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MEASUREMENT OF SOUND LEVELS IN BUILDINGS

ANC Guidelines

Contents

1. Foreword

Introduction

These guidelines cover the measurement of sound pressure levels in buildings from all sources; they supersede both Part 1[1] and Part 2[2] of the ANC Guidelines for measuring noise in buildings, which are withdrawn.

Since the ANC guidelines were first written in 1997 and 1998, International Standards and other guidance have been published that cover measurement of sound in buildings from a variety of sources and frequency ranges. However, measurement of sound inside buildings from general external sources has not received much attention. These guidelines aim to help the reader find an appropriate method for the measurement task in hand; where there is a lack of other formalised guidance, a simple measurement method is proposed that may be appropriate.

Measuring sound within buildings can involve many more complications than are present for external measurements. The simple method proposed may not be appropriate for every situation, but aims to assist in the development of a suitable, bespoke approach. All the methods described in these guidelines are intended to be used by consultants with suitable skills, knowledge and experience in sound level measurements and who are familiar with the appropriate equipment.

Working Group

These guidelines have been produced by the voluntary effort of the Association of Noise Consultants' working group comprising the following members:

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2. Application and Scope

An appropriate method for measuring sound in buildings should be determined by the consultant for a particular case. These guidelines aim to help determine the most suitable method for measuring sound levels in rooms. They are intended to assist in situations where a project specification or requirement does not provide another specific measurement methodology.

This guide is focused on sound measurements to characterise the space, such as may be described by "the sound level in a room". References are given for further reading for measurements outside of the scope of these guidelines.

Although the specification of sound level criteria is outside the scope of these guidelines, Appendix B describes some considerations that may assist specifiers to develop an appropriate specification.

These guidelines are intended to be used to measure the time-average and space-average sound pressure levels in octave and fractional octave bands as well as frequency-weighted full spectrum level descriptors like the A-weighted and C-weighted sound pressure levels. The choice of frequency weighting will depend upon the specified or desired criterion.

These guidelines cover sources of sound that are inside or outside the building or room in question. These guidelines seek to guide the reader towards appropriate standards and guidance for measuring sound inside buildings. In the absence of reference to another specification, a simple method is proposed for specifying and measuring the sound inside a building

The simple method described in the following section is not intended to supersede or form a part of any national standard or legislation; nor is it intended to be prescriptive.

Typical buildings to which these guidelines may be applicable include, but are not limited to, buildings where ambient sound levels are important, for example:

- Offices
- Hospitals
- Dwellings
- Hotels
- Schools and other educational premises
- Commercial and industrial premises
- Places of worship

The context, source and characteristics of the sound, such as frequency content or periodicity, for example, may all influence the method adopted for the measurements. The level of repeatability and reproducibility, and ability to demonstrate robustness in the results may affect the selection of a suitable method. The location of the sound source(s) in question and any confounding sources that are to be excluded from the measurements may also affect the choice of measurement methodology.

Acoustically specialised environments such as auditoria, studios etc normally have particular requirements with well-defined acoustic specifications which would take precedence over these guidelines.

External sound sources covered by the guidelines include the following, typically time-varying sources:

- Road traffic
- Underground, overground railways and light rail systems
- Aircraft
- Industry
- Construction
- Commercial and leisure activities

Internal sound sources covered by these guidelines include:

- Building services and service equipment
- Activities within the building

The ANC simple method, detailed in the next section, can be used for short measurements of internal building services, as well as external sound sources that vary over time, such as transportation sources. This simple method is simpler and quicker than the methods described in ISO 10052[3] and ISO 16032[4], which are summarised in Appendix A. As such, it is likely to yield less repeatable and reproducible results and so if the result could be contentious, a more formalised method may be more appropriate.

These guidelines are intended to be used by suitably qualified persons - i.e. consultants with appropriate skills, knowledge and experience. It is the specifier's responsibility to ensure that these guidelines are used and referenced appropriately. It may be necessary to deviate from the simple method guidelines when a specific measurement procedure is not practicable or appropriate to the case in hand. It is intended that a consultant who does not follow the guidance would justify the use of their alternative methodology.

Appendix A also gives examples of other measurement methodologies that may be useful.

3. ANC simple measurement method

Introduction

This method of measuring sound levels within buildings may be suitable in the absence of a specific requirement for another measurement methodology.

This simple and pragmatic method aims to enable representative results to be obtained using short-term attended sound measurements with a reasonable degree of repeatability and reproducibility.

In addition to measuring sound from internal sources (e.g. building services installations, equipment within rooms, activities within the building, etc), this method also contains guidance for undertaking internal measurements of external sound sources.

The primary source for guidance on measuring environmental sound sources is BS 7445 Part 1[5], Section 5.2.3 which describes measurement positions inside buildings. ISO 1996-1:2003[6] and ISO 1996-2:2007[7] supersede this series but the UK, through BSI, rejected the revision noting "*the fact that few, if any, of the innovations introduced in the revised standard could be supported by existing scientific or technical evidence. In addition, UK Subcommittee EH1/3 had serious concerns over some of the definitions introduced in the revised ISO1996-1*". The ANC Environmental Sound Measurement Guide[8] notes that "*Caution should be applied, therefore, with reference to these ISO documents and their technical content.*"

Contents

The ANC simple method is described in the following sections

- Terms and definitions
- Measurement parameters and precision
- Equipment, calibration and tolerances
- Sampling periods
- Measurement positions
- Measurement conditions
- Correcting for background sound and room conditions
- Reporting

Terms and definitions

Some of the key terms used in these guidelines are defined below:

Table 3-1 Terms and definitions

Term	Definition
Steady sound	Sound which is free from audible fluctuations in level or frequency content over the reference period. [Note1]
Non-steady (Fluctuating) sound	Sound which fluctuates audibly in level or frequency content during the reference period.
Continuous sound	Sound from a source which operates continuously over the reference period. The sound level might vary in a gradual way, but not in discrete steps or resulting from separate events.
Intermittent sound	Sound which is transient, cuts in and out, or changes between discrete settings or conditions over the reference period. For building services sound, this might arise as a result of a single item of plant switching between settings (e.g. "on", "off", "low" and "high") or changes in the number of machines operating at a given time.
Tonal sound	Sound which contains one or more audible tones. [Note2]
Impulsive sound	Sound which contains audible impulses. [Note2]
Specific sound	The sound due to the source under investigation. Where sound from all external events, or alternatively all plant & equipment is under investigation, all should be considered as the sources of specific sound.
Background sound	The sound from sources other than the specific sound source.
Total sound	The combination of specific and background sounds.
Reference period	The time period indicated in the specification of sound levels, represented with the suffix "T" in the measurement parameter.
Measurement period	The measurement period may be longer or shorter than the reference period. Measurement periods are represented with the suffix "T" in the measurement parameter.
Measurement zone	An area within a larger space in which a measurement position is identified.
Measurement position	A normally-occupied position at which the sound level is sampled with either a moving microphone or a number of fixed microphone positions.
Microphone position	A fixed position for the microphone around a measurement position used to sample the sound level.
Moving microphone technique	A method of sampling the sound field at a measurement position using a moving microphone to obtain an energy-averaged spatial sample.

Note 1 The BS 7445-1:2003 definition of steady noise allows fluctuations over a range of 5 dB; this does not apply in the context of these guidelines. In cases where there is a dispute or doubt as to whether a given sound is steady, the measurement procedure for non-steady sound should be adopted.

Note 2 In order to be rated as "tonal" or "impulsive", it is necessary only for these characteristics to be audible in the sound under investigation. References [9], [10] and [11] describe methods of rating tonal sound in terms of its annoyance or prominence. Reference [12] describes a procedure for determining whether or not sound emissions from computer and business equipment include prominent discrete tones. Reference [13] and [14] give guidance on the determination of sound power levels for discretefrequency and narrow-band sources. Reference [15] gives a method for assessing tonality in fan coil units. Reference [16] provides some guidance on the assessment of impulsive sound. Identification of penalties or rating of tonal and/or impulsive character is outside the scope of this method.

The scope of the specific sound may be defined within the specification to be achieved – for example, sound from events that occur on a less than weekly frequency may not be included. When considering sound from external sound sources, sound from sources within the building – such as that from human activity or building services – constitutes background sound.

The range of types of sound sources covered by this part of the guidelines is large and a single measurement parameter will not describe the levels of all of these sources satisfactorily. The sound source might be reasonably steady, such as distant road traffic, where the average sound level, the $L_{eq,T}$, would be sufficient, or it might consist of a number of individual events, such as from trains or aircraft , where the maximum sound level (dB $L_{Amax,T}$) and the sound exposure level (SEL) might also be of interest.

In the first instance, the measurements should be undertaken in accordance with the specification for the specific project. In the absence of a specification the consultant should form the specification against which measurements should be undertaken prior to commencement of the survey. It is important to have clarity on the purpose of the survey and sound level parameters which are to be quantified prior to determining the method of measurement.

Two situations are considered; firstly, where the sound might be characterised by an average, using the L_{eq}, and secondly, where the sound from individual events is relevant. There will be situations where the methods suggested in this document are not suitable, such as for impulsive sound, or where the total period of each sound event is so short that the methods do not give a reliable result. The measurement methodologies described here should, however, offer useful guidance for many commonly encountered situations.

The majority of external sound sources can be categorised by considering two aspects of their temporal characteristics:

- Steady or non-steady; or
- Continuous or intermittent.

This implies the four categories of sound for which examples are given in table below.

Table 3-2 Terms and definitions

Type of sound	CONTINUOUS	INTERMITTENT
Steady sound	Mechanical plant on fixed duty	Mechanical plant on switching duty e.g. pumps, generators etc.
Non-steady	High flow road traffic	Low flow road traffic Aircraft Trains Construction activities Commercial and Leisure activities

In addition to its temporal qualities, a sound might have tonal or impulsive characteristics that require consideration. Corrections for tonality and impulsivity may be given in the specification, but are outside the scope of this guide.

Measurement parameters and precision

The measurement parameter should normally be given in the specification (e.g. NR, dB $L_{Aeq,T}$ etc). If this is not the case one of the following should normally be selected:

- $L_{A90,T}$
- $L_{Aeq,T}$

Where measurements are required in individual spectral bands, for example to calculate NR or RC levels, the time averaged sound level, $L_{eq,T}$, for each band would normally be measured, or calculated using the corrections given in the procedures below.

If the specific or background sound varies during the time of the measurement, the data might require real-time analysis or post-processing. Where a spectral analysis of the L_{max} is required this should be made at the time of the maximum A-weighted sound level.

Attention is drawn to the frequency ranges implicit in the use of weighting systems, for example, NC and PNC curves require measurement from 63 Hz to 8 kHz and the range for NR curves is from 31.5 Hz to 16 kHz. Measurements should include at least octave bands from 63 Hz to 4 kHz, with other octave bands being measured when considered necessary, or in the event of dispute on this matter.

Measured or calculated sound levels should be recorded to 1 decimal place. The final statement of the result(s) should be rounded to the nearest integer value.

Measuring equipment, calibration and tolerances

Equipment

The measuring equipment should be suitably specified for its intended purpose. It would normally be expected that a Class 1 instrument according to BS EN 61672-1:2013[17] would be used.

The measurement equipment should be capable of determining, if required for the relevant measurement parameters:

1. The A-weighted equivalent continuous sound pressure level, dB $L_{Aeq,T}$, over the defined measurement period, T.
2. The A-weighted maximum sound pressure level, dB $L_{Amax,T}$, over the defined measurement period, with equipment set to measure with 'Fast' or Slow time-weighting as required.
3. The A-weighted 90th percentile sound pressure level, dB $L_{AF90,T}$, with equipment set to measure with 'Fast' time-weighting.
4. The sound pressure level in each octave band between the range 63 Hz to 4 kHz as a minimum (measurements in further octave bands, third octave bands or narrow band can be considered in some scenarios).

Calibration

The measurement instrument shall have been calibrated in a UKAS accredited, (or equivalently approved) laboratory within the last two years.

The calibration of the whole system (including any extension cables or adaptors) is to be verified with an acoustic field calibrator prior to and after each survey sequence, including battery changes, to check there is no significant calibration drift (≤+/-0.2dB). A survey sequence is described as a set of measurements taken during a single power cycle of the sound level meter

The calibration level should be set on the meter at the initial calibration check. At each subsequent calibration check, the amount of "drift" from this calibration value should be noted down and recorded in the report. If the drift over the measurement period is greater than 0.2dB then the cause of the drift should be investigated and the test may have to be repeated.

The field calibrator should be calibrated by a UKAS accredited, (or equivalently approved) laboratory within the last 12 months; the laboratory should be similarly approved as for the measurement instrument.

The calibration period could be every 2 years with a formally documented in-house cross-checking procedure consistent with the ANC Pre-Completion Testing Registration Scheme[18].

In addition to calibration checks before and after each survey sequence, the calibration of the measuring equipment chain should also be checked under the following circumstances:

- After any change or interruption to the power supply
- After any change in the measuring equipment, e.g. addition of a microphone extension cable
- After any shock or suspected damage to the measuring equipment
- After exposure to excessive humidity or change of temperature

Instrumentation tolerances

Guidance on likely instrument tolerances under design conditions may be found in BS EN 61672-1:2013. Differences between design conditions and those under which the sound measurements are made should be noted if this is likely to affect the measured sound level.

Sampling periods

Where guidance is given on sample measurement periods these should be regarded as minimum periods; longer measurement samples may be required to obtain results which are representative of the sound from the source over the reference period. The consultant must determine the appropriate length of measurement period in any particular case.

Steady continuous sound

For this category of sound the time-average sound level, $L_{eq,T}$, may be measured, where T is not less than 10 seconds.

Steady intermittent sound

Three measurement methods can be used:

1. The time averaged sound level, $L_{eq,T}$, may be obtained by measurement over at least one entire reference period.

Alternatively, one of two shortened measurement methods may be adopted:

2. Measure the time averaged sound level, $L_{eq,T}$, over a number of complete sound source cycles. Establish that the source cycle repeats consistently throughout the reference period to show that the sampled level is the same as the level that would be obtained by measurement over the entire reference period.
3. Measure at each discrete sound source level and calculate the level averaged over the reference period, $L_{eq,T}$. This approach might be useful for sources that have discrete levels which occur over known periods and result in discrete sound levels that cycle throughout the reference period.

Measurements of the time-averaged sound $L_{eq,T}$, at each discrete sound source level can be weighted according to their relative durations throughout the reference period to calculate the $L_{eq,T}$ over the reference period.

Measurement periods should not be less than 10 seconds at each sound source level unless the period at that level is less than 10 seconds, in which case the full period should be measured.

If the difference between the sound at different steady intermittent levels is 3 dB or more, then each sound level should be reported.

Non-steady continuous sound

For this category of sound, the source is present throughout the reference period but at a level that varies in a non-discrete way during that period, such as sound from road transportation sources. The reference period (e.g. 8 hours over the night-time) may be split into shorter sub-periods chosen to reveal the variation in source level. Measurements within each sub-period should be taken over periods of at least 5 minutes or over the entire sub-period if it is less than 5 minutes. In any case the choice of measurement period should be justified by the consultant.

The level averaged over the reference period may be obtained by time-weighting the sub-period levels, $L_{eq,T}$. The statistical sound levels (e.g. $L_{A90,T}$) for each sub-period cannot be averaged.

Non-steady intermittent sound

This category of sound is characterised by sources that form separate sound events, such as train or aircraft movements. The $L_{eq,T}$ over the entire reference period should be obtained either by measurement over the entire period or by a shortened measurement method similar to that described above for non-steady continuous sources.

For individual events, measurements of L_{AFmax}, $L_{Aeq,T}$ and SEL may be required. The measured SEL of events may be used to calculate the contribution of sound from events to the overall $L_{eq,T}$. It may be necessary to measure a suitable sample of representative individual events to enable post-processing of data.

Measurements should be made over a sufficient duration to provide a representative sample of all events to quantify the spread of sound levels experienced throughout the reference period.

Where the sound level during individual events is of interest, e.g. when measuring maximum noise levels, the sampling time must be appropriate for quantifying the number of individual events that occur during the entire reference period. For example, where maximum sound events are from road traffic passbys, it may be appropriate to measure using a 2-minute sampling time[19].

It is noted that the spatial variation of the L_{AFmax} level across a room may be similar in magnitude to the spatial variation of the continuous equivalent level $L_{eq,T}$ but there is currently insufficient information available to offer further guidance on averaging maximum levels measured at discrete positions.

Measurement positions

The measurement positions should reflect the use of the building. Unless indicated otherwise, it may be assumed that a specified sound level applies at normally occupied positions, and does not apply at other positions. Consideration should be given to alterations to room layouts and the possibility of presently unoccupied positions becoming occupied, for example where demountable partitions form part of the design.

Where an upper sound level only has been specified, measurement positions should include normally-occupied positions that are most exposed to the most significant sources of sound. Where lower levels have also been specified (for masking sound), measurements should be included at the quietest normally-occupied position in the room. It may be necessary to measure at a number of positions to locate these conditions.

A measurement position to characterise the space should comprise the spatial average obtained from using a moving microphone measurement, or from four or more fixed microphone positions. There is guidance on moving microphone techniques in BS EN ISO 16283-1[20], and BS EN ISO 10052. If using multiple fixed microphone positions, the minimum distance between microphone positions should be 0.7m, and the levels should be energy-averaged between microphone positions. A fixed microphone position measurement may be undertaken with a microphone mounted on a tripod, or using a hand-held device. For longer term measurements, for example over many hours, it is likely only to be practical to measure at a single fixed microphone position.

Microphone positions may be considered, for example:

- Typically between 1.2 m and 1.5 m above floor level.
- Not less than 1.5 m from any significant source of sound within a room (e.g. grille, mechanical service, window etc).
- For building services sound sources on or near the ceiling, the measurement position may be directly below the source, observing the minimum distance noted above.
- Where sources are located on walls, the measurement position may be 1.5 m from the source horizontally.
- Where multiple sources are present, multiple measurement positions may be required.
- Measurements should not be taken with the microphone less than 1 m from any sound-reflecting surface except where room dimensions preclude this, in which case, the maximum practicable distance should be adopted.
- When using a moving microphone technique, the microphone path should lie within the minimum distance constraints noted above.

In some circumstances (e.g. where the sound level is controlled by low frequency components) the use of spatial averaging methods may not represent an occupant's experience at a particular position. An alternative measurement method, such as the Finnish "Measurement of low frequency noise in rooms"[21] (2011 - Finnish Institute of Occupational Health), may be more appropriate.

Measurement zones

Within larger rooms, measurements should be undertaken at a suitable number of zones to sufficiently characterise each zone separately. For example, the following guidance from BS EN 50849:2017[22] may be considered:

Table 3-3 Guidance on no. of measurement zones

Floor area, m^2	No. of measurement zones (each reported separately)
≤ 25	1
25 – 99	3
100 – 499	6
≥ 500	10

When measurements are recorded in different zones within a larger space, each value should be reported separately rather than averaged across the space. Thus, a room of 55 m^2, for example, could have three measurement zone values reported. Note that when measuring sound levels following the ANC GPG Acoustic Testing of Schools, the energy-average from three measurement positions is used, which is different to the procedure in this document.

Measurement conditions

Building services operating duty

Measurements should be made with the building services plant operating as described in the sound specification. In the absence of this detail, the plant should be operating at its typical or design duty, as far as can be determined. Where the plant has multiple discrete operating set points it is recommended that measurements are taken at each duty and reported separately for consideration, even if only the lower duty sound level is compared with the specification. In these circumstances, a suitably competent building services engineer should be in attendance to confirm that plant is operating at the correct duty. This would normally be beyond the remit of the acoustic consultant conducting the sound survey.

During measurements, windows and ventilators should be in the normal position for the mechanical ventilation system operation. Where different window or ventilator openings are required at different times of the year, measurements may be made for a variety of window and ventilator opening positions, and reported separately.

External source conditions

Unless specified otherwise, measurements should be undertaken with external sources operating under "normal" conditions, e.g. road traffic measurements on a normal weekday, with no roadworks and when the roads are dry. If external sound levels are regularly controlled by a different activity, for example revelers on a weekend, then it would be appropriate to measure under those conditions.

Meteorological conditions

Consideration should be given to weather conditions (see BS 7445-1 Section 5.3).

Unless otherwise specified, measurements should be undertaken with wind speeds less than 5 m/s (when measured at a height of 3 to 11m above the ground) and no heavy precipitation, according to BS 7445-2 Section 5.4.3.3. The weather conditions should be reported where considered to affect the measurement results.

Correcting for background sound and room conditions

Correcting for background sound

If correction for background sound is desired or required, the principle in ISO 16032 may be followed. Measurements should be made with the building services plant switched off and on in order to differentiate between the total sound and background sound from other sources. The background sound level should be measured in the same way as the total sound level. The specific sound level can then be obtained by subtracting the background sound level as described in the table below. This should be done in either 1/3 or 1/1 octave bands. If, at any measurement position, the background sound is within 4 dB of the total sound level the calculated specific sound level will be subject to considerable uncertainty and the measurements should ideally be repeated at a time when background sound levels are lower. If this is not possible, the acoustic consultant should justify the use of the measurement and define the measurement limits in the report.

A correction for background sound may be made using the same methodology when correcting a measurement as described in ISO 16032, such that:

Table 3-4 Background correction methodology

Difference between Total and Background sound levels, $L_{Total} – L_{Background}$ / dB	Correction for Background to determine the Specific sound level
L_{Total} - $L_{Background} \geq 10$	None
4 < L_{Total} - $L_{Background}$ < 10	Logarithmic correction, i.e. $L_{Specific} = L_{Total} - K$ dB $K = -10 \lg (1 - 10^{-0.1 \times \Delta L})$ dB $\Delta L – L_{Total} - L_{Background}$ dB
L_{Total} - $L_{Background} \leq 4$	Equivalent to a difference of 4 dB, i.e. $L_{Specific} = L_{Total} – 2.2$

Corrections as above should normally be made in each frequency band.

The background sound level itself may be constantly varying and the peaks of sound occur over a very short time. As a result, background sound corrections to maximum sound levels (L_{max}) should not normally be carried out. If the L_{max} of the specific sound level is not at least 10 dB higher than the background sound level then consideration should be given to disregarding the measurement.

If the measurement equipment permits, it is preferable to manually remove from the time history those background sound events that are clearly identified (by means of the observer's notes or audio recordings) from the measurements before the calculation of the specific sound. For example, sound from people in buildings should be excluded from calculations when the specific source is external road traffic.

Correcting for reverberation time

A significant problem with the measurement of sound levels in rooms is that the room provides an acoustic response to any sound within it. The response of the room may change significantly between being in an empty and unfurnished state, and being fully furnished. In the absence of a definitive statement that the specification refers to sound levels in empty and unfurnished rooms, it may be assumed that the specification refers to sound levels when the room is normally furnished, and the level refers to a level standardised to the anticipated or reference reverberation time. For example, a reasonable anticipated reverberation time for a furnished domestic room of typical proportions would be 0.5 seconds, across the relevant frequency range.

Wherever possible, the measurements should be undertaken in typically finished conditions. Where rooms may be used in the empty and unfurnished state – for example a school hall – it is appropriate to measure under these conditions. Where rooms are unlikely to be used in that state – a bedroom for example would be expected to contain a bed, at least – then a correction may be made to account for the anticipated change in reverberation time.

When there is omission of this detail in the specification, the measurement should reference the maximum allowable reverberation time for the room, if there is a standardised level and the reference reverberation time.

Standardising to a reference reverberation time may be carried out in the same manner as described in ISO 16032. This involves measuring the reverberation time in accordance with BS EN ISO 3382-2[23], in frequency bands, with engineering level accuracy when used to correct another acoustic measurement. The standardised level can be calculated from the measured values in each frequency band with adjustment for reverberation time, assuming that the reverberant level is the dominant portion of the sound source at the measurement position, and accounting for background sound also if appropriate.

Reporting

Where measurements are carried out according to this ANC simple method as described above, then the measurement report should normally record the following information:

- The client;
- The person carrying out the measurements and their relevant qualifications;
- Date and time of measurements;
- Location, i.e. name of building, floor, room name or number;
- Description of sound source(s), operating conditions and duties, including metrological conditions where relevant;
- Details of all equipment used, i.e. manufacturer and model, type specification, whether the sound level meter complied with BS EN 61672-1: 2013, specific equipment identifiers such as serial numbers or set number, and calibration dates;
- Confirmation that field calibration checks were within permitted tolerances, making due allowance for calibrator class, sound level meter type specification and drift;
- Description of source sound (e.g. steady, non-steady or impulsive, continuous or intermittent, tonal or non-tonal) and associated measurement parameters;
- Details of the measurement positions, including description of where the highest sound pressure level was measured and, where there is a requirement for masking sound, where the lowest sound pressure level was measured;
- Description of fixed microphone positions, or whether a moving microphone technique was used.
- Measured reverberation times, if relevant, and any corrections used to calculate the standardised sound level.
- Results of the measurements at each position separately, including the derivation of any adjustments for background sound and reverberation time.
- The permissible sound level(s) for the room, and whether any penalty needed to be made for tonality or impulsivity.
- A description of room finishes, furniture, partitioning or the presence of any reflective or absorbent surfaces which could have a significant effect on the measured sound levels.
- Whether any additional diffusing elements were introduced.
- Justification for any deviations from the simple method.
- Whether, when due allowance had been made for the instrumentation tolerances, the specific sound level complied with the specification.

Appendix A - Other Methodologies

Reference	Year	Notes
ANC GPG: Acoustics Testing of Schools [24]	2015	ANC Good Practice Guide: Acoustic Testing of Schools, Version 2, Nov 2015.
ISO 10052 [3]	2004	Survey grade method for measurement of sound levels from service equipment.
ISO 16032 [4]	2004	Engineering grade method for measurement of sound levels from service equipment.
Swedish guide to application of ISO 10052 & 16032 [25]	2015	Swedish guidance on the application of ISO 16032 and 10052 in situations where the service sound level is neither static nor controllable.
Measurement of low frequency noise in rooms [21]	2011	Finnish Institute of Occupational Health. Offers more detailed guidance where frequencies between 20 – 200 Hz are significant.
ISO 16283-3 [26]	2016	Field measurement method of façade sound insulation using traffic noise as an external sound source.
NF S31-199 [27]	2016	French standard for acoustics in open-plan offices, including Annex D (informative), Minimum requirements for measuring L_{Aeq} during an activity.

ANC GPG: Acoustic Testing of Schools

This document sets out the technical guidance for acoustic measurements to determine compliance with the performance standards in Building Bulletin 93[28] (BB93). The purpose of the ANC GPG: Acoustic Testing of Schools is to enable consistency in interpretation of the methods described in BB93 and associated guidance so that acoustic measurements in school buildings may be made consistently between acoustic consultants. The measurement of ambient sound levels in rooms due to both internal and external sources of sound are described in that document.

ISO 16032 and ISO 10052

Measurement of sound from service equipment (including building services) is described in BS EN ISO 16032 and BS EN ISO 10052. These standards were developed following NordTest Report TR 385 (1997)[29], which describes a literature survey comparing 24 methods for sound measurements in rooms, and proposals for new methods.

ISO 10052 describes a survey grade method for field measurements of service equipment sound in rooms with a maximum volume of 150 m^3. Measurements may be of single number quantities, such as dB $L_{Aeq,T}$, directly; frequency band measurements are not necessary. ISO 16032 describes an engineering grade method for the measurement of sound levels from service equipment in rooms with volumes up to approximately 300 m^3. Measurements in octave bands are necessary.

The standard covers service equipment either attached to or installed in buildings, regardless of transmission path. Operating conditions and operating cycles are specified for the most common service equipment in buildings. The principles described in consideration of operating cycles may be applied to other sources of sound.

ISO 16032 specifies that operators should not be present in the room under test during measurements; the presence of an operator in the room may nonetheless be beneficial for the identification of sound sources.

The single number quantities determined according to these standards may be various combinations of:

- maximum or continuous equivalent levels;
- time weighting (fast or slow);
- frequency weighting (A, C or Z);
- uncorrected or corrected to room conditions (i.e. standardised or normalised).

Standardisation, denoted by the subscript $_{nT}$, is a prediction of the sound level if the in-situ reverberation time was equal to the reference reverberation time used for standardisation across the entire frequency range. In dwellings a reference reverberation time of 0.5 seconds is typically used (Ref: ISO 16283-1).

Normalisation, denoted by the subscript $_{n}$, is a prediction of the sound level if the quantity of sound absorption (Sabines) in-situ was equal to the reference value of 10 m^2 across the entire frequency range. Normalisation is used in some countries' national standards, but is not common in the UK.

Measurements of sound levels made without standardisation or normalisation are often referred to as "in-situ" levels. "In-situ" sound levels are dependent on the contents of the room at the time of measurements, as more sound absorption will tend to reduce sound levels.

Swedish Application Guidance for ISO 10052 & 16032

The Swedish guidance was produced to assist in measuring building services sound that varies significantly over time. In Sweden, it is common for central air handling plant to supply many dwellings in multi-residential buildings; this regulates to keep air flows constant as the pressure differences change, which happens as people open windows in other flats of the block, for example. This guidance is intended to be used with either ISO 10052 or ISO 16032, and is accompanied by spreadsheets for the calculations.

This guideline follows the main principles of ISO 10052 or ISO 16032, along with additional guidance in order to reduce uncertainty with respect to the spatial sampling of the sound field in a room as well as uncertainty caused by temporal variations in the sound source. The report is divided into two relatively independent parts, one for each method. This guidance may be useful where sound levels are not steady and continuous.

Measurement of Low Frequency Noise in Rooms (Finnish Guidance)

This Finnish guidance highlights that sound pressure levels at low frequencies (20 Hz to 200 Hz) are strongly dependent on measurement positions in normal-sized rooms. The variation of sound pressure level can be more than 20 dB between different measurement locations, however, there is no standardised method to measure such sound. In this study, published measurement methods of low frequency noise are compared.

The simplest methods specify only one measurement point and a 1-hour long sampling period. This approach is to characterise the experience at a single position within the room; significant variation in sound level can occur between positions, but the focus of this guidance is on the occupant's experience rather than on the room.

Other methods emphasise the corner positions, which can lead to the overestimation of sound pressure levels compared with the occupants' locations. The Finnish Guidance suggests that the literature lacks a simple but occupant-oriented measurement method.

The aim of the study was to develop a simple and reliable method for the measurement of low frequency sound in all kinds of rooms, like dwellings, industrial control rooms or patient rooms. The method was developed based on extensive measurements in five rooms. In addition, finite element modelling (FEM) was used to supplement the analysis of spatial sound pressure level variations. The suggested method includes two alternatives; one for constant and one for intermittent sound. The former is very rapid and it is applied in the first place. The latter also includes a long-term measurement which is applied when temporal variations are observed or expected. In most cases, the constant sound method is sufficient to state whether the limit values are exceeded or complied with. The practical application of the method is illustrated in one case study.

ISO 16283-3

ISO 16283-3 specifies procedures to determine the airborne sound insulation of façade elements and whole façades using sound pressure measurements. These procedures are intended for room volumes in the range from 10 m^3 to 250 m^3 in the frequency range from 50 Hz to 5,000 Hz. The test results can be used to quantify, assess, and compare the airborne sound insulation in unfurnished or furnished rooms whether the sound field approximates to a diffuse field or not.

An 'element method' aims to estimate the sound reduction index of a particular façade element, whereas a 'global' method yields the real reduction of a façade in a given place internally relative to a position 2 m in front of the façade. Road traffic may be used as the sound source; the road traffic method is supplemented by the corresponding aircraft and railway traffic methods.

In this standard, the spatial average is taken over the central zone of the room where the nearfield radiation from the room boundaries is considered to have negligible influence.

The low-frequency sound pressure level is defined in the low-frequency range (50 Hz, 63 Hz, and 80 Hz one-third octave bands). The spatial average is a weighted average that is measured in the room corners where the sound pressure levels are highest and in the central zone of the room where the nearfield radiation from the room boundaries is considered to have negligible influence. This is equivalent to measurements for sound insulation according to ISO 16283-1 and ISO 16283-2 [30]. The low frequency sound pressure level is not used for road traffic, train or aircraft sound sources. It is noted that the low-frequency procedure is necessary in small rooms due to large spatial variations in the sound pressure level of the modal sound field. In these situations, corner measurements are used to improve the repeatability, reproducibility, and relevance to room occupants.

Fixed microphone positions can be used without an operator in the room by using a microphone fixed on a tripod. Alternatively, the operator can be present in the room with the microphone fixed on a tripod, or with the operator using a manually-held microphone at a fixed position. In both cases the trunk of the operator's body should remain at a distance at least an arm's length from the microphone. A minimum of five microphone positions are used in the room. Each set of microphone positions is distributed within the maximum permitted space throughout the room. No two microphone positions may lie in the same plane relative to the room boundaries and the positions should not be in a regular grid. Alternatively, a mechanical continuously-moving or manually scanned microphone may be used.

The minimum averaging times for a loudspeaker sound source are short as the source noise is constant. When using road traffic as the sound source, the averaging time should include at least 50 vehicle pass-bys within the measurement period. Road traffic tends to be a variable sound source and therefore the internal and external sound pressure levels need to be measured simultaneously to accurately determine the façade sound insulation.

NF S31-199: 2016

This French Standard for acoustic performance of open plan offices includes an informative Annex D, *Minimum requirements for measuring L_{Aeq} during an activity*. It describes the requirements for measurement time, measurement conditions, expression of results and equipment.

The measurement duration should cover all activities that are representative of those that will take place in the space. The measurement duration should not be less than 4 hours. The measurement is used to assess the average noise level at workstations. The number of measuring points and their locations are selected in collaboration with the client based on the workstation configuration and type of work.

Measurements should be taken at the position of a workstation where an operator is not present, but at least 75% of workstations should be occupied to avoid periods of low occupancy. The microphone should be 1.2 m above floor level to represent the average height of the operator's ears, assuming operators are seated.

Results should be presented in the form of a commentary on the time-history of measurements, along with the overall value of $L_{Aeq,T}$. Fractile indices such as L_{90}, L_{50} and L_{10} may also complement the results. Observations of events that impact on the sonic environment should also be recorded.

Appendix B - Specification of Sound Level Limits and Application of Criteria

Introduction

The specification of appropriate sound level criteria (e.g. noise limits etc) and the application of criteria are not covered within this guide. However, this appendix presents the factors that may be considered so that an appropriate measurement methodology can be determined. A measurement method should clarify how these factors are taken into account in the measurement of sound levels.

Specifications

In general, there are two aspects of sound measurements that may need to be clearly defined in order that they are meaningful and reproducible. These can be broken down into groups, as follows:

1. Factors which relate to the interpretation of the sound levels.
2. Physical factors which might lead to variations in the measured sound level.

Factors Affecting the Interpretation of the Sound Levels

- The parameter(s) for sound level characterisation, such as NR, NC, RC MkII, L_{An}, L_{Aeq}, L_{max}, stating a maximum acceptable level and, if masking sound is required, a minimum acceptable level.
- The frequency range over which the parameter is evaluated, as appropriate.
- The character of the measured sound and attribution of a "penalty" to the decibel level. For example, penalties may be applied to account for tonal components (tonality may be assessed using a subjective or an objective method), or impulsive components (crashes and bangs, etc.).

Note The RC Mk II metric includes the "Quality Assessment Index", which addresses spectrum balance or imbalance.

Physical Factors Affecting the Measured Sound Level

- Temporal variations, spatial variations, and variations across the frequency range of interest.
- The number of events or cycles to be measured and method of averaging or otherwise processing the data. This should include specification of a method for interpretation of all key indices. For example, if L_{Amax} were important it could be specified that maximum sound level from events over a defined period would be recorded and an appropriate threshold be specified.
- The reference period and the length of the measurement periods.
- The position(s) in the room where the specification must be met, to characterise a potentially occupied position, or a spatial average to characterise the space.
- The type of room in which tests should be performed and the condition of the room, whether furnished or unfurnished.
- Correction for background sound.
- Correction for reverberation time to account for differences in room conditions.
- The frequency range of measurements.
- Measurement equipment type, specification, tolerances, calibration and verification.
- Any control settings or set points for natural ventilation systems, such as trickle vents or opening windows.

- The sound source conditions under which the specified sound level should be measured:
- For external sound this should state the need to avoid atypical events which may affect the measured internal sound level such as interrupted traffic flows on roads due to construction work or reduced maximum train sound levels due to speed restrictions on a railway.
- For internal sound this should state the building services operating condition under which the requirements are to be met such as design or maximum duty. (Any automated control systems may need to be overridden during the measurement period.)
- Weather or meteorological conditions which may influence the propagation of sound from external sources.

An appropriate specification may include requirements for the above factors.

Application of Criteria

There are two common types of specification for internal sound levels:

- Specification of an upper limit only;
- Specification of an upper and lower limit, for example where masking sound is required.

Where the sound source is proposed to be used to provide sound masking, it may be appropriate to apply both an upper and lower sound level limit. Generally, this would only apply to sound from building services plant with broadband and continuous characteristics such as air handling units or masking sound systems.

For intrusive sound, particularly where the sound source is transient or intermittent (e.g. aircraft, trains), it would usually be appropriate to apply an upper sound level limit only since transient events would not provide effective sound masking.

Where sound sources are considered to contain distinguishable characteristics such as tones, impulses, or intermittency, it may be necessary to determine a method of applying penalties to the measured sound levels. Details of the application of penalties would form part of the sound level specification. Alternatively, a specification may indicate that the sound should not contain distinguishable characteristics.

Example Sound Level Specifications

Example 1: Building Services Sound within a New Office Development

1. Spaces of Interest

1.1 Sound levels shall be measured in a sample of one in four spaces.

1.2 Specific spaces are to be agreed with the Client before testing. The spaces selected should include a representative sample of each different room type and performance requirement.

2. Requirements

2.1 The source level due to building services shall be measured in accordance with the ANC Simple Method presented in the ANC Guidelines – Measurement of Sound Levels in Buildings.

2.2 Measurements shall be carried out within finished and normally furnished but unoccupied rooms. Where this is not possible, corrections shall be applied to the measured level to account for the absence of normal furnishing. Corrections shall be applied to standardise the source level to the reverberation time that would be present within a finished and furnished room, as defined in the Project Acoustic Design Report.

2.3 A correction for background sound level shall be applied if appropriate.

2.4 The presence of any tonal or impulsive features in sound from building services shall be noted via subjective observations.

2.5 Source levels shall be quantified in terms of the parameters referred to in the Project Acoustic Design Report.

3. Specific sound level targets

3.1 Where the source level within each space falls within the specific sound level range that is specified within the Project Acoustic Design Report, it is considered to comply with specification. Small deviations from the design criteria (for example up to 2 dB) at individual measurement positions may be acceptable at the project acoustician's discretion.

3.2 Reporting:

a. The information to be reported shall be as described in the ANC Simple Measurement Method.

b. Where, in the subjective opinion of the consultant undertaking measurements, tonal or impulsive features are observed, these shall be highlighted to the Client.

Example 2: Sound Level Specification – Measurement of environmental and building services sound in a residential development.

1. Background

1.1 Planning conditions may refer to demonstration of compliance with internal sound level guidelines for a new multi-residential development, comprising of flats. This would be consistent with ProPG [36] and the AVO Guide [37], which require internal sound level guidelines to be observed, and an assessment of building services sound.

2. Specification of sound limits

2.1 The criteria agreed between the local authority and developer are shown in the table below.

3. Sampling of rooms for environmental sound

3.1 Measurements shall be carried out and reported by a suitably qualified person following the ANC Simple Method described in the ANC Guidelines - Sound Measurement in Buildings.

3.2 Specific rooms for sampling to be agreed with the local authority prior to commencing measurements.

3.3 Environmental sound levels shall be measured in a representative sample comprising at least two dwellings on each façade. The rooms sampled must include those most exposed to environmental sound ingress, i.e. those with the highest external sound impact and those most susceptible to external sound ingress through façade elements.

3.4 For guidance on measuring and assessing noise from events, L_{max}, refer to ANC AVO Guide and ANC Sound Measurement Guide [8].

3.5 Measurements of mechanical services sound shall be made in at least one in ten dwellings. The presence of any tonal or impulsive features in sound from building services shall be noted via subjective observations.

3.6 Measurements in a dwelling shall be taken in all habitable rooms serviced by the mechanical systems, for background ventilation and mitigating overheating separately. The measurements may be standardised to a reference reverberation time of 0.5 seconds across the frequency range, and corrected for background sound if required.

Table C-1 Example environmental and building services sound level criteria for a new residential development

Noise Source	Time Period / function	Living rooms	Bedrooms	Bath, WC, Kitchen
Environmental noise ingress limit with provisions for whole dwelling ventilation rate	Daytime, $L_{Aeq,16h}$	≤ 35 dB	≤ 35 dB	-
	Night-time, $L_{Aeq,8h}$	-	≤ 30 dB	-
	Night-time, ventilation design case L_{AFmax}	-	≤ 45 dB	-
Environmental noise ingress limit with provisions for mitigating overheating	Daytime, $L_{Aeq,16h}$	[Note 1]	[Note 1]	-
	Night-time, $L_{Aeq,8h}$	-	[Note 1]	-
	Night -time, overheating design case L_{AFmax}	-	[Note 1]	-
Mechanical services noise, where systems present	Whole dwelling ventilation rate, $L_{Aeq,T}$	≤ 30 dB	≤ 26 or 30 dB [Note 2]	-
	Extract ventilation rate, $L_{Aeq,T}$	≤ 35 dB	≤ 26 or 30 dB [Note 2]	≤ 45 dB
	At design duty to control overheating [Note 3]	≤ 35 dB	≤ 30 dB	-

Note 1 Agreed limits for environmental noise ingress while using provisions for mitigating overheating may vary depending on the overheating risk and extent of time these measures may be required. Refer to AVO Guide.

Note 2 Suitable limits for mechanical services noise should be adopted, see Section 3.2 of AVO Guide.

Note 3 Refer to Table 3-5 of AVO Guide and consider whether this criterion should be + or – 5 dB.

Appendix C - References and Further Reading

Sector Specific Guidance

Some sector-specific guidelines contain requirements for the measurement of sound levels in rooms, including those listed below. While some of these guidance documents have notes on the measurement of sound in buildings, some refer back to older versions of these ANC guidelines.

Sector	Guidance
Schools	Building Bulletin 93 (BB93) Acoustic design of schools: performance standards (refer ANC GPG: Acoustic Testing of Schools summarised above)
Healthcare premises	Department of Health Acoustics: Technical design manual Version:0.6:England. [31]
Residential	Home Quality Mark Technical Manual 2016 [32]
Offices, Industrial, Retail, Prisons, Non-domestic buildings	BREEAM UK New Construction non-domestic buildings technical manual 2018. Version: SD5078 – Issue: 1.0 – Issue Date: 27/02/2018 [33]
Offices	British Council for Offices: Guide to Specification Best Practice for offices 2019 [34]. (NB The BCO Guide refers to a previous version of the ANC guidelines, which should be superseded by the current version)
Law court buildings	Chapter 5 of Court and Tribunal Design Guide [35]. For assessments in Scotland, see also CN3.

References

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Ref	Title	Author/Publisher	Year
1	ANC Guidelines – Noise Measurement in Buildings. Part 1: Noise from Building Services	ANC	2011
2	ANC Guidelines – Noise Measurement in Buildings. Part 2: Noise from External Sources	ANC	2013
3	BS EN ISO 10052:2004+A1:2010 Acoustics. Field measurements of airborne and impact sound insulation and of service equipment sound. Survey method	British Standards Institution	2005
4	BS EN ISO 16032: 2004 Acoustics. Measurement of sound pressure level from service equipment in buildings. Engineering method	British Standards Institution	2004
5	BS 7445-1:2003 Description and measurement of environmental noise. Guide to quantities and procedures	British Standards Institution	2003
6	ISO 1996-1:2016 Acoustics. Description, measurement and assessment of environmental noise. Part 1: Basic quantities and assessment procedures	International Organization for Standardization	2016
7	ISO 1996-2:2017 Acoustics. Description, measurement and assessment of environmental noise. Part 2: Determination of sound pressure levels	International Organization for Standardization	2017
8	Environmental Sound Measurement Guide (2nd Edition) – The Green Book	ANC	2020
9	Annoyance of tonal noise: a parametric study	D W Robinson, Acoustics Bulletin	1993
10	Objective Method for Assessing the Audibility of Tones in Noise Joint Nordic Method – Version 2	Torben Holm Pedersen, Morten Sondergaard, Bent Andersen	1999
11	BS 7445-2:1991 (ISO 1996-2:1987) Description and measurement of environmental noise. Part 2 Guide to the acquisition of data pertinent to land use	British Standards Institution	1991
12	BS EN ISO 7779: 2018 Acoustics. Measurement of airborne noise emitted by information technology and telecommunications equipment.	British Standards Institution	2018
13	BS EN ISO 3741: 2010 Acoustics. Determination of sound power levels and sound energy levels of noise sources using sound pressure. Precision methods for reverberation test rooms	British Standards Institution	2010
14	BS EN ISO 3745: 2012+A1:2017 Acoustics. Determination of sound power levels of noise sources using sound pressure. Precision methods for anechoic and semi-anechoic rooms.	British Standards Institution	2012

References

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Ref	Title	Author/Publisher	Year
15	BS 4856-4:1997 Methods for testing and rating fan coil units, unit heaters and unit coolers. Determination of sound power levels of fan coil units, unit heaters and unit coolers using reverberating rooms.	British Standards Institution	1997
16	CIBSE Guide A: Environmental Design	CIBSE	2015
17	BS EN 61672-1: 2013 Electroacoustics - Sound level meters. Specifications.	British Standards Institution	2013
18	ANC Pre-Completion Testing Registration Scheme Handbook (Version 13.0)	ANC	2018
19	Assessing L_{max} for residential developments: The AVO Guide Approach	Paxton, B, Conlan, N, Harvie-Clark, J, Chilton, A, Trew D Acoustics 2019, IOA Proceedings Volume 41 Part 1	2019
20	BS EN ISO 16283-1:2014+A1:2017 Acoustics. Field measurement of sound insulation in buildings and of building elements. Airborne sound insulation	British Standards Institution	2014
21	Measurement of low frequency noise in rooms	Finnish Institute of Occupational Health (David Oliva, Valtteri Hongisto, Jukka Keränen, Vesa Koskinen)	2011
22	BS EN 50849:2017 Sound systems for emergency purposes	British Standards Institution	2017
23	BS EN ISO 3382-2: 2008 Acoustics. Measurement of room acoustic parameters. Reverberation time in ordinary rooms	British Standards Institution	2008
24	ANC Good Practice Guide - Acoustic Testing of Schools (Version 2)	ANC	2015
25	Vägleding för mätning av ljudnivå i rum med stöd av S-EN ISO 10052/16032	Krister Larsson, Christian Simmons	2015
26	BS EN ISO 16283-3:2016 Acoustics. Field measurement of sound insulation in buildings and of building elements. Façade sound insulation	British Standards Institution	2016
28	Acoustic design of schools: performance standards (Building bulletin 93)	HM Government	2015

References

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Ref	Title	Author/Publisher	Year
29	Measurement of Sound Pressure Levels at Low Frequencies in Rooms (NordTest Report TR 385)	Christian Simmons	2015
30	BS EN ISO 16283-2:2018 Acoustics. Field measurement of sound insulation in buildings and of building elements. Impact sound insulation	British Standards Institution	2018
31	Department of Health. Specialist services. Health Technical Memorandum 08-01: Acoustics	HM Government	2013
32	Home Quality Mark Technical Manual	BRE Global Limited	2016
33	CIBSE Guide A: Environmental Design	BRE Global Limited	2018
34	British Council for Offices: Guide to Specification Best Practice for offices 2019	British Council for Offices	2019
35	Court and Tribunal Design Guide v1.1 (Feb 2019)	HM Courts and Tribunals Services	2019
36	ProPG Planning and Noise - New Residential Development	ANC/IOA/CIEH	2017
37	Acoustics Ventilation and Overheating – Residential Design Guide	ANC	2020

Further Reading

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Title	Author/Publisher	Year
BS EN 61260-1:2014 (IEC 61260-1:2014) Electroacoustics. Octave-band and fractional-octave-band filters. Specifications	British Standards Institution	2014
BS 4142:2014+A1:2019 Methods for rating and assessing industrial and commercial sound	British Standards Institution	2014
BS EN IEC 60942:2018 Electroacoustics. Sound calibrators	British Standards Institution	2018
BS EN 61672-1:2013 Electroacoustics. Sound level meters. Specifications	British Standards Institution	2013
BS EN ISO 9612:2009 Acoustics. Determination of occupational noise exposure. Engineering method	British Standards Institution	2009
BS EN ISO 11201:2010 Acoustics. Noise emitted by machinery and equipment. Determination of emission sound pressure levels at a work station and at other specified positions in an essentially free field over a reflecting plane with negligible environmental corrections	British Standards Institution	2010
BS EN ISO 11202:2010 Acoustics. Noise emitted by machinery and equipment. Determination of emission sound pressure levels at a work station and at other specified positions applying approximate environmental corrections	British Standards Institution	2010
CIBSE Guide B5: 2002 Noise and Vibration Sound Control for HVAC	CIBSE	2002
ANSI/ASA S12.72-2015 Measuring The Ambient Noise Level In A Room	Acoustical Society of America	2015
Measurement of sound pressure levels at low frequencies in rooms. Comparison of available methods and standards with respect to microphone positions	Christian Simmons Acta Acust. United Acust. 1999, 85, pp. 88-100	1999
On the efficacy of spatial sampling using manual scanning paths to determine the spatial average sound pressure level in rooms	Carl Hopkins I. Acoust. Soc. Am. 2011, 129 (5), pp. 3027-3034	2011
Making noise comfortable for people	G. Leventhall, S. S. Wise	1998
ISO 532-1:2017 Acoustics. Methods for calculating loudness. Part 1: Zwicker method	International Organization for Standardization	2017

Further Reading

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Title	Author/Publisher	Year
ISO 532-2:2017 Acoustics. Methods for calculating loudness. Part 2: Moore-Glasberg method	International Organization for Standardization	2017
Psychoacoustic Analyses I (Application Note – 02/18) Loudness and Sharpness Calculation	HEAD Acoustics	2018
Tonality (Hearing Model) (Application Note – 07/18) Using the new psychoacoustic tonality analyses	HEAD Acoustics	2018

MEASUREMENT OF SOUND LEVELS IN BUILDINGS

ANC Guidelines

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