ROOM ACOUSTIC EVALUATION OF DIFFERENT ROOM TYPES

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ABSTRACT

Different types of room will create such different sound fields that various descriptors are required if a meaningful acoustic evaluation is to be made. The list of actual types of rooms can of course be very long, but if we restrict ourselves to the most common ones, three different basic acoustic types can be identified. These are the reverberant room, the room with an absorbent ceiling and the open-plan space. In this paper characterising properties for these room types are described and suitable room acoustical descriptors are suggested and motivated.

1. INTRODUCTION

Room acoustic recommendations in standards and guidelines are very much about reverberation times. The reverberation time as an overall descriptor of room acoustical conditions is not suitable in all types of rooms. It is more or less restricted to reverberant rooms (Sabine room) where the diffuse conditions are prevailed during the decay process. In other room types like ordinary room with acoustical ceiling treatment or open-plan spaces supplementary measures are needed that better reveal the acoustical conditions and the subjective perceived acoustics. To create room acoustic comfort you have to consider the interaction between the person, the room and the activity. Hearing is complex and that is why several room acoustic attributes have to be addressed. Preferably measures related to human perception of reverberance, clarity of speech, auditory strength and spatial decay of sound are useful. For certain room types, some of these measures are weekly related which motivates that more than one parameter is used. As an example, in rooms with absorbent ceilings, the late reverberation time (T_{20}, T_{30}) normally don't reveal the reduction in the steady-state noise levels.

2. ROOM TYPES

In this paper three different acoustical room types are discussed. The room types are the reverberant room (Sabine room), the room with acoustical ceiling treatment and the open-plan space. The behavior of fundamental parameters like reverberation time and steady-state sound pressure level is discussed. Suitable acoustical descriptors for the different room types are suggested.

2.1. The reverberant room

This room is characterized by low absorption and high diffusion, like the reverberation chambers in acoustic laboratories. In these rooms the reverberation time is related to the total absorption in the room according to Sabine formula

$$T = 0.16\frac{V}{A} \qquad (1)$$

where T is the reverberation time, V the room volume and A the total equivalent absorption area.

Further, at large distances from the sound source, in the reverberant field, the sound pressure level (L_p) from a steady-state sound source is related to the total absorption as

$$L_p = L_W - 10\log(\frac{A}{4}) \qquad (2)$$

where L_W is the sound power level given by the sound source.

In equation 2 the equivalent absorption area could be replaced by the reverberation time in accordance with Sabine formula. Thus, in reverberant rooms, the sound pressure level is given by the reverberation time.

Sabine formula assumes a diffuse sound field and as a consequence, increasing the amount of non-absorbing sound scattering objects like furniture or equipment in the room will not change the reverberation time.

Conclusions for the reverberant room:

- Reverberation time is given by the sound absorption (Sabine formula)
- Sound pressure level can be calculated from the reverberation time knowing the sound power from the source
- Negligible influence of sound scattering non-absorbent objects
- The overall acoustical conditions are incorporated in the reverberation time

2.2. Room with acoustic ceiling

The reverberant room is quit rare in practice. A more common type of room is the room with acoustic ceiling. In these rooms, the reverberation time does not only depend on absorption. The room's sound-scattering furnishings, how the absorbers are placed and the shape of the room also play an important role. However, the sound level will mainly depend on the room's total absorption. The more absorption the room is given, the lower the sound level will be.

In rooms with absorbent ceilings, we distinguish between two situations the "steady-state" and the decay situation. In the case of steady-state, a sound source emits sound continuously, with the room thus having a constant level of sound. Even in rooms with absorbant ceilings, the sound is more or less diffuse at steady state. Consequently, we can determine sound level reduction in the same way as for the hard room described above. In the case of reverberation, the situation is somewhat more complex than for steady-state. When the sound source is turned off, the sound waves that hit the ceiling absorber will disappear much more quickly than the sound waves that propagate almost parallel to the ceiling and floor. This is of course related to the fact that much of the sound energy that reaches the ceiling is absorbed.

If there are no furnishings in the room, and if the walls and floor are plane surfaces with a low level of absorption, the reverberation time will be determined by the ceiling absorption for grazing incidence and the walls' and floor's absorption. Grazing incidence means here that the sound waves propagate almost parallel to the ceiling and floor. The ceiling's absorption factor for grazing incidence is often significantly less than the absorption factor that is normally stated. The reverberation time here will be much longer than could be expected from a calculation using Sabine's formula.

When the room is furnished, the grazing sound field will be split up and some of the horizontal energy will be transmitted up into the ceiling absorber. The effect of this sound scattering is that the reverberation time will be shorter. In rooms where the main absorption is in the ceiling, the effect of non-absorbant furnishings will therefore also be expressed as increased absorption.

To calculate the reverberation time in a room with an absorbant ceiling, the following must be taken into consideration:

1. Absorption factor for grazing incidence for the ceiling absorber.
2. The absorption effect of sound-scattering and sound-absorbing furnishings
3. Absorption factor for walls and floor
4. Air absorption

A formula for calculating the late reverberation time in rooms with absorbent ceilings has been formulated outgoing from the behaviour of the grazing sound field [1, 2]. In this formula the factors listed above are taken into account and suggestion of how to estimate them are given.

A decay curve measured in a room with an absorbent ceiling is shown in figure 1. The room only contains a small number of sound-scattering objects. The curve shows an uneven course, with the sound energy diminishing quickly in the early section of the curve and then slowing down in the later part. In the early section, the gradient of the curve corresponds quite well with a curve estimated using Sabine's formula, indicating that we have a diffuse sound field exactly at the point when we turn off the sound source, i.e. in the case of steady-state. When evaluating T_{20} and T_{30} it is, however, the later section of the curve that is evaluated and that corresponds to the grazing field.

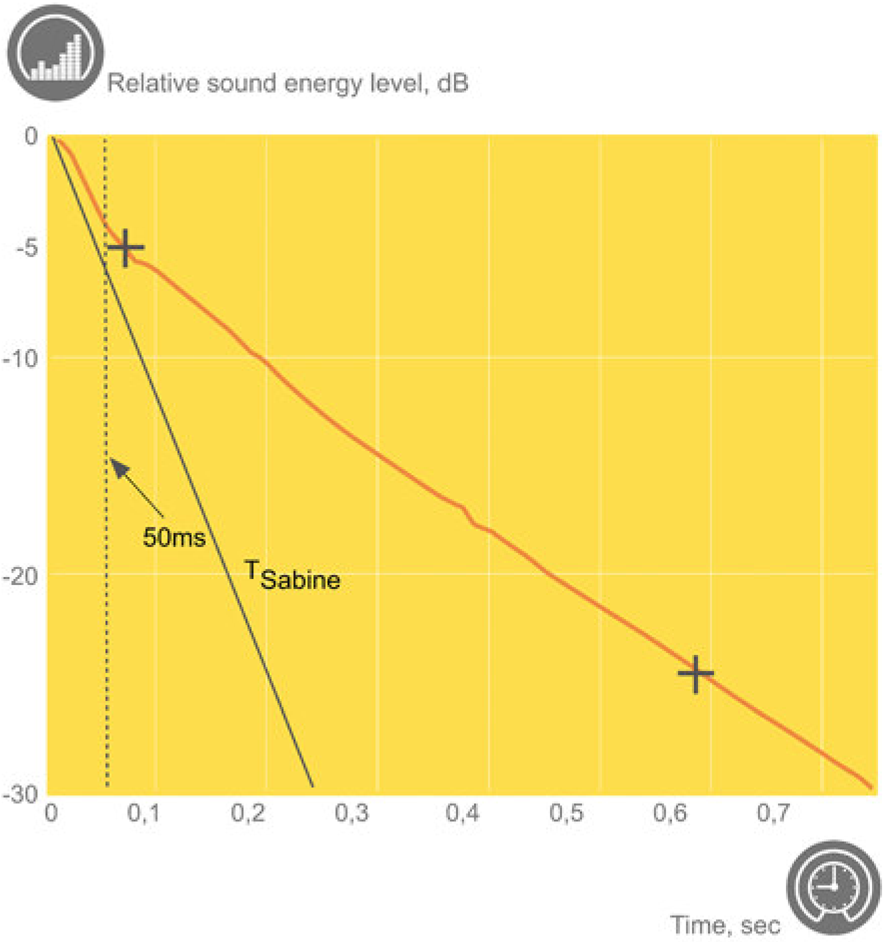

Figure 1. *Reverberation curve in a room with an absorbant ceiling.*

Reflections that arrive within 50 ms after the direct sound contribute to speech intelligibility and are thus regarded as beneficial reflections. Sound that arrives later can cause diminished speech intelligibility. Since T_{20} and T_{30} are not evaluated until after the sound level has fallen by 5 dB , the effect of early reflections is often not included in these descriptors. By only evaluating the reverberation time (T_{20}, T_{30}), acoustic information that is important to the subjective experience is missed. Sound level and early reflections, in this respect, are significant. These components are not included in the reverberation time. It is therefore very important to supplement the reverberation time with other room acoustic descriptors linked to these aspects in particular. Examples of such descriptors are Strength (G) and Clarity of Speech (C_{50}) according to ISO 3382-1 [3] and STI according to IEC 60268-16 [4]. Strength is a measure of the room's contribution to the sound or noise level from a sound source. Clarity of Speech measures the effect of the room's early reflections and STI measures quality of speech transfer from speaker to listener. These descriptors can differ from room to room although the late reverberation times are the same, and better reflect the subjective difference that is perceived.

At steady-state the sound field in a room with an absorbent ceiling can be considered as almost diffuse. This behaviour is to be clear from figure 1 where the Sabine decay and the initial part of the measured decay curve almost correspond. Consequently, equation 2 can be used to estimate the steady-state level if the equivalent absorption area is calculating using the statistical absorption coefficients as measured according to ISO 354. However, calculating the steady-state levels based on measured (late) reverberation times could be misleading since these are not related to the diffuse part of the sound field. The latter is also noteworthy in connection with sound insulation measurements between rooms where the receiving room has a suspended absorbent ceiling. Compensation for the absorption is preferably done by using the steady-state relation in equation 2 and a constant sound power source instead of measured reverberation times. The former method is better in accordance with the diffuse field assumption than the latter one.

Conclusions for rooms with an absorbent ceiling:

- There is no clear relation between (late) reverberation time and sound pressure level at steady-state
- Acoustical treatment given the same reverberation time can have different influence on the steady-state sound pressure level
- Non-absorbent sound scattering objects have large influence on reverberation time but not on steady-state sound pressure level
- Additional parameters necessary e.g. Strength (G), Speech Clarity (C_{50}), STI

2.3. Open-plan spaces

Room with extended forms such as open-plan offices and corridors constitute another group. Open-plan rooms are an example of room design where the reverberation time must be supplemented with descriptors that are adapted to the room's geometrical shape and that can provide guidance for the acoustical design. A central question regarding open-plan rooms is how the acoustic planning will affect the propagation of the sound in the premises and, thus, the acoustic comfort.

The main acoustic source of disturbance in an open-plan area is usually speech. It is therefore important that people who need to communicate sit near each other while, at the same time, different work groups must be sufficiently separated acoustically not to disturb each other.

Common room acoustic descriptors like reverberation time, STI and others, normally varies with distance from the sound source in an open-plan space. For that reason they are not suitable for characterising the overall acoustical conditions. Measures related to the sound's propagation are more appropriate.

To characterise the sound's propagation, there are descriptors that describe how much sound diminishes per doubling of distance. This descriptor that is designated DL_2 and measured in dB states the gradient of the sound propagation curve. Another descriptor designated DL_f and also measured in dB, states how the sound level at a certain distance behaves in relation to the sound level at the same distance in a free sound field, i.e. without reflecting objects. DL_2 and DL_f are defined in ISO 14257 [5]. By increasing the DL_2 value and simultaneously reducing the DL_f value, the distance to the place where the sound level is no longer disturbing (distracting) will have decreased. This is illustrated in figure 2 where the principal effect of a suspended absorbent ceiling in an open-plan space is shown.

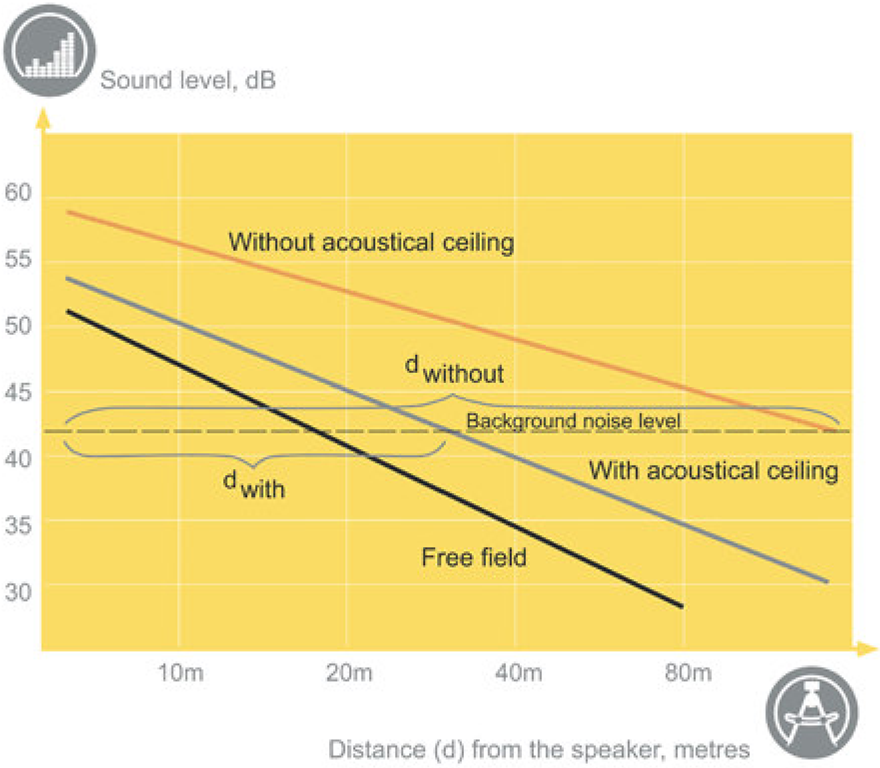

Figure 2. *The figure shows that the ceiling reduces the sound level and increases the rate at which the sound level decreases over distance. This also means that the (comfort) distance required between work stations in order to achieve an acceptable level, i.e. a speech level that does not disturb or distract, will be shorter.*

Conclusions for open-plan spaces:

- Room acoustical descriptors like reverberation time, STI and others varies over distance, thus …
- ordinary room acoustic descriptors are not well suited as “global” parameters characterizing the acoustical conditions in open-plan spaces
- Measures related to the propagation of sound are more suitable for these types of rooms

3. CONCLUSIONS

Different types of room will create such different sound fields that various descriptors are required if a meaningful evaluation is to be made. Three different basic acoustic types can be identified i.e. the reverberant room, the room with a sound-absorbing ceiling and rooms with extended forms like open-plan spaces and corridors. It is concluded that for the reverberant room the reverberation time is suitable as an overall descriptor characterising the acoustic conditions in the room. For the room with an absorbent ceiling the late reverberation time needs to be complemented with additional measures related to the conditions at steady-state and the very early part of the decay process. Measures like Strength (G) and Clarity of Speech (C_{50}) are suggested. For the open-plan space measures related to the sound propagation over distance are recommended. For a calibrated sound source the parameters DL_2 and DL_f can be used to define a distance of comfort between working groups in an open-plan offices.

4. REFERENCES

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