Improving acoustics from the concert hall to the office

by Jens Holger Rindel

Whether listening to a concert, or working in an open plan office, getting the acoustics right is important. The ISO 3382 series on *Acoustics – Measurement of room acoustic parameters*, is raising acoustic standards in performance spaces, open plan offices and other types of room.

The scientific approach to acoustics in rooms started in the 1890s, when Wallace C. Sabine, a young physics professor at Harvard University, established the concept of reverberation time.

Getting the acoustics right is important.

The first International Standard in this area, ISO 3382:1975, *Acoustics – Measurement of reverberation time in auditoria*, specified the measurement technique as applied to concert halls.

Acoustic science has continued to develop, and today, ISO 3382 consists of three-parts covering performance spaces, ordinary rooms and open plan offices.

Sabine's acoustics

Sabine defined reverberation time, as the time for a decay of 60 decibels (dB) after a stationary sound source has been stopped.

However, around the year 1900 there were no microphones or other electronic devices that could be used for measurements. The telegraphone, the first device for electromagnetic recording of sound, had recently been invented by the Danish engineer Valdemar Poulsen (patented 1898), but this was not used for acoustic measurements until the 1930s by Vilhelm Lassen Jordan at the Technical University of Denmark.

To measure the reverberation time of a room, Sabine used a method with a stopwatch and four identical sets or organ pipes (see **Figure 1**). Relying on his own ears, he measured the time from when the organ pipes were turned off to the moment the sound became inaudible. Repeating this with four organ pipes instead of one, Sabine could derive the time difference that would represent a decay of 6 dB (i.e. exactly 1/10 of the reverberation time that represents a decay of 60 dB).

The first step

ISO 3382:1975 stated, "At present, several methods exist for the measurement of reverberation time and there are some new ideas in this field. Each of these methods may give a different result for the same auditorium. The first step is to standardize a widely used method so that it is possible to compare the data obtained by this one method."

Although a loudspeaker is the preferred sound source, other possible ones are mentioned: a pistol shot or, in churches and concert halls, an organ.

An orchestra may also be used: "Fortissimo passages of musical compositions followed by adequately long pauses are suitable." Beethoven's Coriolan Ouverture is often used for acoustical measurements as it has suitable interrupted chords at the start.

During the following decades, the technique for sound measurements developed, microphones and loudspeakers were used and the so-called level recorder became the preferred device for measuring reverberation

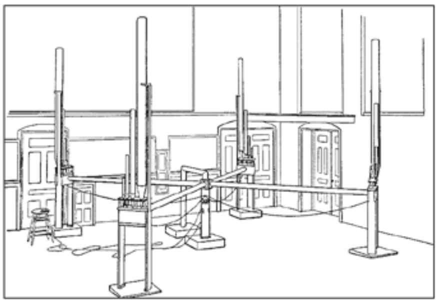


Figure 1: *Sabine's setup for measuring reverberation time using four sets of organ pipes. (Ref. W. C. Sabine, 1922.* Collected Papers on Acoustics, *Harvard University Press, 1922 [reprint by Dover Publications, New York 1964]).*

time. The level recorder had a pen that could draw a graph of the sound pressure level in dB on a long strip of paper, moving with a well-defined speed. Thus, when the sound source in a room was stopped, the slope of the decaying curve was used to calculate the reverberation time (see **Figure 2**).

The shortcomings of the first standard soon became apparent. For example, an impulse source, such as a pistol shot, does not give the same results as an interrupted, stationary sound source such as a loudspeaker.

Making it better

In 1997, ISO 3382 was updated to resolve incomparable measurement methods. The direct analysis of a pistol shot or other impulse sources was abandoned; instead the integrated impulse response method was established as equivalent to the traditional method of interrupted noise.

As in the first edition of the standard, this second edition focused on auditoria and, in particular, concert halls for classical music.

New annexes define a number of room acoustic parameters to describe the listening conditions in an auditorium. The idea is that reverberation time, though important as an overall descriptor of the acoustics of a room, is not sufficient to describe acoustic quality. Listening to music in a hall is a multi-dimensional perception (see **Box**).

The room acoustic parameters in ISO 3382:1997 have created a common reference that allows comparison of data measured around the world.

The standard has also established a solid basis for discussion among researchers in the field. This has been demonstrated by international conferences in acoustics, in which special sessions have been devoted to the ISO 3382 parameters.

Room acoustic parameters

Listening to music in a hall is a multi-dimensional perception. To characterize the acoustical quality of an auditorium, reverberation time must be joined by other parameters and several are defined in ISO 3382-1:2009, *Acoustics – Measurement of room acoustic parameters* – Part 1 : *Performance spaces*.

For the listener in the audience, the five sound parameters are :

- Subjective level of sound (neither too high nor too low)
- Perceived reverberance (neither too dry nor too reverberant)
- Perceived clarity (the preferred value varies from high for speech to low for choir and organ music)
- Apparent source width (sound reflections from the side walls contribute to an audio perception that the sound comes from a wide source, not from a point)
- Listener envelopment (the feeling of being embedded in sound)

For the musicians on stage, two other parameters are :

- Ensemble conditions (how well the musicians can hear each other)
- Perceived reverberance (how well the musician can hear the room's response to his/her instrument)


Photo : Bjarne Bergius Hermansen

New concert hall in Copenhagen (2009). Architect : Jean Nouvel.

New measurement techniques

New measurement techniques have been recently developed to save time and improve the accuracy of reverberation time measurements. ISO 18233:2006, *Acoustics – Application of new measurement methods in building and room acoustics*, describes two such methods using advanced digital signal processing to derive the room impulse response.

The maximum length sequence method (MLS) uses pseudo-random noise combined with autocorrelation technique.

Today we have a three-part ISO standard covering ordinary rooms, performance spaces and open plan offices.

The second method uses a sine-sweep, that is, a sine tone slowly changing the frequency from very low to very high, combined with a so-called de-convolution to derive the room impulse response.

Other fields of application

Reverberation time is widely used in a variety of rooms, not just auditoria. These include classrooms, meeting rooms, restaurants, sports halls, industrial halls, railway stations and airport terminals.

In addition, reverberation time has to be measured in connection with several other acoustic measurements, such as sound insulation between two rooms. In this case, the

New open-plan office in Oslo (2008).

reverberation time is used as a correction to ensure that the sound insulation is measured independently of the acoustic condition of the receiving room.

It was, therefore, unsatisfactory that the existing standard for measuring reverberation time was devoted to concert halls. Source positions and microphone positions, for example, were described in terms of the stage and seats in the audience area.

For this reason, it was decided to divide ISO 3382 into two parts :

- Part 1 on performance spaces (2009)
- Part 2 on reverberation time in ordinary rooms (2008)

Open plan offices

This could have been the end of the story, had it not been for the open plan or open-space offices becoming increasingly more common. There can be severe acoustic problems in open plan offices. Several research projects in this field have shown that reverberation time is not a sufficient descriptor of the acoustic properties in these rooms.

The most important parameters are the amount of sound absorption material, the possible use of screens between work stations, the level of background noise and speech and, more generally, the seating plan.

Listening to music in a hall is a multi-dimensional perception.

Following this, ISO 3382-3:2012, *Acoustics – Measurement of room acoustic parameters* – Part 3 : *Open plan offices*, introduces some completely different acoustic parameters ; spatial decay rate of noise with a typical speech spectrum as a measure of the sound propagation in the room and speech intelligibility as a function of distance.

From the second of these, two simple measures can be derived : the privacy distance and the distraction distance. The former is the distance from a source in which speech is not intelligible due to attenuation and background noise ; and the latter is the distance as which speech is only partly intelligible, but mostly contributes to background noise.

This recently published standard with new acoustical parameters may form a common basis for the research and development of better designed open plan offices. As we have seen in previous decades in relation to concert halls, it can be an important step forward to have measuring methods and parameters that are well defined, and allow comparison of data from different researchers and different cases.

The Euronoise international conference in June 2012 featured a session on the design of open plan offices, where delegates discussed the results of using the new ISO 3382-3.

It is hoped ISO 3382-3 will contribute to an improved understanding of problems in open plan offices, leading to better designs in the future.

World-class acoustics

Many recently built concert halls now claim to have " world-class acoustics ". Although this may not be entirely true in all cases, is seems that new halls generally have much better acoustics than before. ISO 3382 has helped to achieve this, in combination with improved prediction tools. ■

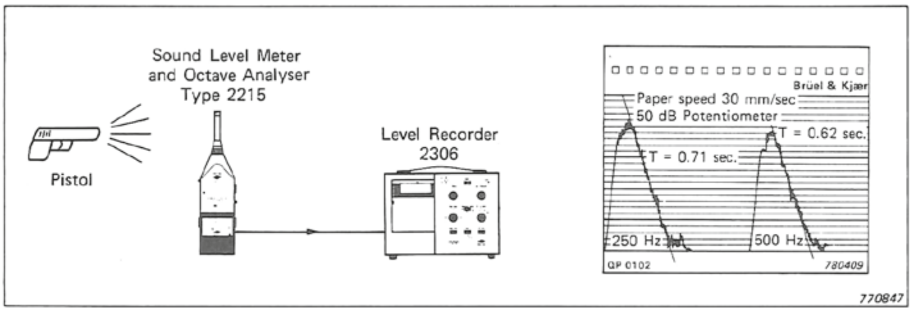
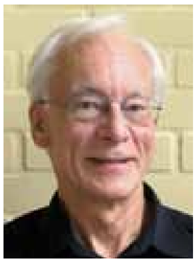


Figure 2 : *Portable setup for measuring reverberation time using a pistol shot and level recorder (Ref. K.B. Ginn (1978).* Architectural Acoustics*, Brüel & Kjær, Denmark).*

About the author



Dr. Jens Holger Rindel is a senior consultant in Multiconsult A/S Norway, senior researcher in Odeon A/S Denmark and former professor in acoustics at the Technical University of Denmark. Dr. Rindel has been Convenor of ISO technical committee ISO/TC 43, *Acoustics*, subcommittee SC 2, *Building acoustics*, working group WG 19, *Measurement of reverberation time in rooms*, ISO/TC 43/SC 2/WG 24, *Application of new measuring methods in building acoustics* ; and ISO/TC 43/SC 2/WG 25, *Measurement of the random-incidence scattering coefficient of surfaces*.