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Optimum Room Acoustic Comfort™ (RAC™) can be achieved by using a selection of appropriate acoustic descriptors

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In order to create an optimum Room Acoustic Comfort™ (RAC™) in rooms it is important to consider a variety of different acoustic descriptors. These descriptors must match and facilitate for wanted human qualities such as ability to concentrate, reduced stress, clear speech etc. In this process it is important to consider the people, what they do (the activity) and what room they will be in. Today, when designing ordinary rooms from an acoustic perspective, mainly reverberation time (T_{20}) is utilised - both in practice but also in building regulation and standards. Reverberation time (T_{20}) only describe the later part of the decay curve, and therefore only partly mirror the wanted acoustic reality. Thus, based upon a large number of acoustic measurements, we suggest a "cocktail" of acoustic descriptors for ordinary rooms in buildings like schools, offices, health care premises etc. These descriptors have to cover both early and late decay, sound levels and speech quality. Our suggestions are Speech Clarity (C_{50}), Speech Transmission Index (STI), Reverberation Times (EDT, T_{20}) and Strength (G). Moreover, in open and long spaces we also suggest the acoustic descriptors Rate of Spatial Decay (DL_2) and Excess of Sound Pressure Level (DL_f).

1 Introduction

The way we evaluate the acoustical quality in ordinary room, for instance in schools, offices and hospitals, has been the same for a very long time. Just one descriptor has been used – reverberation time. The hearing experience is multi-dimensional, with several different components of the sound being significant for how it is perceived. Therefore to create room acoustic comfort more than one descriptor has to be considered. A large number of systematic acoustic measurements [1] provided objective data on how various ceiling treatments perform in field conditions with regards to a variety of room acoustic descriptors. Moreover, it also revealed the influence of sound scattering objects.

2 Room Acoustic Comfort™

A room and its acoustic quality should be a support for people and the activities in which they are involved. To create the correct acoustic conditions is to create Room Acoustic Comfort™. Three things are important – the people, the room and what kind of activity is going to happen there. Good room acoustics involves the adaptation of the acoustics to the activities being carried on in a room. This might involve low noise levels; ease of hearing speech and, in music rooms, the acoustics must contribute to good sound reproduction. Sometimes limited sound propagation is required, such as in an open office landscape, while the music in a concert hall has to be heard properly at all the seats.

3 From source to ears

On its way from its source to the auditory canal, sound is affected by the room and its furnishings as well as by the shape of the head and the outer ear. These factors influence the way in which the sound will be perceived. When the sound has entered the ear and been received by the auditory sense, physiological and psychological factors affect how we perceive it. Individual preferences modify our final assessment of the sound.

4 Acoustic assessments

The comprehensive acoustic assessment of ordinary rooms requires the measurement of several different parameters if the hearing experience is to be correctly reflected. This is a question of room acoustic descriptors that are linked to reverberance, speech clarity, auditory strength and spatial decay. As regards acoustic design, it is an advantage if different designs and procedures can be evaluated objectively. For this purpose, a number of measurable room acoustic descriptors have been defined. These descriptors can be used to formulate room acoustic specifications and to check the effect of different measures. It would, of course, have been an advantage to have only one descriptor that works in all rooms. But hearing is multidimensional so several descriptors are required.

5 Reverberation time is not enough

The traditionally used designations for reverberance and reverberation time, T_{20}, T_{30}, only measure the late part of the decay process. This late part is less important for subjective perception. In rooms with suspended ceilings, depending on the characteristics and configuration of the room, you may have similar reverberation time but significant differences in other subjective attributes or descriptors (Clarity, Strength etc.). In some room types (open-plan solutions) reverberation time is not at all suitable for overall room acoustic description since it vary with the distance from the sound source.

6 Four human qualities

Different wanted room acoustic qualities correspond to different perceived sound attributes. These attributes can be described as reverberance, speech clarity, auditory strength and spatial decay. Objective room acoustic descriptors quantify these attributes.

- Reverberance is linked to the speed at which sound energy disappears in a room
- Speech clarity concerns the quality of speech transfer to the listeners
- Auditory strength is the level at which we experience sound

- Spatial decay is about the sound level decrease as the distance to the sound source increases

For our most common types of rooms, the four attributes tell a whole different story about the Room Acoustic Comfort™ than just only one – reverberance.

Perceived attribute	Objective descriptor	Designation	Unit	Explanation	Standard
Reverberance	Reverberation times	EDT, T_{20}, T_{30}	Second (s)	Measures speed at which sound disappears in a room.	ISO 3382-1 / 2
Speech clarity	Speech clarity	C_{50}	dB	Measures effect of the room's early reflections. This is important for speech clarity.	ISO 3382-1
Speech clarity	Speech Transmission Index	STI	Index (0-1)	Measures quality of speech transfer from speaker to listener.	IEC 60268-16
Auditory strength	Strength	G	dB	Measure of the room's contribution to the sound or noise level from a sound source.	ISO 3382-1
Spatial decay	Rate of spatial decay of sound pressure per distance doubling.	DL_2	dB	Measures how much the sound decreases with distance from sound source.	ISO 14257
Spatial decay	Excess of sound pressure level with respect to a reference sound distribution curve.	DL_f	dB	Measure of room's contribution to the sound or noise level at different distances from sound source.	ISO 14257
Spatial decay	Articulation Class	AC	Index	Classification of ceilings in accordance with their ability to contribute to privacy in open-plan offices.	ASTM E 1110 (2001)

Table 1 Suggested perceived attributes (human wanted qualities) and corresponding objective room acoustic descriptors for ordinary rooms such as in schools, hospitals, offices etc.

7 Sound propagation

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. 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.

In addition to reducing the sound level and increasing the reduction in sound level that occurs over distance, an absorbent ceiling will improve the function of screens and other screening furnishings. The degree to which a ceiling improves the effect of screens can be classified in an AC value (Articulation Class). The AC value is determined in accordance with ASTM E 1110 (2001). For an office ceiling, the AC value should be at least 180.

8 Acoustic room types

Different types of room will create such different sound fields that this in itself requires different descriptors if a meaningful evaluation is to be made. The list of actual types of rooms can of course be made very long but, if we restrict ourselves to the most common ones, three different basic acoustic types can be identified.

- The first is a room with little sound absorption, a so called "hard room" in which the surfaces reflect most of the sound.
- Another type of room which is much more common is a "room with a sound-absorbing ceiling". This type acts differently than the hard room and, as a rule, requires several descriptors for an acoustic assessment.
- A third type is a "room with extended forms" such as open-plan areas and corridors.

8.1 Hard rooms

Traditional evaluation of the acoustics in a room means in many cases that only the reverberation time is measured. In hard rooms, it is usually sufficient to have the reverberation time as the room acoustic descriptor. Both the sound level and the reverberation time here are more or less only dependent on the total sound absorption in the room. If the reverberation time and the sound effect that a sound source sends out into the room are known, the sound level in the room can be calculated. However, the hard room is, in reality, very rare.

The well-known and often used "Sabine's formula" states that the reverberation time is only dependent on the total absorption in the room and not on the placement of the absorbers nor on the sound-scattering effect of furniture and other furnishings in the room. It is assumed that the sound field is diffuse, meaning that the sound, at each location in the room, disperses with the same intensity in all directions

8.2 Rooms with absorbent ceilings

Rooms with absorbent ceilings are more common in reality. 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 that we call "steady-state" and "reverberation" [2]. 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 absorbent ceilings, the sound is more or less diffuse at steady state. Consequently, we can determine sound level in the same way as for the hard room.

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-absorbent furnishings will therefore also be expressed as increased absorption.

To calculate the reverberation time in a room with an absorbent ceiling, the following [3, 4] must be taken into consideration:

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

8.3 Open-plan rooms

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.

The acoustic planning of an open-plan area requires that a number of factors should be taken into consideration, such as;

- location of work stations
- choice of absorbent ceiling
- design of furnishings (furniture, screens, wall absorbers)
- silent work areas
- floor surface

- work methodology and technical aids
- background noise

In order to achieve acceptable acoustic conditions in an open-plan area at all, a sound-absorbing ceiling is a necessity. The ceiling should have a high absorption factor and be installed at as low a level as possible to have the best possible acoustic effect.

The ceiling reduces the sound level and increases the rate at which the sound level decreases over distance. This also means that the 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.

9 Reverberation curve in a room with absorbent ceiling

If a room only contains a small number of sound-scattering objects the decay 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 may correspond 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 decay curve that is evaluated and that corresponds to the grazing field.
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 (G, C_{50}, STI) linked to these aspects in particular. These descriptors can differ from room to room although the reverberation times are the same, and better reflect the subjective difference that is perceived.

10 Prioritise

Room Acoustic Comfort™ (RAC™) means that, when performing an evaluation of room acoustics, it is important to take into account different types of rooms and what people do there. Therefore one must give priority to one or more different acoustic attributes such as reverberance, speech clarity, auditory strength and spatial decay. For example:

- Sound level reduction (auditory strength) will be most important in a kindergarten
- In a music room, the response of the room in the form of reverberance can be the most important aspect
- In a teaching situation, it is important to give priority to speech clarity, reduction of reverberance and sound level (auditory strength)
- In an open office landscape, it is essential that the sound propagation is restricted (spatial decay) in order to minimise disturbance, mainly between different work groups. It is important that the sound level falls quickly with distance

The room acoustic descriptors are guidance for achieving the desired acoustic function and for ensuring room acoustic comfort where people, and what they do, are put in focus.

11 Conclusion

A room and its acoustic quality should be a support for people and the activities in which they are involved. To create the correct acoustic conditions is to create Room Acoustic Comfort™. Room acoustic comfort does not only involve a certain reverberation time. The hearing experience is multi-dimensional, with several different components of the sound being significant for how it is perceived. Thus it is important to consider a variety of different room acoustic descriptors. Regarding "hard rooms" (all surfaces are reflecting) this applies: 1) Reverberation time is given by the sound absorption (Sabine formula) 2) Sound pressure level can be calculated from the reverberation time knowing the sound power from the source 3) Negligible influence of sound scattering non-absorbent objects. For "rooms with absorbing ceilings" this applies: 1) No clear relation between reverberation time and sound pressure level 2) Acoustical treatment given the same reverberation time can have different influence on the sound pressure level 3) Non-absorbent sound scattering objects have large influence on reverberation time but not on sound pressure level. For "open plan rooms" this is valid: 1) The reverberation time, STI and other room acoustic descriptors vary with the distance from the sound source 2) Sound propagation descriptors are suitable.

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