# FESI DOCUMENT A5 Acoustics in rooms

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    - Abstract: The first theory developed was Sabine\'s formula (1902) and it is the basis of the so-called \"classic the- ory\" ... formulae: Sabine and Eyring. All these formulae assume that the acoustic field in the room is diffuse. Reverberation time defined by Sabine is ...

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Acoustics in rooms
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Acoustics in Rooms

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## A5-0 Intention

The FESI Document A5 "Acoustics in rooms" is one of a series of five papers on acoustical problems that present themselves to the builder together with their solutions.

The terminology used have been taken from CEN in close co-operation with the acoustical technical committee TC 126.

The total block of acoustical documents will comprise the following titles:

- A2 "Basics of acoustics" May 2000
- A3 "Product characteristics – Acoustic insulation, absorption, attenuation" September 2002
- A4 "Acoustics in buildings"
- A5 "Acoustics in rooms"
- A6 "Industrial acoustics" 2nd revised edition, January 2006

With the edition of the remaining document A4 "Acoustics in buildings" the total series of documents will be completed by 2006.

## A5-1 Introduction

The rooms under consideration could be very different, with very different desired acoustic characteristics dependent upon the nature of the activities foreseen and the size of the location.

One could distinguish between two great categories of rooms:

- those that need to be treated without it being necessary to obtain very precise acoustic performances, such as offices, classrooms, meeting rooms ...
- those that need to be treated in a very precise fashion because the satisfaction of users will depend on the quality of sound production and the possibility to listen. This concerns rooms for demonstrations, auditoriums, theatres, operas, but also recording studios and even rooms for acoustical tests, dead rooms or reverberation rooms.

The study and the realisation of acoustical treatment of rooms of the first category could be made by a specialised company having personnel of a basic knowledge in acoustics available. In this document, we give the principles of treatment and the necessary tools for their determination.

Regarding the rooms of the second category, it is prudent to address a specialist. And in this document we address the decision criteria to be used with a view that specialised companies may be able to understand what is demanded of them.

The acoustic in rooms is not an exact science. If one considers that a room will be appreciated by an individual who is using it, one realises that one immediately enters into an area of subjectivity. There are certain criteria to be known and to be studied, relative developments to be respected, but the values to be obtained by these criteria are always of an indicative nature.

To realise the acoustic quality of a room, regardless of its nature, one uses the characteristics of absorption, reflection and diffusion of the materials. However, these characteristics are not very well known: for example, the absorption coefficient of a product is measured in a reverberation room by using a formula which need not be applicable for the configuration measured. Nevertheless, in the majority of questions under consideration the values given by laboratories are sufficient, considering the desired precision of the results. On the other hand, in case of need for precise results, it is useful to foresee an initial treatment, a measurement of the results and an adaptation by a treatment using the results of that measurement.

Finally, this document does not treat electronic systems (loudspeakers, chain electro-acoustics etc.).

## A5-2 Acoustic performance in different rooms

### A5-2.1 General

The characteristic of the acoustic field inside an enclosure or room is intimately related to the dimensions of that room. The surrounding surfaces play an important role in the processes of radiation and reception of the sound. The theoretical studies of the acoustic field are based on the theories that are described below.

Besides, it is also necessary to keep in mind the psycho-acoustic theories, that consider the subjective sensation instead of the theoretical acoustical performance of a room.

#### Statistical theory

It considers the sounds (speech and music) produced inside the room, as well as the phases of the waves radiated by the sources of sound, as random and irregular signals. This method does not discover the intrinsic physical details of the phenomenon, although with some empirical and simple math, permits to obtain objective conclusions. The fundamental concepts used by this theory are: reverberation time and acoustical energy density.

#### Geometric theory

The sound field is considered a combination of rays, based on the laws of optical geometry. This theory applies when the interior surfaces are covered with materials of different absorption characteristics. The acoustic field is studied by means of the acoustic energy obtained in any point from the rays that after being reflected, pass through that point. At low frequencies, this theory renders results of limited accuracy only.

#### Wave theory

This theory is based on the fact that the empty space inside a room behaves as a vibratory system, that is excited by the signal from the sound source. It utilises the theory of waves and modes.

In this FESI document, that intends to be practical and descriptive, concepts and parameters of all the previous theories will be used, but without focusing on any of them in particular.

### A5-2.2 Reverberation

#### A5-2.2.1 General

Reverberation time has traditionally been considered the most important parameter in order to characterise the acoustic quality of a room. In fact, it was the only parameter used until the 60 – 70's of the twentieth century.

Although there are a number of acoustic parameters resulting from the advances performed in fields such as room acoustics and psycho-acoustics, and specially in rooms with high acoustic performance (auditoria), reverberation time is still a parameter of primary importance.

Reverberation time (T) allows us to assess the acceptability of a room, in particular auditoria and halls for music or lectures; and also the intelligibility of a speech in a given room.

The physical concept of reverberation time is first discussed and then we will approach its calculation and measurement

Let us consider a room where a noise is produced and reaches a receiver. Paths of different length can be considered from the source to the receiver. Noise will reach the receiver directly (at time t after it has been emitted), but also indirectly after reflections at walls, floor and ceiling (at times $t + \Delta t1$, $t + \Delta t2$…depending on the distance travelled by the reflected noise before reaching the receiver). This means that sound will arrive step by step at the receiver's location until the total stationary sound level is attained.

Also, when noise emission ends once the source is turned off, direct noise will vanish first, followed by the reflected noise.

Actually, the final sound arrives (and ends) continuously since there are many paths from the source to the receiver. The following figure shows in a realistic way how a noise level is reached by turning on a stationary source ("On") and ends when the source is shut off ("Off") in a room.

ON OFF
F
SPL
TIME

Figure 1: Sound pressure level (SPL) variation with the time, when a sound source starts (ON) or stops (OFF)

#### A5-2.2.2 Nature of reverberation

Once a stationary sound field is formed, sound picked up by a microphone consists of both direct an indirect sound. The direct sound is the same as would exist in the open or in an anechoic chamber. The indirect sound is the sound that results from all the various non-free field effects characteristic for an enclosed space. These effects are unique to a particular room, and may be called “room response”.

There are three kinds of indirect sound, or factors involved:

a) The indirect sound that arrives after the direct sound has arrived, as a set of reflections from room surfaces. These are spread out in time because of the different path lengths travelled.

b) Room resonances. They predominantly occur in the low frequency region, when the wavelengths of the sound are comparable to the room dimensions. The ray concept works for higher frequencies and their shorter wavelengths. Around 300 – 500 Hz is a transition zone.

c) Materials of construction (doors, windows, walls, floors). They are set into vibration by the sound from the source, and this sound produced by these vibrations decays at its own particular rate when excitation is removed.

As reverberation is the composite of all three types of indirect sound – albeit c above being clearly the weakest and least important – , measuring reverberation time does not reveal the individual components. Herein lies the weakness of reverberation time as indicator of a room quality. This is why it is said that reverberation time is an indicator of a room's acoustical condition, but not the only one (even if it is the most important in many cases).

### A5-2.2.3 Reverberation time

Reverberation time (T) is defined as the time required for the sound in a room to decay 60 dB (a change in sound power of 1 million, and in sound pressure of 1000) from the moment the source is stopped. In terms of hearing sensation, it shows the time required for a sound that is very loud to decay to inaudibility. The following left figure shows the theoretical determination of reverberation time.

Figure 2: Determination and process of a reverberation time

In practice, the real situation is mostly the one shown in the right figure. It is necessary to extrapolate the straight portion of the decay to evaluate the T.

### A5-2.2.4 Measuring reverberation time (T)

It is possible to calculate T according to various formulae and information on absorption materials. Anyway, the measurement of T, even if not very easy to make, is more accurate than calculation, due to the uncertainty in the absorption coefficients of the materials and the complexity of the reverberation process.

Despite the continued use of reverberation to characterise the acoustics of rooms, few studies have examined its dependence on a particular method of measurements, and a lot of investigation still needs to be done. For instance, some studies have detected differences of up to 20% in reverberation time measured, depending on the microphones used. This shows that even measurements are burdened with uncertainties.

To measure the reverberation time, it is necessary to excite the room. Then, the sound source must have enough energy throughout the frequency spectrum considered, to assure decays sufficiently above the background noise. For large spaces, all kinds of impulse sources have been used, very commonly used is a pistol firing blank ammunition. For small rooms, it is possible to obtain the T with a steady-state exciter: a noise source giving random noise (white or pink). Then, two methods of exciting rooms are available: broad-band or impulse response.

In the traditional method a broad-band noise source is used, and after the source has been switched off, the decay curve can be recorded. However, this curve can have strong fluctuations due to the stochastic character of the excitation noise, and several decay curves should be evaluated in each position.

Another traditional method is the use of a pistol shot as an excitation signal. By this method the impulse response of the room is measured. One major quality of this method is that there will be no stochastic fluctuations, so one excitation in each position will be sufficient to get a decay curve.

There are other special methods, occasionally used, outside the scope of this document.

In practice, it is rarely possible to realise the entire 60 dB decay, it is more usual to get 45 – 50 dB decays, or even lower ones.

In order to make a good measurement of T, all the modes of the room should be excited. In some cases this is possible (for instance, in a regular rectangular room), but in most situations, for the usual calculations, this is not a realistic approach.

As there are important variations of reverberation time dependent on the position of the microphones, it is necessary to take measurements at several positions, and to use the average of those measurements.

Measuring the T, the greatest fluctuations are in the lower bands (63, 125 Hz); and the least in the highest one (4 – 8 kHz), due to the fact that in the high bands there is a statistical smoothing of the great number of normal modes included.

It is important for measuring reverberation time, to know how the equipment and the software used work.

There is one ISO standard regarding the T measurement: ISO 3382 (the update of this standard is expected during 2006).

Below, some ideas based on that standard are given. This can help to measure T in practical cases. For difficult and complex situations (auditoria, special rooms (anechoic)..., the job has to be done by specialists.

The norm provides reverberation time T measurements as well as recommendations for noise control in enclosed spaces and music/ speech auditoria. However, these do not apply to laboratories or reverberant chambers.

Reverberation time T determined by the slope of the best linear fit of the real curve measured between 5 dB and 35 dB below the maximum level (in some documents and bibliography, 25 dB instead of 35 dB are given).

Furthermore, the number of occupants of the hall has to be known, together with features like the presence of curtains and if the orchestra pit is opened or closed. The existence of a reflecting shell must also be considered.

In order to take into account environmental absorption, temperature and relative humidity need to be measured with a precision of +-1ºC and +-5% respectively.

In the standard, specifications about acoustic sources and suggested microphones and filters can be found in agreement with the usual norms and depending on different aspects.

Enough measurement positions must be selected to cover the whole room and to avoid the influence of direct sound with a minimum distance between source and microphone given in meters by the expression:

V

dmin = 2 · [1]

cT

3

where: V is the volume of the room in m

c is the speed of sound in m/sec.

T is the reverberation time in s

For small rooms where the previous requirement is not satisfied, an acoustic barrier with negligible absorption can be introduced between source and microphone

In considering the excitation of a room, two methods are established: the interrupted noise method and the impulse response method, equivalent to the two methods (with sound source/ with impulse source) mentioned earlier.

The Norm suggests to measure frequencies in octaves between 63 Hz and 4 kHz in concert halls/ speech auditoria; and in third-octaves between 100 Hz and 5 kHz in rooms for other purposes. Modern equipment allows for a measurement in octaves in every case, which is easier.

### Measurement of short reverberation times, below 0,3 seconds

For some rooms, (listening and recording studios, video-conferencing rooms, radio and TV control rooms), reverberation time is too short to be measured in one-third octave bands by usual methods. Even if some useful information is given in the standard for reverberation rooms ISO 354, the measurement of short reverberation times is outside the field of that standard. Consequently, the measurement procedures must be defined utilising experience from other practical measurements, and the possibilities offered by modern instrumentation. This is a very complicated area to be dealt with only by specialists.

### A5-2.2.5 Calculation and prediction of reverberation time

There are many formulae more or less suitable for the prediction of the reverberation time in a room, depending on the individual room characteristics. Mainly, two sets of theories can be mentioned, the "classic theory" and the "directional theory".

### Classic theory

The first theory developed was Sabine's formula (1902) and it is the basis of the so-called "classic theory". Also, the Eyring and Norris (1930-32) and Millington and Sette (1932-1933) or the Kutturff formulae are included in this theory. We present the two most popular formulae: Sabine and Eyring.

All these formulae assume that the acoustic field in the room is diffuse.

Reverberation time defined by Sabine is inversely proportional to the averaged absorption coefficient, which is obtained as the arithmetic mean of all absorption coefficients for all surfaces in the room. This equation is valid for rooms with long reverberation times and diffuse acoustic fields.

V V

TSab = 0,16 · −

= 0,16 [2]

A

S · α Sab

where: TSab is the reverberation time, calculated with the Sabine Formula

αSab must be distinguished from α , measured or calculated in-situ. This theoretical Sabine’s absorption coefficient can reach a value greater than 1, as found sometimes in literature and suppliers’ information. If so, a value of 1 or even maximum 0,9 should be generally applied. Yet, when smaller absorber panels are used as single elements, which means that they are mounted with mutual distance, absorption coefficients greater than 1 are allowable.

The Sabine and Eyring formulae are slightly different. For high total sound absorption, the Sabine formula gives longer reverberation times than the Eyring formula, but the differences become smaller as the total amount of sound absorption decreases. Generally, it can be said that, when α Sab > 0,2 , the error according to Sabina’s formula is greater than 10%. In this case, the Eyring formula is recommended.

In most cases, a mention of T means TSab.

### Directional theory

It is generally known that Sabine's or Eyring's formulae are seriously in error if the sound absorption of the room is unevenly distributed. Then, in order to predict the reverberation time in rooms with non-homogeneous absorption distribution, other formulae must be used.

Some formulae, introducing correction to the classical theory, have been developed: Fitzroy (1959), Arau (1988), Tohyhama (1995), Neubauer (2000), Nilsson (EN 12354-6).

Unfortunately, even if the actual problem is very common (for instance: classrooms with absorption only in the ceiling, offices with absorpt