record speed.

When the decay has been recorded for replay through filters and an integrating device, it can be beneficial to time-reverse the responses during replay (see Reference [10]).

4.2.2.4 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 (or appropriate equivalent), 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 or, if appropriate, the effective reverberation time as described in the penultimate paragraph of 4.2.2.3.

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 dB [= 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 approximately 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 reset 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.

4.2.2.5 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

Source positions should be located where the natural sound sources in the room would typically be located. A minimum of two source positions shall be used. The height of the acoustic centre of the source should be 1,5 m above the floor.

Microphone positions should be at positions representative of positions where listeners would normally be located. For reverberation time measurements, it is important that the measurement positions sample the entire space; for the room acoustic parameters described in Annexes A and B, they should also be selected to provide information on possible systematic variations with position in the room. Microphone positions shall be at least half a wavelength apart, i.e. a 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. See A.4 for more details.

No microphone position shall be too close to any source position, in order to avoid a too-strong influence from the direct sound. In rooms for speech and music, the height of the microphones above the floor should be 1,2 m, corresponding to the ear height of average listeners in typical chairs.

A distribution of microphone positions shall be chosen that anticipates the major influences likely to cause differences in reverberation time throughout the room. Obvious examples are the differences for seating areas close to walls, underneath balconies or in spaces which are decoupled (e.g. in church transepts and chancels compared with church naves). This requires a judgement of the evenness of the “acoustical” distribution to the different seating areas, the equality of the coupling of the separate parts of the volume and the proximity to local perturbations.

For reverberation time measurement, it can be useful to assess the room against the following criteria (which in many cases will simply require a visual assessment) to determine whether single spatial averages will adequately describe the room:

a) the materials of the boundary surfaces and any suspended elements are such that, judged in terms of their absorption and diffusion properties, they are reasonably evenly distributed among the surfaces which surround the room, and

b) all parts of the room volume communicate reasonably equally with each other, in which case three or four microphone positions will be adequate — these positions being chosen to cover the seating area, in an evenly spaced array — and the results of the measurements may be averaged.

For a) above, if the ceiling, side, front and rear walls, when assessed individually, have no regions covering more than 50 % of their respective areas, with properties different from those of the remaining surfaces, then it may be considered that the distribution is acceptably even (in some spaces it can be helpful to approximate the room geometry to a rectangular parallelepiped for this assessment).

For b) above, the room volume may be considered to operate as a single space if there are no parts of the floor area which have their lines-of-sight blocked to any other part of the room that is more than 10 % of the total room volume.

If these conditions are not satisfied, then the room is likely to show areas with differing reverberation times, and these shall be investigated and measured separately.

5 Measurement procedures

5.1 General

Two methods of measuring the reverberation time are described in this part of ISO 3382: 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 in each frequency band.

For measurements in octave bands, the bandwidth of the signal shall be greater than one octave, and for measurements in one-third-octave bands, the bandwidth of the signal shall be greater than 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 at least a few seconds and not less than half the reverberation time.

For the survey method, a short excitation or an impulse signal may be used as an alternative to the interrupted noise signal. However, in that case, the measuring accuracy is less than that stated in 7.1.

