AS 1045—1988

Australian Standard®

ACOUSTICS—MEASUREMENT OF SOUND ABSORPTION IN A REVERBERATION ROOM

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PREFACE

This Standard was prepared by the Association's Committee on Acoustics—Architectural to supersede AS 1045—1971, *Method of measurement of absorption coefficients in a reverberation room*. It is based on ISO 354—1985, *Acoustics—Measurement of sound absorption in a reverberation room*, but it contains some technical changes which are significantly different from the corresponding provisions of ISO 354. The main deviation from ISO 354 concerns the level of precision (hence repeatability) to which laboratories should be allowed to work when performing tests. In cases where a laboratory must be permitted a choice from a range of a variable that affects precision, ISO 354 has no mandatory adjustment required for the number of decays to be performed in an attempt to compensate for the variation in precision caused by the choice made.

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FOREWORD

The purpose of this Standard is to promote uniformity in the methods and conditions of measurement of sound absorption in reverberation rooms, so that values determined by different laboratories agree to the greatest extent possible. In order to achieve an improved precision, it may become necessary to limit further the variability of test conditions.

In order to attain the above objectives, a more diffuse sound field than the one which ordinarily exists in most rooms, auditoria, etc, is required, and certain other constraints, e.g. on the dimensions of the reverberation room, are necessary. Although the sound absorption data determined by this method are intended for use in design calculations, deviations between predicted and measured values of reverberation time may occur in typical rooms, auditoria, etc, where the sound field is less diffuse than in the laboratory.

When a sound source operates in an enclosed space, the level to which reverberant sound builds up, and the subsequent decay of reverberant sound when the source is stopped, are governed by the sound-absorbing characteristics of the boundary surfaces and objects within the space. In general, the fraction of the incident sound power absorbed at a surface depends upon the angle of incidence. In order to predict the change in reverberation time or the noise reduction that would be effected by an absorbing treatment of an auditorium, office, workshop, etc, a knowledge of the sound absorption characteristics of the surfaces, usually in the form of a suitable average over all angles of incidence, is required. The distribution of sound waves in typical enclosures includes a wide and largely unpredictable range of angles, but it is convenient, for the purposes of standardization, to take a uniform distribution as the basic condition. If, furthermore, the sound intensity is independent of location within the room, such a distribution is called a diffuse sound field and the sounds reaching a room surface are said to be at random incidence. However, the placement of a highly absorbing sample in a reverberation room will itself reduce the diffusion that existed in the empty room.

Measurements under reverberant conditions are necessary because, in this way, the effects of practical mounting conditions can be included. Furthermore, it is the only way to determine the sound absorption of discrete objects such as chairs, office landscaping screens, etc.

STANDARDS ASSOCIATION OF AUSTRALIA

Australian Standard
ACOUSTICS—MEASUREMENT OF SOUND ABSORPTION IN A REVERBERATION ROOM

SECTION 1. SCOPE AND GENERAL

1.1 SCOPE. This Standard sets out a method of measuring the sound absorption coefficient of acoustical materials used as wall or ceiling treatments, or the equivalent sound absorption area of objects such as furniture, persons, or space absorbers, in a reverberation room. It is not intended for measuring the absorption characteristics of weakly damped resonators.

1.2 APPLICATION. The results obtained, using the method outlined in this Standard, can be used for comparison purposes and for design calculation with respect to room acoustics and the reduction of the reverberant component of the sound field.

1.3 PRINCIPLE OF THE METHOD. The method requires measurement of reverberation times in a reverberation room as a function of frequency, with and without the test specimen, denoted $T_{60,e+s}$ and $T_{60,e}$ respectively. From these reverberation times, the equivalent sound absorption area (A_s) of the test specimen is calculated.

For a plane test specimen, the sound absorption coefficient is obtained by dividing the equivalent sound absorption area (A_s) by its surface area (S).

When the test specimen comprises several identical objects, the equivalent sound absorption area of an individual object is found by dividing A_s by the number of objects.

1.4 STANDARD DEVIATION OF MEASUREMENTS. Information on the standard deviations of repeatability and of reproducibility, expected to be observed among measurements made to the requirements of this Standard, is given in Appendix B.

1.5 REFERENCED DOCUMENTS. The documents below are referred to in this Standard.

AS

1633 Acoustics—Glossary of terms and related symbols

Z41 Octave, half octave and one-third octave band pass filters intended for the analysis of sounds and vibrations

1.6 DEFINITIONS. For the purpose of this Standard, the definitions given in AS 1633 and those below apply.

1.6.1 Reverberation time—the time required for the sound pressure level to decrease by 60 dB after the sound source has stopped.

The quantity is denoted by T_{60} and is expressed in seconds.

NOTE: For the purpose of this Standard, it is assumed that the value of T_{60} may be determined from the inverse of the mean rate of decay of sound pressure level over a range of approximately 30 dB in the early part of the decay of level, the background level being sufficiently low to avoid interference.

1.6.2 Equivalent sound absorption area of a room—the hypothetical area of a totally absorbing surface without diffraction effects which, if it were the only absorbing element in the room, would give the same reverberation time in that room.

For the empty reverberation room, this quantity is denoted by A_e; for the reverberation room containing a test specimen, it is denoted by A_{e+s}. The quantity is expressed in square metres.

1.6.3 Equivalent sound absorption area of a test specimen—the difference between the equivalent sound absorption area of the reverberation room with (A_{e+s}) and without (A_e) the test specimen.

The quantity is denoted by $A_s = (A_{e+s} - A_e)$ 1.6.3(1)

1.6.4 Sound absorption coefficient—the equivalent sound absorption area of a test specimen divided by the area (S) covered by the test specimen.

The quantity is denoted by α_s.

It is defined only for specimens of materials intended for covering solid surfaces having dimensions that are large compared with the overall material thickness. When the specimens are mounted for test on one of the plane test room boundaries, S is taken as the area of the plane covered, not the total frontal area of the specimen, which may be deeply grooved or modelled.

NOTE: When the sound absorption coefficient from measurements in a reverberation room are being evaluated, the results should be denoted by the subscript 's'. The use of this subscript avoids confusion with the sound absorption coefficient, defined as the ratio of non-reflected to incident sound energy if a plane wave strikes a plane wall at a particular angle of incidence. This 'geometric' sound absorption coefficient is always smaller than unity and may therefore be expressed as a percentage. The sound absorption coefficient evaluated from reverberation time measurements may have values larger than unity, e.g. due to diffraction effects, and α_s should not be expressed as a percentage.

1.6.5 Repeatability standard deviation (s_r)—the standard deviation of a number of complete standard measurements of α_s or A_s of a test specimen, repeated in one laboratory, by the same operator, using the same room, apparatus and procedure each time. It is assumed that variables such as microphone position, source position, specimen position (for discrete absorber) and particular burst of random noise, which this Standard leaves for the operator to choose randomly as part of the procedure of a measurement, would be chosen afresh for each of the repeated measurements.

1.6.6 Reproducibility standard deviation (s_R)—the standard deviation of a number of complete standard measurements of α_s or A_s of a material, the measurements being done once in each of a number of different laboratories, involving different operators, rooms, apparatus and test specimens of the material. It is recognized that the techniques used by the different operators, although all in accordance with the Standard, may differ from one another.

NOTE: Experimental surveys to determine the reproducibility standard deviation of a standard measurement method sometimes circulate the *same* specimen to all laboratories. The value s_L thus obtained owing to differences of laboratory attributes alone is less than s_R, the component due to standard deviation between specimens of the material (called standard deviation of production (s_p)) being absent, i.e.—

$$s_L = (s_R^2 - s_p^2)^{1/2} \quad \text{1.6.6(1)}$$

SECTION 2. INSTRUMENTATION

2.1 SIGNAL GENERATION. The test signal shall consist of band-limited white random noise having a continuous frequency spectrum and a bandwidth of at least one-third octave.

2.2 SOURCE FILTER OR SPECTRUM SHAPER. The spectrum of the signal may be shaped to provide the bandwidth and the spectral shape required by Clause 4.1.2. The bandwidth shall be not less than that provided by a one-third octave filter complying with AS Z41.

2.3 LOUDSPEAKERS. Loudspeakers shall have a radiation pattern as non-directional as possible.

2.4 MICROPHONES. The microphone(s) shall have a flat random-incidence frequency response throughout the frequency range of interest. Pressure microphones with a diameter less than 13 mm, or with a nominal diameter of 25 mm with random-incidence corrector, normally comply with this requirement.

2.5 MEASURING FILTER. The measuring filter shall be a one-third octave band filter complying with AS Z41.

2.6 RECORDING EQUIPMENT. The recording system shall be a level recorder or any other adequate equipment for determining the average slope of the curve of decay of sound pressure level. The instrumentation for recording (and displaying or evaluating) the decay in sound pressure level may use—

(a) exponential averaging, with a continuous curve as output;

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

(c) linear averaging, with successive discrete linear averages as output, in some cases with pauses of considerable duration between determinations of averages.

The recording system shall have a frequency response within ±1 dB over the frequency range of interest. Over the range of level displayed, the linearity of the recording system shall be as follows:

(i) 0 dB to −35 dB, ±0.5 dB.

(ii) 0 dB to −45 dB, ±1.0 dB.

The time scale shall be accurate within ±1%.

SECTION 3. TEST ARRANGEMENT

3.1 REVERBERATION ROOM AND DIFFUSION OF SOUND FIELD.

3.1.1 Volume of reverberation room. The volume of the reverberation room shall be not less than 180 m^3. For new constructions, the volume should be approximately 200 m^3.

3.1.2 Shape of reverberation room. The shape of the reverberation room should be such that the following condition is fulfilled:

$$l_{max} < 1.9 V^{1/3} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 3.1.2(1)$$

where

l_{max} = the length of the longest straight line which fits within the boundary of the room (e.g. in a rectangular room it is the major diagonal)

V = the volume of the room.

To promote a uniform distribution of modal frequencies, especially in the low-frequency bands, no two dimensions of the room shall be equal or in the ratio of small whole numbers.

3.1.3 Diffusion of sound field. The decaying sound field in the room shall be sufficiently diffuse.

NOTE: To achieve satisfactory diffusion, whatever the shape of the room, the use of stationary suspended diffusers or of rotating vanes is, in general, required (see Appendix A).

3.1.4 Sound absorption area. The equivalent sound absorption area (A_e) of the empty room, determined in one-third octave bands, shall not exceed the values given in Table 3.1 for a room volume of 200 m^3.

If the volume (V) of the room differs from 200 m^3, the values given in Table 3.1 shall be multiplied by the factor $(V/200)^{2/3}$

The equivalent sound absorption area of the empty room in any one-third octave band from 125 Hz to 4 kHz should not differ by more than 15% from the mean of the values of both adjacent one-third octave bands.

3.2 TEST SPECIMEN.

3.2.1 Planar absorbers. Test specimens of planar absorber materials shall comply with the following requirements:

(a) The test specimen shall have an area between 10 m^2 and 12 m^2. If the volume (V) of the room is greater than 250 m^3, the normal test specimen area limits shall be increased by the factor $(V/250)^{2/3}$.

NOTE: For the testing of materials with exceptionally small sound absorption coefficients, test specimens of area larger than the above maximum may be used in order to obtain a significant difference between the measured reverberation times $T_{60,e}$ and $T_{60,e+s}$ (see Clause 5.1). However, materials with α_s approaching that of the room surface covered cannot be measured accurately (see Note 1 to Clause 5.1.4).

(b) Where appropriate, the test specimen shall be of rectangular shape. The ratio of width to length shall be between 0.7 and 1. Where the material is such that a rectangular test specimen with an aspect ratio of 0.7 to 1 is not representative, then the shape and the size of the specimen tested shall be reported. It shall be placed so that no part of it is closer than 1 m to any edge of the boundary of the room. The edges of the test specimen should preferably not be parallel to the nearest edge of the room.

(c) The test specimen shall be mounted in accordance with the relevant specifications provided by the manufacturer or with the application details provided by the user.

(d) For a test specimen directly mounted on a room surface, the edges shall be totally and tightly enclosed by a frame constructed from sound-reflective non-porous material of thickness not greater than 20 mm and surface density not less than 4 kg/m^2. The frame shall not protrude beyond the surface of the test specimen. It shall be tightly sealed to the room surface on which it is mounted.

(e) For a test specimen backed by an air gap, e.g. to simulate a suspended ceiling, sidewalls shall be constructed perpendicular to the test surface. The sidewalls shall enclose both the air gap and the test specimen edges, and shall be subject to the same requirements as for the frame in (d) above, except that if the total depth enclosed exceeds 150 mm, the surface density of the sidewalls shall be not less than 8 kg/m^2.

NOTES:

1. It is not a requirement of this Standard that more than one position for the test specimen be used for planar absorbers.
2. The measurement of the reverberation time of the empty room should be made with the frame or the sidewalls of the test specimen present. This is the direct opposite of ISO recommendations.
3. Some composite products intended for use on ceilings rely on gravity to ensure correct disposition of their absorbent pads, spacers, resistive films, perforated facings, etc, and can be correctly simulated only by a face-down installation of the specimen on the ceiling of the test room.

3.2.2 Discrete sound absorbers.

3.2.2.1 *General*. Discrete objects, e.g. chairs, persons, space absorbers, shall be installed for test in the same manner as they are typically installed in practice. For example, chairs or freestanding screens shall rest on the floor, but they shall be not closer than 1 m to any other boundary. Space absorbers shall be mounted at least 1 m from any boundary or room diffusers, and at least 1 m from any microphone.

A test specimen shall comprise a sufficient number of individual objects (in general, at least three) to provide a change in the equivalent sound absorption area of the room greater than 1 m^2, but not more than 12 m^2. If the volume (V) of the room is greater than 250 m^3, these values shall be increased by the factor $(V/250)^{2/3}$.

3.2.2.2 *Individual objects*. Objects normally treated as individual objects shall be arranged randomly spaced at least 2 m apart. If the test specimen comprises only one object, it shall be tested in at least three locations, at least 2 m apart, and the results averaged.

3.2.2.3 *Extended arrays of sound absorbers*. Specimens of extended arrays of sound absorbers, e.g. theatre chairs, noise absorber pads, shall be prepared and arranged as for a test specimen of a planar absorber. The test specimen shall be a representative sample of the extended array. The edges of the test specimen shall be enclosed with a sound reflective surround having a height equal to the height of the objects forming the array. The requirements of Clause 3.2.1 and the Notes thereto shall apply to extended arrays.

NOTE: The absorption of groups of seats with seated persons may vary considerably with the configuration of the floor on which they are mounted, e.g. a flat floor compared with a raked or stepped floor.

3.2.3 Curtains. Curtains tested against walls shall be treated as discrete absorbers, and tested without an edge surround (see Clause 3.2.2.2.). Alternatively by agreement of the parties concerned, the curtains may be considered as part of an extended array and tested with an edge surround (see Clause 3.2.2.3).

3.3 TEMPERATURE AND RELATIVE HUMIDITY. The temperature in the room shall be between 10°C and 40°C and the relative humidity between 40% and 90%. During a series of measurements of reverberation times $T_{60,e}$ and $T_{60,e+s}$ (see Clause 5.1), the temperature and relative humidity shall be as constant as possible, and in any case shall comply with the requirements in Table 3.2.

The temperature and humidity shall be measured by instruments with accuracy not inferior to ±1°C, ±2% RH, respectively.

NOTE: It is assumed that the *relative changes* in temperature and relative humidity, between their mean values during the $T_{60,e}$ and $T_{60,e+s}$ measurement periods respectively (at most a few hours apart), can be determined with uncertainty much less than implied by the accuracy requirements stated.

The test specimen should be allowed to attain equilibrium in the room, with respect to temperature and relative humidity, before the measurements of $T_{60,e+s}$ commence.

During the measurements of both $T_{60,e}$ and $T_{60,e+s}$, temperature and relative humidity shall be measured at regular intervals of not greater than 1 h. The mean values of t and RH during the period when the T_{60} measurements in the frequency bands of 2000 Hz to 5000 Hz are performed shall be taken as the temperature and relative humidity pertaining to the $T_{60,e}$ or $T_{60,e+s}$ measurement concerned, for the purpose of air absorption corrections (see Clause 5.1 and Appendix C).

NOTE: After the mounting of a test specimen in the room, it may take several hours for the temperature and humidity to stabilize, especially if a hygroscopic specimen has not been preconditioned elsewhere. After removal of a specimen, which is usually carried out more quickly than installation, stability can be re-established relatively quickly. For this reason, it is recommended that the measurements with test specimen present be carried out first.

TABLE 3.1

MAXIMUM EQUIVALENT SOUND ABSORPTION AREAS FOR ROOM VOLUME OF 200 m³

Centre frequency of one-third octave band, Hz	125	250	500	1 000	2 000	4 000
Equivalent sound absorption area, m²	6.5	6.5	6.5	7.0	9.5	15.0

TABLE 3.2

REQUIREMENTS FOR CONSTANCY OF TEMPERATURE AND RELATIVE HUMIDITY DURING MEASUREMENTS OF $T_{60,e}$ and $T_{60,e+s}$, FOR FREQUENCIES 2 000 Hz to 5 000 Hz INCLUSIVE

Relative humidity, %		Temperature constancy °C
Range	Constancy	
≥ 40 ≤ 60	±3	±3
> 60 ≤ 90	±5	±5

SECTION 4. TEST PROCEDURE

4.1 GENERATION OF SOUND FIELD.

4.1.1 General. The sound in the reverberation room shall be generated by one or more loudspeakers. For frequencies below 300 Hz, measurements shall be made with a sound source in at least two successive positions at least 3 m apart or with an equivalent multiple source arrangement, the sources not sounding simultaneously unless driven by separate (incoherently related) noise sources.

The level of the steady test signal before decay shall be sufficiently above the level of the background noise to permit evaluation of the decay curves as specified in Clause 4.2.2.

The duration of the test signal before switching off should be sufficiently long to produce a steady sound pressure level in the room.

4.1.2 Signal spectrum. If a signal with a bandwidth greater than one-third octave is used, long reverberation times in adjacent frequency bands can influence the lower part of the decay curve. If the reverberation times in two adjacent bands between 100 Hz and 5 kHz differ by more than a factor of 1.5, the reverberation time for the band with the shorter reverberation time should be measured individually using one-third octave filtering of the sound source.

Wide-band noise to make simultaneous measurements may be used for all frequency bands subject to the factors mentioned above. For these measurements with wide-band noise, the average sound spectrum in the room in the steady state should be approximately pink with differences in sound pressure level preferably less than 3 dB but not more than 6 dB between adjacent one-third octaves.

4.2 MEASUREMENT OF REVERBERATION TIME.

4.2.1 Receiving equipment. The receiving equipment shall consist of one or more microphones, which are as non-directional as possible, the necessary amplifiers, filters, and a measuring system for reverberation time.

The recordings shall be made with at least three microphone positions at least $\lambda/2$ apart, where λ is the wave-length of sound for the centre frequency band of interest.

Only one microphone shall be used at a time unless circuitry is employed which adds the squares of the instantaneous voltages from several microphones simultaneously. The microphones shall be at least 1 m from the test specimen, 1 m from room surfaces or diffusers, and 2 m from the sound source(s).

The recording system shall be a level recorder or any other adequate equipment for determining the average slope of the curve of decay of sound pressure level.

The averaging time of an exponential averaging device (or approximate equivalent, see Note 2) shall be less than $T_{60}/20$. The averaging time (integrating time) of a linear averaging device shall be less than $T_{60}/7$. For apparatus in which 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.

NOTES:

1. The averaging time of an exponential averaging device is equal to 8.69 divided by the decay rate, in decibels per second, of the device.
2. Commercial level recorders in which the sound pressure level is recorded graphically as a function of time are approximately equivalent to exponential averaging devices.
3. The above limitations on averaging time of devices are to ensure, for the exponential measurement, that the measured decay slope will not be subject to bias due to a too-slow device; and for the linear measurement, that there will be at least three points, enabling any change of slope to be evaluated. In both cases, however, the standard deviation of measured T_{60} is increased by reducing the averaging time of the device, so it is desirable to keep the averaging time *just* below the appropriate limit if possible. In some sequential measurement 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 smallest reverberation time in any band should be used for measurements in all bands.

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

4.2.2 Evaluation of decay curves. The reverberation time shall be evaluated from the averaged slope of the decay curve over a range of not less than 30 dB, beginning about 0.1 s after the sound source is switched off, or from a sound pressure level approximately 1 dB to 5 dB lower than that at the beginning of decay. The bottom of this range shall be at least 10 dB above the combined background noise level of the reverberation room and the recording equipment for each one-third octave band.

Decay records for which the measured slopes of the first and second halves of the record differ by more than 25% shall be discarded owing to the possibility of their corruption by a transient interfering noise.

For each combination of microphone and loudspeaker position, and for each one-third octave band, an ensemble averaging procedure, involving the superposition of several repeated excitations of the room, may also be used to obtain a single decay curve from which the reverberation time can be evaluated.

4.3 FREQUENCY RANGES FOR MEASUREMENTS. The measurements shall be carried out at the following centre frequencies, in hertz, from the one-third octave band series:

100	125	160	200	250	315
400	500	630	800	1 000	1 250
1 600	2 000	2 500	3 150	4 000	5 000

However, by agreement of parties involved, the measurement can be carried out using a reduced set of one-third octave band measurements with centre frequencies, in hertz, of

125	250	500	1 000	2 000	4 000

4.4 NUMBER OF MEASUREMENTS. The minimum number of measurements required for each frequency band is as follows:

(a) From 100 Hz to 250 Hz twelve decays (e.g. two for each of six sound source/microphone combinations).

(b) From 315 Hz to 800 Hz nine decays (e.g. three for each of three sound source/microphone combinations).

(c) From 1000 Hz to 5000 Hz six decays (e.g. two for each of three sound source/microphone combinations).

SECTION 5. EXPRESSION OF RESULTS AND TEST REPORT

5.1 METHODS OF CALCULATION.

5.1.1 Calculation of reverberation times $T_{60,e}$ and $T_{60,e+s}$. The reverberation time of the room in each frequency band is expressed by the arithmetic mean of the total number of reverberation time measurements made in that frequency band.

The mean reverberation times $T_{60,e}$ and $T_{60,e+s}$ in each frequency band shall be calculated and expressed to at least two decimal places.

5.1.2 Calculation of A_e. The equivalent sound absorption area (A_e), of the empty reverberation room shall be determined from the following equation:

$$A_e = \frac{55.3\,V}{c_e T_{60,e}} = A_{eb} + A_{ea} \quad \ldots\ldots\ldots\ldots \quad 5.1.2(1)$$

where

A_e = equivalent round absorption area, in square metres

V = volume of the reverberation room, in cubic metres

c_e = velocity of sound in air at the time of the measurement, in metres per second

$T_{60,e}$ = reverberation time of the empty reverberation room, in seconds

A_{eb} = the component of A_e due to the boundaries and objects in the room, in square metres

A_{ea} = the component of A_e due to the volume of air in the room, in square metres
= $8\alpha_a V$

α_a = air attenuation coefficient, in nepers per metre.

NOTE: For temperatures in the range 10°C to 40°C, the velocity of sound in air (c), in metres per second, can be determined from the equation:

$$c_e = 331 + 0.6t \quad \ldots\ldots\ldots\ldots \quad 5.1.2(2)$$

where

t = air temperature, in degrees Celsius.

5.1.3 Calculation of A_{e+s}. The equivalent sound absorption area (A_{e+s}), of the reverberation room containing a test specimen, shall be determined from the following equation:

$$A_{e+s} = \frac{55.3\,V}{c_{e+s} T_{60,e+s}} = A_{(e+s)b} + A_{(e+s)a} \quad \ldots\ldots\ldots\ldots \quad 5.1.3(1)$$

where

A_{e+s} = equivalent sound absorption area, in square metres

V = volume of reverberation room, in cubic metres

and

c_{e+s}, $T_{60,e+s}$, $A_{(e+s)b}$, and $A_{(e+s)a}$ have meanings corresponding to c_e, $T_{60,e}$, A_{eb}, and A_{ea}, but after introduction of the test specimen.

5.1.4 Calculation of A_s. The equivalent sound absorption area (A_s), of the test specimen shall be determined from the equation

$$A_s = 55.3\,V\left(\frac{1}{c_{e+s}T_{60,e+s}} - \frac{1}{c_e T_{60,e}}\right) - 8V(\alpha_{a(e+s)} - \alpha_{ae})$$
$$= A_{(e+s)b} - A_{eb} \quad \ldots\ldots\ldots\ldots \quad 5.1.4(1)$$

where the symbols have the same meanings as in Equation 5.1.2(1) and Equation 5.1.3(1), and the values of $\alpha_{a(e+s)}$ and α_{ae} are as determined from Appendix C.

However, provided that the requirements of Clause 3.3 and Table 3.2 have been complied with, then—

(a) for band centre frequencies up to 1600 Hz inclusive, it may be assumed that $\alpha_{a(e+s)} - \alpha_{a(e)} = 0$; and

(b) for band centre frequencies of 2000 Hz to 5000 Hz inclusive, provided also that the temperature in degrees Celsius during all relevant time periods remained within the range given by—

$$t = (11 + 840/RH)(1 \pm 30/V) \quad \ldots\ldots \quad 5.1.4(2)$$

where

t = temperature, in degrees Celsius

RH = relative humidity, in percent

V = room volume, in cubic metres.

then it may also be assumed that—

$$\alpha_{a(e+s)} - \alpha_{a(e)} = 0.$$

NOTES:

1. The area of room surface covered by the test specimen is not taken into account by Equation 5.1.4(1). For normal absorbing materials, there is a small error in the calculated value due to neglecting the absorption of the area covered by the test material, the calculated value being slightly too low.

   A greater error would, however, certainly result if the sound absorption coefficient of the covered area is calculated from the reverberation time of the empty room, because this time depends not only on the absorption of the walls, but probably more on that of the other objects (such as doors, loudspeakers, light fittings), by dissipation of sound energy in the air, and by vibrations of the walls and ceiling which are not hindered if they are covered with absorbing material.

2. Equation 5.1.4(2) also ignores the change in room volume on introduction of the specimen. For specimens that occupy large volume (e.g. more than $0.02V$), this may be taken into account. Where such an allowance has been made, it should be stated in the test report.

5.1.5 Calculation of α_s (see also Note 1 to Clause 5.1.4). The sound absorption coefficient (α_s) of a planar absorber shall be determined from the following equation:

$$\alpha_s = \frac{A_s}{S} \quad \ldots\ldots\ldots\ldots \quad 5.1.5(1)$$

where

α_s = sound absorption coefficient

A_s = equivalent sound absorption area determined in accordance with Equation 5.1.4(1), in square metres

S = the area of the test specimen, in square metres.

5.1.6 Calculation of equivalent sound absorption area of discrete absorbers. For discrete absorbers, the result should generally be expressed as equivalent sound absorption area per object, which is determined by dividing A_s by the number of objects tested.

For a specified array of objects, the result should be given as equivalent sound absorption area of the whole configuration.

5.2 STATEMENT OF RESULTS. For all frequencies of measurement, the following results shall be reported, presented in the form of a table and as a graph:

(a) For planar absorbers or sample of extended arrays, the sound absorption coefficient (α_s) rounded to 0.05.

(b) For discrete objects, the equivalent sound absorption area per object, rounded as follows:

  (i) where the sample comprised 1 or 2 objects . . . . to 0.5 m^2.

  (ii) where the sample comprised 3 or 4 objects . . . . to 0.2 m^2.

  (iii) where the sample comprised 5 or more single objects . . . . to 0.1 m^2.

NOTE: The precision of the results may be worse than might be concluded from the above decimal rounding steps (see Appendix B).

In the graphical presentation, the points of measurement should be connected by straight lines, the abscissa giving the frequency on a logarithmic scale and the ordinate showing the equivalent sound absorption area or sound absorption coefficient on a linear scale. The ratio of the ordinate distance from $A_s = 0$ to $A_s = 10$ m^2, or from $a_s = 0$ to $a_s = 1$, to the abscissa distance corresponding to five octaves should preferably be 2:3.

5.3 TEST REPORT. The test report shall make reference to this Standard and shall include the following information:

(a) Name of the organization that performed the test.

(b) Date of test.

(c) Description of the test specimen, mounting, and position in the reverberation room, preferably by means of drawings; and for absorbing systems, plane or otherwise, intended for mounting on plane portions of room boundaries, the projected area (S) of plane test room boundary occupied by the specimen. Whether the frame was in the room for the A_e determination. Where relevant, the age of the specimen.

(d) Shape of the reverberation room, its diffusion treatment (number and size of diffusers), and the number of microphone and sound-source positions.

(e) Dimensions of the reverberation room, its volume, and its total surface area (walls, floor, and ceiling, excluding diffusers).

(f) Type of test signal used.

(g) Instrumentation used including locations of microphones and sound source(s), the date of the most recent calibration of the instruments and the type of performance checking used.

(h) Temperature and relative humidity.

(j) Mean reverberation times (T_e and T_{e+s}) at each frequency.

(k) The results, reported in accordance with Clause 5.2.

(l) A reference to this Standard, i.e. AS 1045.

(m) A reference to Appendix B (optional).

APPENDIX A

DIFFUSIVITY OF THE SOUND FIELD IN THE REVERBERATION ROOM

(This Appendix forms an integral part of this Standard.)

A1 DIFFUSERS. An acceptable diffusivity can be achieved by using fixed or rotating diffusers or both. Ideally, these diffusing elements should be damped sheets with low sound absorption and of mass per unit area at least 5 kg/m^2. Diffusers of different sizes, ranging from approximately 0.8 m^2 to 3 m^2 (for one side) are recommended. The sheets may be slightly curved, should be oriented and positioned at random, throughout the room.

If a rotating diffuser is used, it should have an area of 5 m^2 to 10 m^2. The decay repetition frequency and the frequency of rotation of the diffuser should not be in the ratio of small whole numbers.

A2 CHECK OF DIFFUSIVITY. The diffusivity shall be checked as follows:

(a) Select a suitable test specimen, e.g. a sample, 50 mm to 100 mm thick, of a homogeneous, porous absorbing material which, under optimum conditions, has a sound absorption coefficient greater than 0.9 over the frequency range from 500 Hz to 4000 Hz. (Certain glass-wools, rockwools or polyurethane foams meet this criterion.)

(b) Mount a test specimen in accordance with Clause 3.2.

(c) Perform sound absorption measurements on the test specimen as follows, with any rotating diffuser system present and operating—

 (i) with no added stationary diffusers;

 (ii) with a small number of stationary diffusers added (approximately 5 m^2); and

 (iii) with increasing quantities of stationary diffusers, in steps of approximately 5 m^2.

(d) For each set of measurements, calculate the mean value of the sound absorption coefficients, in the range 500 Hz to 4000 Hz, and plot these values against the area of diffusers used in each case, including the area of any rotating diffuser.

In the majority of reverberation rooms the mean sound absorption coefficient approaches a maximum and thereafter remains constant with increasing area of diffusers. The optimum area of diffusers is that at which this constant value is first attained, and it is recommended that this area should remain installed for all future use of the room to measure α_s.

NOTE: From experience, it has been found that, in rectangular rooms, the area (both sides) of diffusers required to achieve satisfactory diffusion is approximately 15 percent to 30 percent of the total surface area of the room. Whether a rotatable diffuser is rotating or not does not have much effect on the mean measured absorption coefficient, but rotation is effective in reducing the spatial component of standard deviation of decay rate, and hence the standard deviation of measured absorption coefficient.

APPENDIX B

EXPECTED REPEATABILITY AND REPRODUCIBILITY STANDARD DEVIATIONS FOR A_s OR α_s FOR THE METHOD IN THIS STANDARD

(This Appendix does not form an integral part of this Standard.)

B1 REPEATABILITY STANDARD DEVIATION (s_r).

B1.1 Theoretical prediction. The uncertainty in a value of absorption measured by this method is mainly due to the variation of decay rate in a room, firstly between decays initiated by different random noise bursts, for a particular fixed microphone and source combination (called ensemble variance); and secondly, between different positions of the microphone, or source, for a decay initiated by the same noise burst (called spatial variance). These variances are the two major contributors to the square of the standard deviation of repeatability of A or α_s.

The ensemble and spatial variances of decay rate can be predicted by Equations B1.1(1), B1.1(2) and B1.1(3) below. The final factors in these equations are empirical corrections of importance only at low frequencies, where the modal overlap M_s is small, (see reference B3.1). In a particular frequency band, the modal overlap is the product of the modal density (number of modes per unit bandwidth) and the typical bandwidth of the individual room modes in that frequency region.

Independent of the type of averaging device used, the spatial variance of decay rate $\mathrm{var}_s(d)$ may be calculated as—

$$\mathrm{var}_s(d) = \left(\frac{10}{\ln 10}\right)^2\left(\frac{12}{B_1}\right)\left(\frac{d}{D}\right)^3 F\left(\frac{\ln 10}{10}D\right)\left(0.75 + \frac{2.78}{M_s}\right) \quad \text{B1.1(1)}$$

The ensemble variance of decay rate $\mathrm{var}_s(d)$, when an exponential averaging device is used may be calculated, as

$$\mathrm{var}_e(d) = \left(\frac{10}{\ln 10}\right)^2\left(\frac{12}{B_1}\right)\left(\frac{d}{D}\right)^3 F\left(\frac{\ln 10}{10}\Upsilon D\right)\left(0.98 + \frac{1.32}{M_s}\right) \quad \text{B1.1(2)}$$

or when a linear averaging device is used, as

$$\mathrm{var}_e(d) = \frac{\left(\frac{10}{\ln 10}\right)^2 12\left(\frac{1}{B_1 I} + \frac{2}{N}\right)}{a^2\left(\frac{D}{da} + 2\right)\left(\frac{D}{da} + 1\right)\left(\frac{D}{da}\right)}\left(0.98 + \frac{1.32}{M_s}\right)$$

where

d = decay rate in the room, in decibels per second = $60/T_{60}$

B_1 = statistical bandwidth of the bandpass filter used, in hertz
≈ 0.278 times the centre frequency for a one-third octave filter (f_c) complying with AS Z41

D = number of decibels of decay measured
≈ 30

$$F(x) = 1 - \frac{3}{x}(1 + e^{-x}) - \left(\frac{12}{x^2}\right)e^{-x} + \left(\frac{12}{x^3}\right)(1 - e^{-x})$$

where

x = $\frac{\ln 10}{10}D$ or $\frac{\ln 10}{10}\Upsilon D$, as appropriate

Υ = ratio of decay rate of exponential averaging device to decay rate of the room

I = averaging (or 'integrating') time of a linear averaging device, in seconds

N = number of instantaneous microphone signal waveform samples contributing to an average in a period I

a = interval between the starting times of successive linear averages, in seconds

M_s = statistical modal overlap
= $3\, m_r \ln(d/6)$

m_r = modal density
≈ $4\,\pi V f_c^2/c^3 + \pi S_T f_c/2c^2$

V = room volume in metres cubed.

S_T = total area of room boundaries (excluding diffusers) in metres squared.

The determination of A_s of a specimen involves averaging of decay rate over m decays at each of n spatial configurations of source and microphones, with and without the specimen present. The total variance of the mean A_s so determined may be calculated as

$$\mathrm{var}(A) = \left(\frac{4V\ln 10}{10c}\right)^2 \left(\frac{\mathrm{var}_s(d_e)}{n} + \frac{\mathrm{var}_e(d_e)}{mn} + \frac{\mathrm{var}_s(d_{e+s})}{n} + \frac{\mathrm{var}_e(d_{e+s})}{mn}\right) \quad \text{. . B1.1(4)}$$

and the total variance of the mean α_s of a specimen of area S may be calculated as—

$$\mathrm{var}(\alpha_s) = \frac{\mathrm{var}(A)}{S^2} \quad \text{. . . . . B1.1(5)}$$

The square root of the variance calculated by Equation B1.1(4) or Equation B1.1(5) can be used as a prediction of the repeatability standard deviation $s_r(A)$ (or $s_r(\alpha_s)$) that would be observed if the whole standard determination of mean A_s (or mean α_s) were repeated many times.

B1.2 Calculated example. The equations in Paragraph B1.1 show that many variables are involved. A particular representative case has been calculated to illustrate how the standard deviation of repeatability of α_s depends on frequency and the magnitude of the α_s measured. The results are tabulated in Columns 3 to 9 of Table B1.

A number of assumptions are made as follows:

(a) An exponential averaging device is used.

(b) Values of m and n are the minimum values set in Clause 4.4.

(c) $V = 208$ m^3, $S_t = 218$ m^2, $S = 10.0$ m^2, $c = 343.6$ m/s where S_t is the total surface area (walls, floor and ceiling excluding diffusers).

(d) Total absorption (A_e) in the empty room has the value given in Column 2 of Table B1.

(e) $\Upsilon = 3.0$, just greater than the minimum (2.9) required implicitly in Clause 4.2.1.

(f) $D = 30$ dB, $B_1 = 0.278 f_c$ Hz.

TABLE B1

EXPECTED REPEATABILITY STANDARD DEVIATION s_r, AND ONE EXAMPLE OF THE ADDITIONAL COMPONENT CONTRIBUTING TO REPRODUCIBILITY STANDARD DEVIATION

1	2	3	4	5	6	7	8	9	10	11
⅓ octave band centre frequency	Assumed A_e in empty room	Expected repeatability standard deviation s_r for the coefficient α_s measured by this method. For various assumed values of α_s, and subject to other assumptions stated in Paragraph B1.2.							Additional component s_x due to room, technique, and specimen differences (one material)	
Hz	m^2	$\alpha_s = 0$	$\alpha_s = 0.2$	$\alpha_s = 0.4$	$\alpha_s = 0.6$	$\alpha_s = 0.8$	$\alpha_s = 1.0$	$\alpha_s = 1.2$	α_s of material	s_x
100	3.85	0.026	0.027	0.034	0.041	0.051	0.061	0.073	0.12	0.10
125	3.90	0.019	0.021	0.027	0.034	0.042	0.051	0.061	0.23	0.09
160	3.96	0.014	0.017	0.022	0.028	0.035	0.043	0.051	0.34	0.08
200	4.00	0.011	0.014	0.018	0.023	0.030	0.037	0.044	0.50	0.07
250	4.07	0.009	0.011	0.015	0.020	0.026	0.032	0.039	0.68	0.07
315	4.24	0.010	0.013	0.018	0.023	0.030	0.037	0.045	0.88	0.06
400	4.40	0.009	0.012	0.016	0.021	0.026	0.033	0.040	0.97	0.06
500	4.57	0.008	0.010	0.014	0.019	0.024	0.030	0.036	1.04	0.05
630	4.91	0.007	0.010	0.013	0.017	0.022	0.027	0.033	1.10	0.05
800	5.24	0.007	0.009	0.013	0.016	0.020	0.025	0.030	1.08	0.06
1 000	5.58	0.007	0.010	0.013	0.017	0.021	0.025	0.030	1.09	0.06
1 250	6.13	0.008	0.010	0.013	0.016	0.020	0.024	0.028	1.07	0.06
1 600	7.25	0.009	0.011	0.013	0.016	0.020	0.023	0.027	1.05	0.07
2 000	8.36	0.010	0.012	0.014	0.017	0.020	0.023	0.027	1.04	0.07
2 500	9.70	0.011	0.013	0.015	0.017	0.020	0.023	0.026	1.04	0.08
3 150	11.0	0.012	0.013	0.015	0.018	0.020	0.023	0.026	1.05	0.09
4 000	12.4	0.012	0.014	0.016	0.018	0.020	0.023	0.025	1.05	0.10
5 000	13.9	0.013	0.014	0.016	0.018	0.020	0.023	0.025	1.05	0.11

B2 REPRODUCIBILITY STANDARD DEVIATION (s_R). The standard deviation (s_R) of measurements of α_s between a number of Australian laboratories has been studied for one material, and it is very significantly greater than s_r (Reference B3.2). Two major components contributing to this excess have been identified as being due to systematic differences in implementing the standard procedures and to systematic differences in the rooms concerned. Column 10 of Table C1 shows the α_s characteristic of the material concerned, and Column 11 gives a smoothed representation of the combination s_x of these two main observed components, plus a small component of 0.02, independent of frequency, for differences between specimens.

For materials having a similar α_s characteristic to that tabulated, the reproducibility standard deviation (s_R) at a given frequency can be predicted by combining the s_r value from the appropriate α_s column, with the s_x value in Column 11—

$$s_R = (s_r^2 + s_x^2)^{1/2} \qquad \text{B2(1)}$$

There is insufficient Australian data available to present s_x as a wide function of α_s, but overseas data indicate that at low frequencies, if α_s approaches 1, the s_x values may be considerably greater than those tabulated here.

B3 REFERENCES.

B3.1. DAVY, J.L., The variance of decay rates at low frequencies. *Applied Acoustics*, Vol. 23(1), 63-79, 1988.

B3.2. DAVERN, W.A., and DUBOUT, P., Second Report on Australasian Comparison Measurements of Sound Absorption Coefficients. CSIRO, Division of Building Research, 1985.

APPENDIX C

CALCULATION OF AIR ATTENUATION COEFFICIENT

(This Appendix forms an integral part of this Standard.)

The air attenuation coefficient (α_a) for the sound pressure of a plane wave travelling in air is a function of the temperature, humidity, and pressure of the air, and the frequency of the sound. The following equations are derived from the American National Standard ANSI S1.26—1978 with some amendments to constants as recommended in ISO/TC43/SC1/N578 of December 1986. It is assumed that the value of α_a at the centre frequency of a one-third octave band may be taken to apply to the whole band if the continuous spectrum of random noise in the band is approximately pink.

$$\alpha_a = f_c^2 \left[1.84 \times 10^{-11} \left(\frac{p_s}{p_{so}}\right)^{-1} \left(\frac{T}{T_0}\right)^{1/2} + \left(\frac{T}{T_0}\right)^{-5/2} \left\{ 1.275 \times 10^{-2} \frac{\exp\left(\frac{-2239.1}{T}\right)}{\left(f_{r,o} + \frac{f_c^2}{f_{r,o}}\right)} + 1.068 \times 10^{-1} \frac{\exp\left(\frac{-3352}{T}\right)}{\left(f_{r,N} + \frac{f_c^2}{f_{r,N}}\right)} \right\} \right] \quad \ldots\ldots \text{C(1)}$$

where

α_a = air attenuation coefficient, in nepers per metre

f_c = centre frequency of the band, in hertz

p_s = atmospheric pressure (see Note), in pascals

p_{so} = reference value for atmospheric pressure
= 101.325 kPa

T = temperature, in kelvin
= t + 273.16

T_0 = reference temperature, in kelvin
= 293.16

$f_{r,o}$ = vibrational relaxation frequency of oxygen, in hertz

$$= \left(\frac{p_s}{p_{so}}\right) \left\{ 24 + 4.04 \times 10^4 \frac{h\,(0.02 + h)}{(0.391 + h)} \right\} \quad \ldots\ldots \text{C(2)}$$

$f_{r,N}$ = is the vibrational relaxation frequency of nitrogen, in hertz

$$= \left(\frac{p_s}{p_{so}}\right) \left(\frac{T}{T_0}\right)^{-1/2} \left\{ 9 + 280h \exp\left(-4.170 \left(\left(\frac{T}{T_0}\right)^{-1/3} - 1\right)\right) \right\} \quad \ldots\ldots \text{C(3)}$$

where

h = the molar concentration of water vapour, in percent
= $h_r(p_{sat}/p_s)$

h_r = relative humidity, in percent

p_{sat} = saturation vapour pressure of water at the prevailing temperature and air pressure, in pascals

Saturation vapour pressure may be evaluated from the following equation:

$$\log_{10}\left(\frac{p_{sat}}{p_{so}}\right) = 10.795\,86 \left\{ 1 - \left(\frac{T_{o1}}{T}\right) \right\} - 5.028\,08 \log_{10}\left(\frac{T}{T_{o1}}\right) + 1.504\,74 \times 10^{-4} \left\{ 1 - 10^{-8.296\,92 \left[\left(\frac{T}{T_{o1}}\right) - 1\right]} \right\} + 0.428\,73 \times 10^{-3} \left\{ -1 + 10^{4.76\,955 \left[1 - \left(\frac{T_{o1}}{T}\right)\right]} \right\} - 2.219\,598\,3 \quad \ldots\ldots \text{C(4)}$$

where

T_{o1} = triple-point isotherm temperature for water, in kelvin
= 273.16 K

NOTE: For the atmospheric pressure (p_s), the mean value prevailing at the locality may be used.

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