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Room Acoustic Comfort™ in healthcare premises

Anthony Thomas[a]
Saint-Gobain Ecophon Ltd., Ramsdell, Hampshire RG26 5PP, United Kingdom

Katrin Bergmark
Marc R. Janssen
Saint-Gobain Ecophon AB, Box 500, 26061 Hyllinge, Sweden

ABSTRACT

Nowadays healthcare facilities have to deal with unprecedented competition. Hospitals are transforming themselves into health centres, attracting not just patients but doctors and nursing staff as well. In this context, an environment that promotes and preserves health is assuming increasing importance in purely economic terms. In this respect, room acoustics are attracting increasing scrutiny from forward looking clients. While convincing evidence shows that the sound environment in hospitals has become worse over the years, studies are being carried out to find the right sound control measures for supportive healthcare design. In order to create an optimum Room Acoustic Comfort™ in rooms, it is important to consider a variety of different acoustic descriptors. These descriptors must match and facilitate the nurses' ability to concentrate, reduce stress for patients, make speech clearer while performing surgery etc. In this process it is important to consider the people (patient or staff), what they do (the activity) and what room they are in. Today, when designing ordinary rooms from an acoustic perspective, mainly reverberation time (T_{20}) is used - both in practice but also in building regulations and standards. However, subjective experience is not always reflected by measuring only this parameter. We suggest a "selection" of acoustic descriptors for the respective room types. Studies will be highlighted to demonstrate the use of four human attributes; reverberance, speech clarity, strength and spatial decay for several room types within healthcare facilities.

1. INTRODUCTION

Studies have been presented at previous acoustic conferences showing that there is a general noise problem in healthcare premises[1,2]. Poor acoustic conditions tend to have a detrimental effect on patients and staff. Conversely, studies show that improved acoustic conditions positively affect quality of care by providing patient and staff outcomes such as:

- Reduction of the amount of pain medication used
- Improvement of sleep quality
- Lowering of blood pressure
- Lowering of readmission rates
- Improvement of the well-being and perceived performance of staff

What we are presenting today is a concept for evaluating and designing room acoustic environments to provide the best possible acoustic conditions in healthcare premises.
We will look at which acoustic parameters are mainly used and will suggest the use of several (new) parameters that are most relevant to the acoustic perception of the occupants and outcomes in various rooms within the building. We will consider the characteristics of the room, its occupants and the activities in which they are involved. This is what we refer to as Room Acoustic Comfort™.

2. ROOM ACOUSTIC NEEDS

In order to create an optimum Room Acoustic Comfort™ in Healthcare premises, it is important to consider a variety of different acoustic descriptors. These descriptors must amongst others:

- match and facilitate the nurses' ability to concentrate
- reduce stress for patients
- make speech clearer during surgery etc.

3. SOUND AND INDIVIDUAL PREFERENCES

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 perception of the sound. 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; for example, it's too loud, too echoic or difficult to understand etc.

4. ACOUSTIC PARAMETERS VS. SUBJECTIVE EXPERIENCE

The way we evaluate the acoustical quality in hospitals, has been the same for a very long time. Until today, when designing rooms from an acoustic perspective, mainly reverberation time (T_{20}) is used - both in practice but also in building regulation and standards. However T_{20} only describes the later part of the decay curve and therefore only partly mirror the wanted acoustic reality.
Different wanted room acoustic qualities correspond to different perceived attributes. These attributes can be described as:

- **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

Based upon a number of measurements, we suggest a “cocktail” of acoustic descriptors.

A. Reverberance

Reverberation times EDT, T_{20}, T_{30} (Seconds) - (ISO 3382-1/2)
Measure the speed at which sound disappears in a room.

B. Speech Clarity

- *Speech clarity* C_{50} (dB) - (ISO 3382-1)
  measures the effect of the room's early reflections. This is important for speech clarity.
- *Speech Transmission Index,* STI Index (0-1) - (IEC 60268-16)
  measures the quality of speech transfer from speaker to listener.

C. Auditory strength

Strength G (dB) – (ISO 3382-1)
Measures the room's contribution to the sound or noise level from a sound source.
Auditory strength is the level at which we experience sound

D. Spatial Decay

- *DL_2* (dB) Rate of spatial decay of sound pressure per distance doubling - (ISO 14257) measures how much the sound decreases with distance from the sound source.
- *DL_f* (dB) Excess of sound pressure level with respect to a reference sound distribution curve – (ISO 14257)
  measures the room's contribution to the sound or noise level at different distances from the sound source.
- *Articulation Class* AC Index (ASTM E 1110)
  a classification of ceilings in accordance with their ability to contribute to privacy in open-plan offices.

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)

Figure 1: Perceived attributes and objective descriptors.

5. ACOUSTIC ROOM TYPES

Different types of rooms 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 room types 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.

A. Rooms with little sound absorption, a so called "hard room" in which the surfaces reflect most of the sound.
B. A 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.
C. Rooms with extended forms" such as open-plan areas and corridors.

A. 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. The well-known and often used "Sabine formula" states that the reverberation time is only dependent on the total absorption in the room and not on the placement of the absorbers or 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. The hard room is, in reality, very rare.

B. Rooms with absorbent ceilings

Rooms with absorbent ceilings are more common. 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 is added to the room, the lower the sound level will be. In rooms with absorbing 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 absorbing 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

C. Rooms with extended forms

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)
• availability of rooms for concentration
• 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.

6. REVERBERATION CURVE IN A ROOM WITH AN ABSORBING 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 such as G, C_{50} and STI, linked to these aspects in particular. These descriptors can differ from room to room even though the reverberation times may be the same, and they better reflect the subjective difference that is perceived.

7. PRIORITISE

Room Acoustic Comfort™ (RAC™) in healthcare premises means that, when designing or performing an evaluation of the room acoustics, one should acknowledge that different types of rooms constitute a variety of usage/activities.

The task from an acoustical point of view is to first define the main activities and then prioritise them and finally choose the acoustic parameters that best reflect the result of those activities. An example; a recovery room should allow for patients to physically and mentally restore from an operation. Lowering sound pressure levels have shown to reduce stress and increase the quality of sleep, both beneficial to the recovery. Contrary to this, an operating theatre would require at least a focus on speech clarity because of the need for clear and intensive communication between staff (high risk of medical errors).

Because of the difference in priorities, the right acoustic attribute and the use of acoustic parameters should be made accordingly;

- Auditory strength for Recovery rooms – G (dB)
- Speech clarity in Operating theatres – (STI, C50)

Since it is sometimes not desired to only make one priority, using additional acoustic attributes might be considered beneficial. It's obvious that the absorbing factor, the amount and the placement of absorbing materials used throughout the room will have a great impact on the final result.

8. EXAMPLES FROM STUDIES

The room acoustic descriptors are guidance for achieving the desired acoustic function and for ensuring room acoustic comfort. Let's exemplify this with some cases.

In a study at Thorax ICU, Karolinska Solna in Stockholm[3], measurements were taken and calculations made with respect to Reverberation Time and reduction of SPL before and after an acoustic interventions (changing the acoustic ceilings).
RT measurements (mean, 500 to 4000 Hz) gave the following results:

- without acoustic ceiling, 0.43 sec
- with Class A acoustic ceiling, 0.32 sec
- with Class C acoustic ceiling, 0.34 sec.

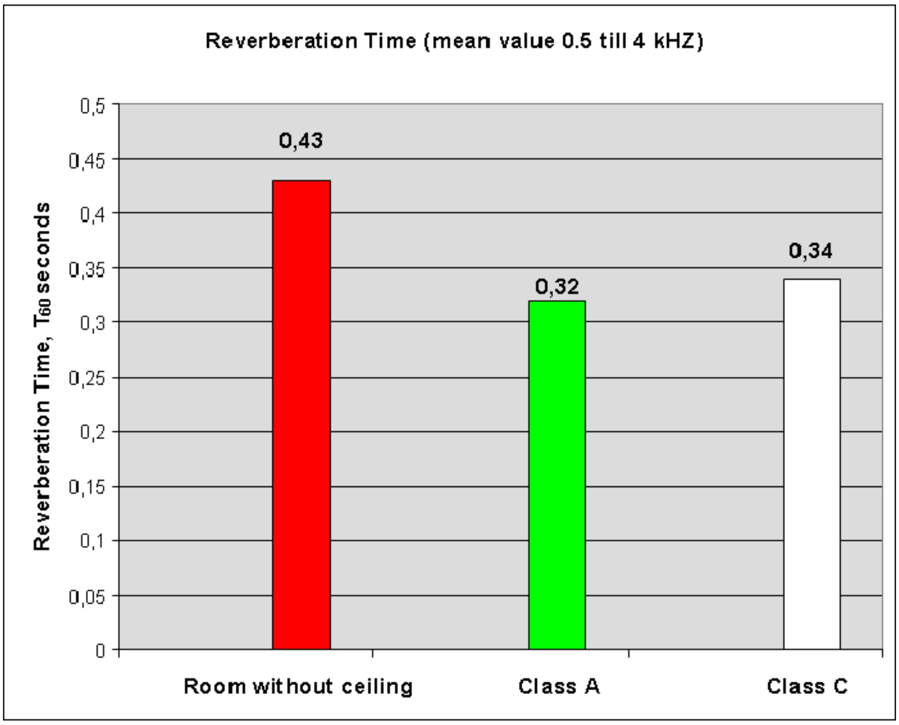

Figure 2: Reverberation Times measurements.

This would suggest very little difference in perceived acoustics in the room between Class A and Class C absorption. In fact, from questionnaires completed by the users of the room there were substantial differences in perceived acoustic qualities with the different classes of absorbers.

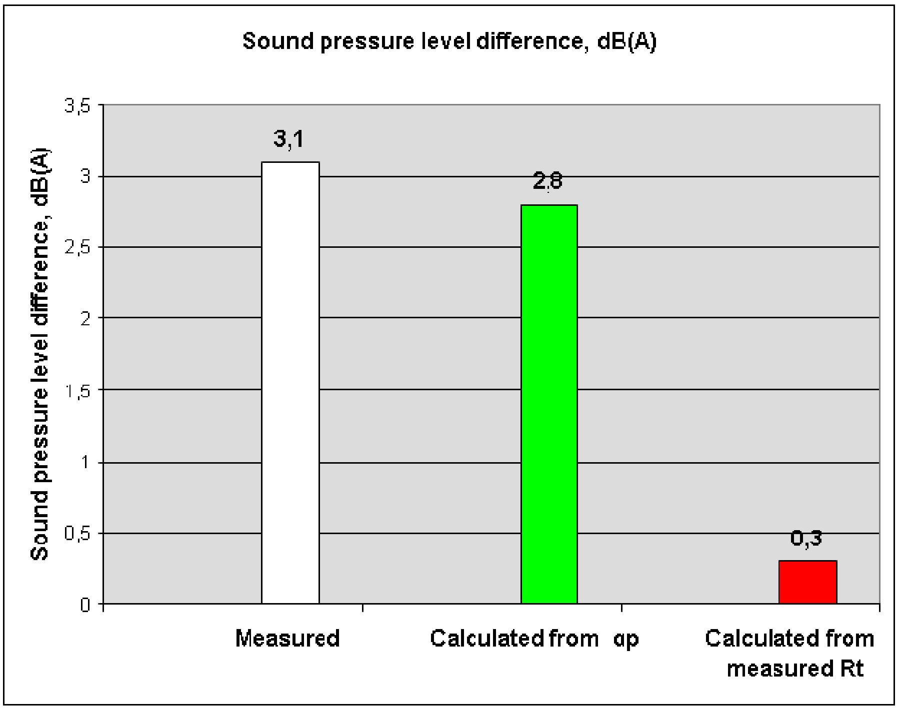

Figure 3: Sound pressure level differences between Class A and Class C absorbing ceiling

The result showed a difference in sound level of 3.1 dB (A), which can be regarded as a considerable reduction. A reduction of the background level by about 3 dB(A) in a speech/communication situation has a significant effect on speech comfort, often resulting in the people speaking reducing their voice level and thus further reducing the noise level in the room. When calculating this SPL reduction, the result of 2.8 dB(A) using the absorption co-efficient (α_p)showed good correlation with the measured value, compared to 0.3 dB(A) result calculated using the reverberation time.

It is clear that the "new sound environment" has influenced the staff's behaviour as regards communication and their perception of the noise from equipment
It is interesting to note, too, that staff with hearing difficulties noticed a significant difference after the change in the sound environment

This indicates that in this room type Reverberation Time was not the right parameter to use when calculating SPL reduction, nor was it valid in representing the actual human perception of the room's acoustic qualities with different amounts of absorption. This case demonstrates that this can involve risks since this parameter does not show any difference between the two situations involving different absorbents. In this instance, the Class A absorbing ceiling's ability to reduce SPL was more relevant than the reduced RT.

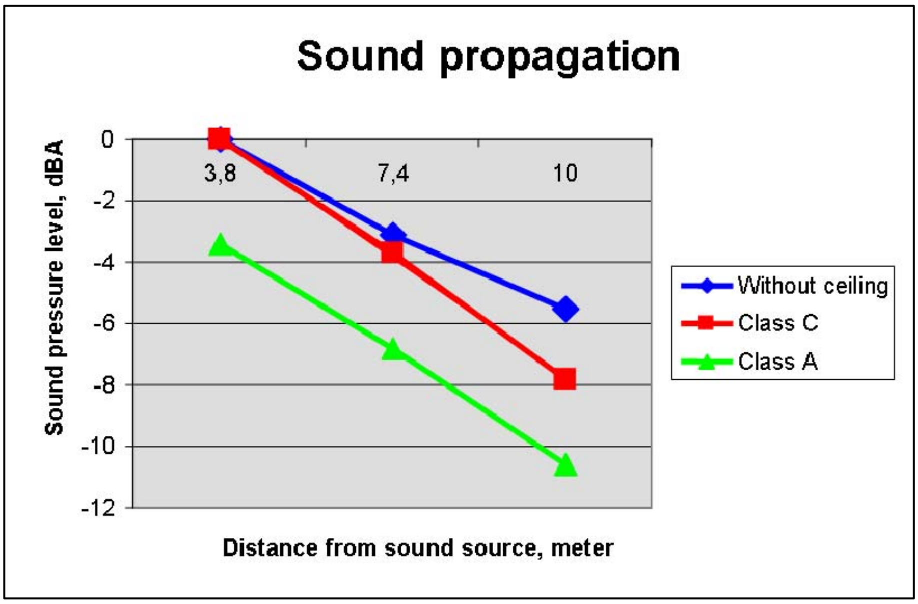

Figure 4: Sound propagation measurements.

Finally sound propagation measurements were made. The diagram illustrates the relative difference in sound level at the measurement points along the length of room. The sound level is thus 3-4 dB(A) lower at a distance of 3.8 metres as a result of the new acoustic ceiling.

9. EVALUATION AT AN EMERGENCY DEPARTMENT

During the yearly Trauma week (training) at the emergency Unit at Karolinska University Hospital location Huddinge, room acoustical measurements for several acoustical parameters were made both before and after sound absorbents are mounted in the room.

Figure 5 and 6: photo's of the room with and without acoustic ceiling and wall panels.

The absorbents used are Ecophon Master Meditec 40 mm glued to the ceiling. It can be noticed that only 50% of the ceiling could be covered by absorbents due to the ventilation ducts and lights. An absorbent area equal to 25 % of the ceiling is mounted on the walls. The total absorbent area therefore equals 75 % of the ceiling. Several acoustical parameters were measured before and after the absorbents were mounted:

- C_{80}, and C_{50}
- T20 and EDT
- Strength and Loudness
- STI

A. Reverberation time

The reverberation time was changed from approximately 0.7 to 0.3 seconds.

B. Sound pressure level

If the mean sound pressure level (microphone position 1) for the trauma sessions is calculated for the eight sessions presented in report 1 and the two measured in December 2007 the result is 66.6 dB(A). The mean value for the four measurements done after the absorbents were mounted is 64 dB(A) i.e. the sound pressure level has decreased by 2.6 dB(A).
If the measurements are compared the mean value without and with acoustical treatment is 67.5 dB and 64 dB i.e. a difference of 3.5 dB. Microphone 1 was placed close to the sound sources i.e. patient and equipment and the receiver i.e. the staff. If a similar comparison as presented above is made for microphone position 2 the result is 66.5 dB(A) before acoustical treatment and 61.5 dB after i.e. a 5 dB(A) difference. This can be explained by the fact that microphone 2 is placed further away from the sources. This is a significant drop in sound pressure level.

C. C_{50} and C_{80}

The C50 parameter is the most relevant one when it comes to speech, compared to C80 used for music. The relation between early and late reflection have increased. Since the early-to-late arriving sound energy ratio have increased this will have a positive effect on the speech intelligibility. The mean C50 rose from 5,5 to 12,3.

D. STI

The STI-scale can be divided according to the following:

Figure 7: Qualification of STI.

0-0,3	BAD
0,3-0,45	POOR
0,45-0,6	FAIR
0,6-0,75	GOOD
0,75-1	EXCELLENT

Before the absorbents were mounted the STI varied between 0.35 and 0.55 (Poor – Fair) when the equipment was on. This value increased to 0.6 (Fair/Good) when the absorbents were mounted.

E. Strength

The strength value has changed from 15 to 12 G(dB) i.e. 3 dB. This is in the same order as the sound pressure level drop.

F. Loudness

The loudness before acoustical treatment is 13 Sone and after 11 Sone.

G. Evaluation

There are several indications which show that the room acoustics have been improved after the sound absorbents were mounted. The first and perhaps most important is that staff has reported that the acoustics have been improved. To judge which parameters best match the human perception and increased performance. It would be beneficial to include questionnaires in the measurements. Based on the results of the 2 cases described, it will be of great value to further explore the link between acoustic parameters and subjective experience as to be able to create Room Acoustic Comfort™.

10. CONCLUSION

A room and its acoustic quality should be a support to the recovery of patients, well-being of staff, economics and the quality of care provided by the institution. 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. To create the correct acoustic conditions is to create Room Acoustic Comfort™.

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