The same reverberation time in two identical rooms does not necessarily mean the same levels of speech clarity and sound levels when we look at impact of different ceiling and wall absorbers.

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ABSTRACT (837)

It is common to only use Reverberation Time (RT) for setting the acoustic conditions in a classroom for teaching and learning activities. To calculate the RT in rooms with ceiling absorption is common but this data can also be misleading. Indeed, we measured the same RT values in two identical rooms with different acoustic treatment, even though the calculations predicted significant differences and interestingly the rooms are also be perceive quite differently in reality.

Assuming that the user perceptions are valid, the measured RT data alone leaves us in the dark when seeking to explain the difference in human user perception. Measuring additional room acoustic parameters such as speech clarity and the difference in sound levels, identifies other differences between the two rooms with the same RT and points to why only one of the two rooms seems fit for purpose as a group activity room.

We will discuss how to achieve acoustic comfort in classrooms; low RT, low sound levels and high speech clarity. In addition to commonly accepted low RT values we will discuss recommended objective values for good Speech Clarity to support good speech communication activities in typical teaching and learning rooms in real life situations.

Keywords: Sound, Absorption, Classrooms, Reverberance, Speech Clarity.

1. INTRODUCTION

During the last 50 years, awareness of the importance of classroom acoustics has increased steadily. The benefits for teaching and learning have been well documented and the acoustic performance has also increased in new and upgraded classroom acoustic standards. However the way we evaluate classroom acoustics has not evolved much during this period. The acoustic characteristics of a room can be calculated, measured and many classroom acoustic standards have been set around one common parameter – Reverberation Time (RT). Over the years, RT has been widely understood and referenced as the most practical measure to evaluate the quality of

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acoustics in a classroom.

In recent decades it has also become increasingly common for the acceptable reverberation time values to be lowered (shortened) and indeed in many cases, the previous recommended minimum value levels have been removed. In the Nordic countries according to Rasmussen[14], the trend has clearly indicated that a shorter RT is assumed to be better. However, even when a classroom meets these (shorter objective) RTs, it does not necessarily mean the classroom will be subjectively perceived as having good speech intelligibility or low sound levels by the users when the room is occupied.

Measuring the RT means that we mostly consider the decay of the late reflections and we miss the overall room response to a given sound and in particular the early reflections which are very significant when it comes to the clarity of speech and how it will be perceived as found in listening tests performed by Nilsson[5].

Background

In Sweden alone, around 1500000 young people spend most of each day in a school environment. Increasingly, additional spaces are being used for teaching and learning as a complement to the traditional (60m2 circa) classroom to provide a room where quiet individual study or group work can take place and where speech communication is actively encouraged. Smaller group rooms now increasingly have to support a broader pedagogic approach.

It has been acknowledged in several studies, that learning and the ability to remember and concentrate are affected by acoustic conditions as well as general wellbeing and stress related symptoms. In the study by Ljung and Hygge et al.[17] the effect of different signal to noise ratios on the ability to recall words shows that noisy surroundings in classrooms impair learning.

The effect of room acoustic improvement on the learning activities in schools has been investigated in several studies.[1,2,3,4,6] It has been shown[1] that with improved room acoustic conditions, the students´ social behaviour becomes calmer and the teachers experience lower physiological load (heart rate) as well as less fatigue.

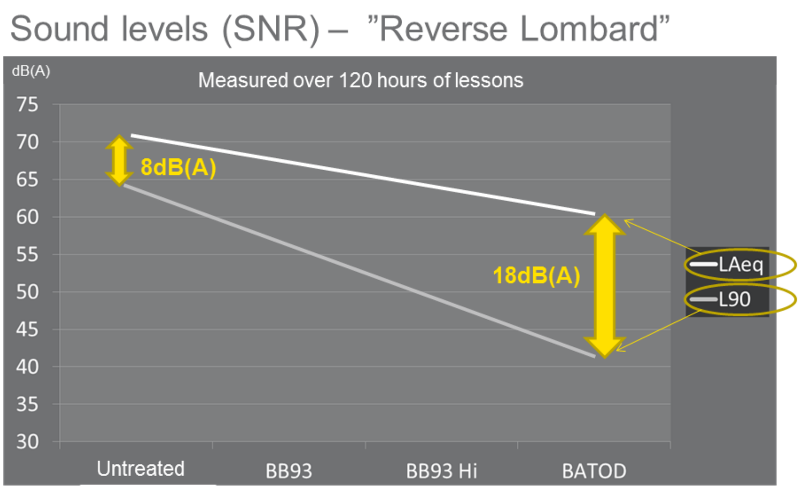
Knowledge about how we characterize the acoustical conditions in classrooms has increased in recent years. Several investigations have highlighted the necessity of including more acoustic parameters for a relevant characterization of the acoustic environment. Parameters related to the noise levels and to speech intelligibility have shown to be an important and necessary complement to the RT.

In Bradley's paper[10], the use of the room acoustic parameters C_{50} and Strength are examined both experimentally and theoretically. In Barron, Nilsson,[12,13] a model is presented for calculating C_{50} and G. There was particular focus on explaining the non-diffuse sound field in rooms with ceiling treatment and how this influences these parameters. In national standards and regulations e.g. UK, Germany, [Nordic countries see Rasmussen] there is still a clear dominance of RT as the parameter for characterizing the acoustic quality.

In view of the above, it is clear that the practice of only defining a single number evaluation of RT potentially restricts development of optimal acoustic conditions.

The effect of acoustic treatment as manifested in objectively measured parameters, only provides the physical characterization of the classroom. It has been shown that there is also a psychological “feedback” effect arising from the acoustic design that influences the behaviour of the people in the room[3]. For example, one effect is that in a well-treated classroom, the noise due to the student activity is not only subdued as a direct result of the acoustic treatment but is also reduced because students behave more quietly. This effect is sometimes referred to as “reverse lombard” or “library effect”. It is illustrated in Figure 1a. Ref Essex Study[3]: the sound levels dropping as a result of increased levels of absorption. The “Lombard effect” has been found to be very significant in average sized classrooms and we think it is also important to consider the acoustics in even the smallest of teaching and learning rooms, so we want to understand how significant different acoustic treatments are for smaller educational rooms which are also used for speech communication.

Figure 1a: Essex Study Sound Pressure levels for four different acoustic treatments.



The Different Types of educational spaces and sound fields

What about the physical environment then? Different types of spaces and rooms, for instance in a school, 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:

1. The reverberant room

2. The room with a sound-absorbing ceiling

3. Rooms with extended forms like open-plan spaces and corridors.

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}/D_{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 D_{2S} and L_{pAS4m} can be used to define a distance of comfort between working groups in an open-plan learning space. Room acoustic quality – lowering sound levels (noise limitation), increasing speech intelligibility and control of reverberance will lead to a better learning environment.

The acoustical quality of rooms should provide support for the occupants and the activities in which they are involved. To create the correct acoustic conditions is to create room acoustic comfort. Room acoustic comfort involves more than just 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) the following 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 only absorbing ceilings” the following applies: 1) No clear relation between reverberation time and sound pressure level 2) Different acoustical treatment giving 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” the descriptors D_{2S} and L_{pAS4m} are suitable and vary with the distance from the sound source.

2. Outline Objective

In this study we wanted to look into objective measurement data which we understood to have a significant correspondence to the subjective perceptions of the room for the users. In the long term, the intention is that those findings should improve the target values in standards and recommendations and in that way secure optimal acoustic condition in small classrooms or group rooms.

If we look beyond reverberance / RT’s, we can better illustrate and understand the room acoustic characteristics for rooms with sound absorbing ceilings and wall absorbers when it comes to the measured outcomes for various acoustic and human qualities.

What does it really take to find acoustic harmony: a low RT, low sound levels and high speech clarity, in a room? To achieve room acoustic comfort in these two group rooms, by measuring additional parameters we can achieve a more accurate assessment or picture of how these rooms will respond to sound, how close they are to the theoretical diffuse sound field and whether it will actually be fit for purpose in reality.

The diffuse sound field is a theoretical situation which is in reality, very often not achieved in a classroom, where the ceiling is predominately used for the absorption treatment. Increasingly in modern school classroom design and furnishings, there are fewer diffusing elements i.e. shelving for books, model displays etc. More information is digitalized and resources are online and this combined with design trends means that classrooms are becoming more minimalistic regarding furniture and large flat surfaces. Hard flat surfaces like plasterboard and glass are also more prevelant, on external walls it is common to have the curtain wall glazing combined with internal glazing on the opposing wall which is encouraged to increase transparency through to the corridor or internal school spaces.

It is not suprising then that the reverberant sound decay does not follow the straight decay path in line with the theory. In non-diffuse rooms as found by Nilsson,[13] when stopping the sound source, the early decay correlates to the theoretical curve but the late part deviates creating longer than expected RT's.

We measured T20, commonly used which begins recording 5dB below the initial sound source. This is significant as the first 10dB (EDT) according to Nilsson,[13] is widely accepted as a crucial area where we perceive the reverberant sound. By not recording the initial 5dB drop in relation to the overall decay we miss some valuable information regarding the balance of direct sound and early reflections which relate more closely to our perception of sound and speech clarity.

So regarding how users may perceive sound including the speech clarity, by continuing with a single number value (RT), we over simplify the room acoustic analysis for calculating (with Sabine) and measuring the room characteristics. However we should not be surprised if in modern classroom designs, increasingly RT becomes more inaccurate to define how sound will actually be perceived.

In modern classrooms, where the rooms are increasingly non-diffuse and combined with changes in teaching and learning approaches, we need to re-evaluate if the single number RTs indicate whether a classroom is "fit for purpose" or not. Teaching methods are increasingly moving from a more traditional teacher centred approach where speech from one person (teacher) dominates, to a more student centred approach where students are actively encouraged to be more engaged in their learning process. This means actively encouraging increased student speech interaction including; questions / discussions, group work or speech conversations in pairs.

The room acoustic measurements we focused on includes parameters related to quality aspects such as speech intelligibility, sound strength / levels as well as reverberance. These parameters we believe correspond well to the subjective response concerning the pupils and teachers' judgment of different acoustic conditions in respect to speech communication and the general perception of the work environment related to sound exposure.

It is important to be able to specify good room acoustics in an objective way. It has been shown that the acoustical conditions influence the quality of teaching and learning as well as the well-being of teachers and students during their activities in schools.

The objective of this study is to establish the conditions for optimal classroom acoustics as manifested in the room acoustic parameters; Speech Clarity C_{50} (dB), Sound Strength G (dB) / Sound Levels and reverberation time T20 (s). C_{50} evaluates the effect of the room's response to a given sounds and the balance of the early reflections in relation to the late reflections. G or Sound Strength measures the room's overall contribution to a given sound. The parameters are defined in the standards ISO 3382-1/2[15,16]. In general, these additional parameters C_{50} and G outlined in ISO 3382-1[16] were intended for large performance spaces rather than for speech in smaller basic classrooms, however, they have been found to be good indicators regarding the room acoustic quality as well as RT [7,9,10,12,13]. It has also already been identified that in larger typical classrooms that C_{50} and G values can be different even when the RT is the same.

Today, the main parameter in acoustic design of ordinary room types is the RT. RT is well represented in national standards and regulations. Nevertheless, it is well known that the RT alone is not sufficient for a relevant characterization of the acoustical conditions in rooms.

The purpose of this modest investigation was to show the beneficial effect of using several parameters and acoustic configurations together with the RT for smaller group rooms. Optimal acoustic conditions should be specified by a balance of objectively measureable parameters related to speech clarity, sound strength and reverberation time. Target values corresponding to optimal room acoustics are presented as well as design recommendations concerning acoustical treatment of group rooms and any similarities with typical classrooms. This will be an important input for the establishment of meaningful and more accurate recommendations concerning optimal acoustic conditions in classrooms to be used in future standards and requirements where increasingly small group rooms have to fit a broader pedagogic approach.

3. Group room configurations:

The sizes of the rooms we used are length x width x height = 3,2 m x 3,7 m x 2,06 m. The size of the closet in each is = 0,81 m x 0,80 m x 2,06 m. 11.19m2 and 23.06m3.

The rooms have identical furniture and surfaces apart from the acoustic treatment on the ceiling and the additional wall absorption. Both have suspended square edged ceiling panels installed in an exposed grid system with the same overall depth of system in the ceiling void. (Note the lightweight construction of the walls (plasterboard / gypsum hollow construction with integrated lightweight insulation).

Room 1. The ceiling panel installed is a 20mm panel with “Absorption Class A” glass wool absorber. Both rooms were then measured again with additional wall absorption on one wall. 40mm “Absorption Class A” wall absorber in accordance with ISO 11654.

Room 2. The ceiling panel is 14mm panel with “Absorption Class E” wet pressed mineral wool absorber. The acoustic measurements were done using an impulse response in order to evaluate the following room acoustic descriptors; T20, C_{50} and G in accordance with ISO 3382-1. Due to the size of the group rooms it is not possible to measure G in accordance with ISO 3382-1 so we measured the dB(A) sound pressure levels in addition.

4. Methodology (intervention study)

The main part of this small study was to measure and analyse data from two otherwise identical group rooms which had different acoustic treatment. The data collected consists of room acoustic measurements (impulse response measurements). The rooms were furnished but unoccupied.

Acoustic design: potential best practice

Active choice of absorbing panels and configurations to fulfil considered target values over the relevant frequency range, including special attention to low frequency absorption, the existing room construction properties and the effect of the distribution of the absorption.

Fine structure of impulse responses:

The room acoustic parameters chosen are defined in ISO 3382-1/2. Using recorded impulse responses it was possible to investigate the additional parameters T20, C_{50} and G in accordance with ISO 3382-1. Due to the size of the group rooms, it was not possible to measure G in accordance with ISO 3382-1 so we measured the sound levels in dB(A).

Measurement of room acoustic parameters:

The procedure for measuring parameters was tested in advance. Expected standard deviations were established by measuring under laboratory conditions (Ecophon laboratory).

Objective measurements parameters:

Measures related to speech clarity, sound strength / sound level and reverberation time.

Analysis of data:

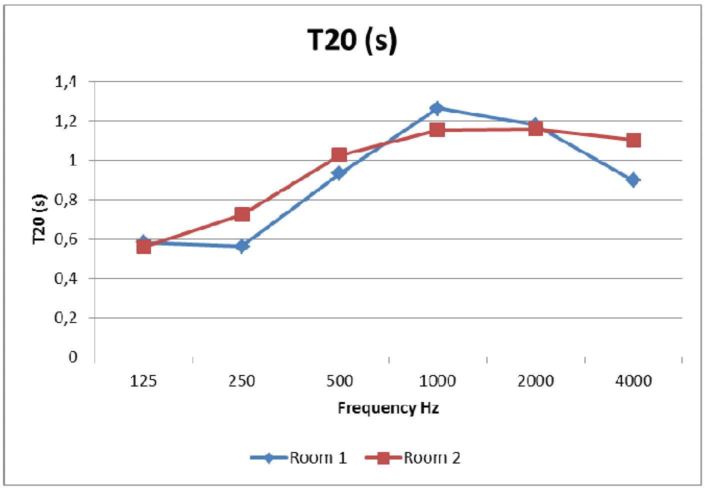
Analysis of the room acoustic parameters measurements. This data was compared to target values for the room acoustic parameters relevant for more typical larger sized classrooms. The results will serve as input for the acoustic design guidance for future small group rooms.

5. Results:

The Ecophon Ecorama group room acoustic measurements.

Image 1: The two group rooms tested.

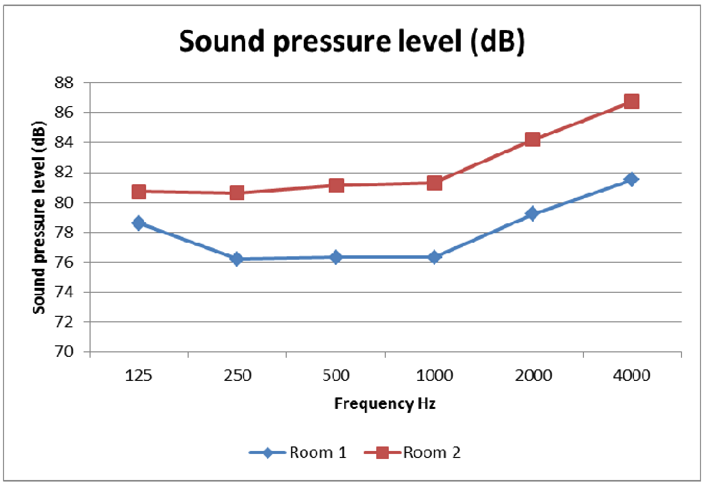
Figure 1 – T20 in both rooms with ceiling absorption only.



Room 1 – ”Class A” absorber Room 2 – ”Class C” absorber

In Figure 1: we see the T20 (125-4000Hz). Here we can see that both rooms are quite similar with marginal differences of 0.1-0.2 above and below in both cases, with no clear separation, so nothing significant to interpret from this. Average values across (125-4000Hz) Room 1: 0.9s Room 2: 0.96s.

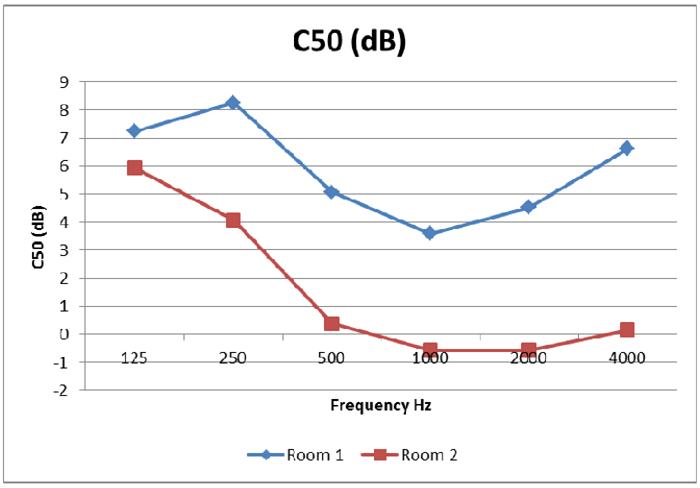
Figure 2 – SPL in both rooms with ceiling absorption only.



Room 1 – ”Class A” absorber Room 2 – ”Class C” absorber

In Figure 2: we can see a clear separation in the SPL. The sound level in room 2 is over 4dB(A) higher than room 1 between 250 - 4000Hz which is quite significant and around 2 dB(A) more at 125Hz even though the T20 at 125Hz reads the same. So despite the T20 being very similar we can clearly see that the sound levels are significantly lower in room 1. Average values across (125-4000Hz) Room 1: 78dB(A). Room 2: 83dB(A).

Figure 3 – C50 in both rooms with ceiling absorption only.



Room 1 – ”Class A” absorber Room 2 – ”Class C” absorber

In Figure 3 we also see a clear separation regarding the two rooms. Again the values show room 1 to have a significant improvement in Speech Clarity (C_{50}). While at 125Hz there is only a marginal (but just noticeable difference) improvement of around 1 dB(A) between 250-4000Hz we can see a consistent and more significant improvement in Speech Clarity of at least 4dB(A) or at least 12% for D_{50}. Average values - Room 1: C_{50} values across (125-4000Hz) 6dB(A). Room 2: 1dB(A). For ease of understanding when converted to D_{50} the values across (125-4000Hz) are Room 1: 80%. Room 2: 65%.

Image 2: Ceiling absorption only.

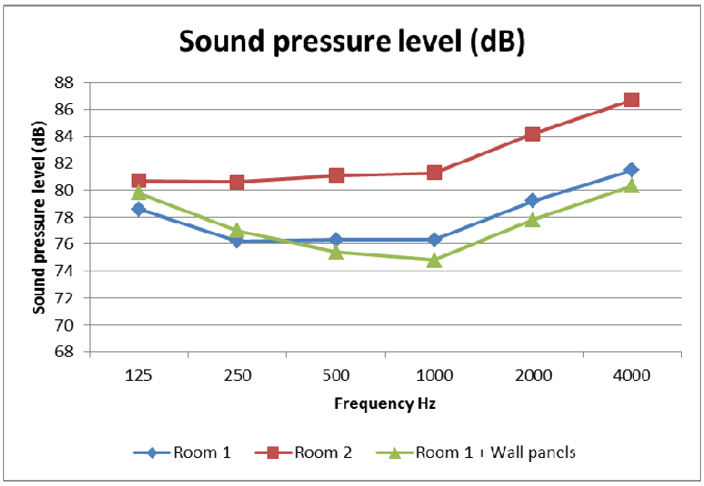
Image 3: Ceiling and wall absorption.

Figure 4 – T20 in both rooms with ceiling and additional wall absorption in room 1 only.

Room 1 – ”Class A” absorber   Room 2 – ”Class C” absorber

In Figure 4 we see the T20 (125-4000Hz). Here again, while we can see that although both rooms are quite similar, with no clear separation in values with the ceiling absorption treatment only, when we compare with the values including the influence of the wall absorption, there is a significant shortening of T20 particularly above 500Hz in the mid and high frequencies. In general, we see a flatter curve with average values across (125-4000Hz) room 1 with ceiling and wall absorption: 0.55s.

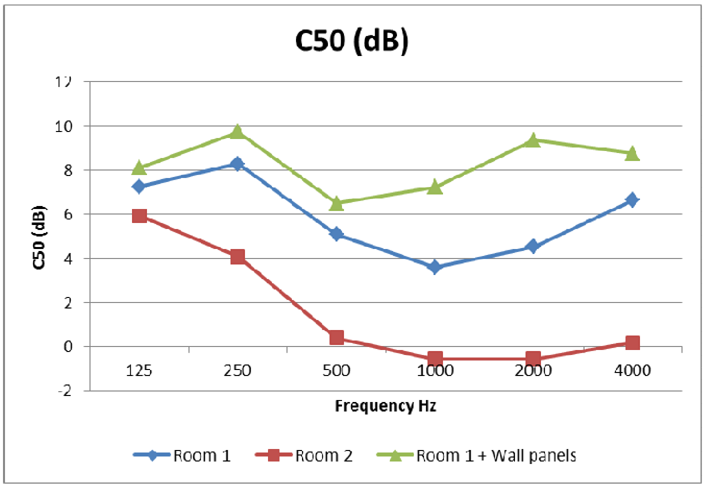
Figure 5 – SPL in both rooms with ceiling and additional wall absorption in room 1 only.



Room 1 – "Class A" absorber Room 2 – "Class C" absorber

In Figure 5 where we can see a clear separation in the SPL between the two rooms of over 4dB(A) despite the T20 being very similar, we can clearly see that the sound levels are significantly lower in room 1. Adding the wall absorption, we don't see any significant difference in sound level across any of the frequencies with only marginal but only (+-)1dB(A) over the frequencies which is on the margin of a "just noticeable difference" and might not be perceived. More research and questionnaire feedback would be interesting here and also long term SPL measurements to see if the difference effects a human behavioural change or not. There might be more significant differences under occupied conditions during the actual learning activities.

Figure 6 – C50 in both rooms with ceiling and additional wall absorption in room 1 only.



Room 1 – ”Class A” absorber Room 2 – ”Class C” absorber

In Figure 6 we see the most significant improvement in Speech Clarity (C_{50}) at 1000 and 2000 Hz with the additional wall absorption clear separation regarding the two rooms. Average values - Room 1 with ceiling and wall absorption: C_{50} values across (125-4000Hz) is 8dB(A) which is 86% when converted to D_{50} (125-4000Hz).

6. Discussion and conclusion

In this paper the aim was to look beyond reverberance / RT and discuss the impact of sound absorbing ceilings and wall absorbers on the measured outcome for various acoustic and human qualities in small group rooms.

When looking at only one parameter such as Reverberation Time, we have found that it is possible for two identical rooms to have the similar values even though the room acoustics can be perceived quite differently.

The RT alone leaves us in the dark when seeking to explain the actual human user perception of room acoustics and a difference which we believe in defining the appropriate conditions has a significant impact on the conditions for speech communication in teaching and learning activities.

Looking at the objective measurements of the two identical rooms with different acoustic treatment we are unable to see any difference in RT, however just being in the rooms one can perceive a clear / significant difference, listening with our own ears. By measuring the additional relevant acoustic parameters which we believe have a closer correspondence to the subjective human qualities (C_{50}/ D_{50} and the difference in SPL’s) we found a better indication as to why the occupants perceive the room acoustics quite differently. We also found a significant indication suggesting that there is merit in not only having the absorption on one surface i.e. the ceiling only but the walls also.

Image 4: Four additional wall absorbers in Room 1.

By having absorption on the wall in addition to the ceilings, we created not only a little more absorption but also a more diffuse sound environment where we were able see significant additional benefits which could help future room acoustic guidance. These measurements in room 1 indicate a significant difference in both the sound levels or speech intelligibility over room 2 which are likely to be even more significant if applied to a larger room of similar characteristics with a greater volume. The difference between the “Absorption Class A” and the “Absorption Class E” ceiling panels while showing no significant difference in RT shows a sound level drop of over 5dB(A) (500-4000Hz) and a speech clarity increase of 7 dB which is over a 20% in D_{50}.

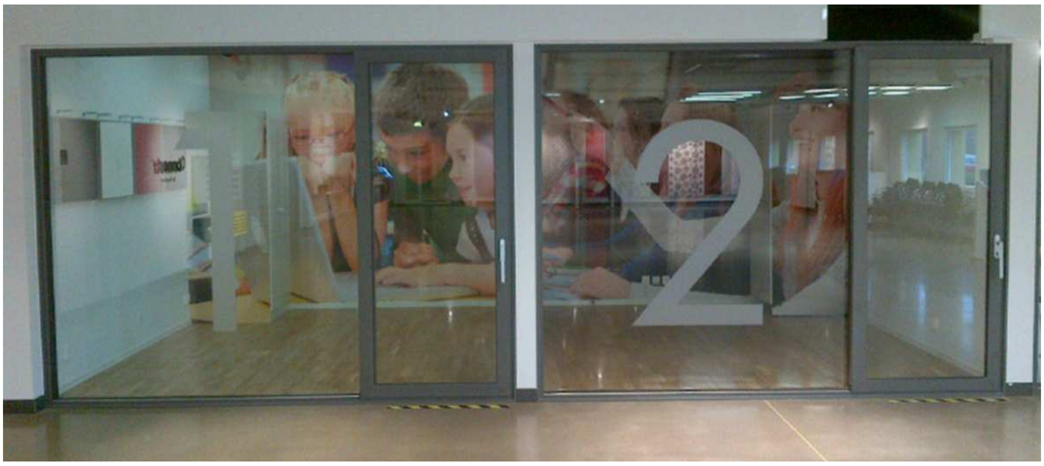


Image 5: Room 1 and Room 2. Look the same when only looking at T20.

When the wall absorption is added we could see that there was now no significant change in the sound levels however the RT drops significantly and we also a continued significant increase in the speech clarity in Room 1.

Image 6: Room 1 where we are able to shine the light on the acoustic differences and where acoustic harmony is achieved.

This helps explain why only Room 1 (with the same reverberation time as Room 2) seems fit for purpose as a group activity room for speech communication while the other doesn't.

It is apparent from this and other studies that in order to have acoustic harmony it is important to carefully consider all three of the room acoustic qualities and descriptors to achieve; a low Reverberation Time, low sound levels and high speech clarity. So to achieve room acoustic comfort in group rooms, it is quite clear that we need to measure and consider all three of these parameters in order to get a true picture of how the room will respond to sound and whether it will be fit for purpose in reality.

Target values corresponding to optimal room acoustics for larger typical classrooms are similar as well as design recommendations concerning our findings with the best acoustical treatment of group rooms.

Below is a summary of the values achieved in these group rooms for RT, C_{50} / D_{50} and SPL.

Table 1: T20, C_{50}, D_{50} and SPL average values.

Room measurements	Acoustic treatment	T20 125-4000Hz	C_{50} (dB)	D_{50} (dB)	SPL dB(A)
Room 1	Class A ceiling treatment only	0.9s	6	80%	78
Room 1	Ceiling and wall treatment	0.55s	8	86%	78
Room 2	Class E ceiling treatment only	0.96s	1	55%	83

Table 1 above shows the average values for the two different acoustic configurations in the two rooms. These are in line with extensive values, measured and collected by Ecophon previously in larger but typical classrooms.

Looking beyond the sole use of a single number RT, we need to connect and clarify the way room acoustics are predicted and subsequently measured in order to secure good room acoustic outcomes which are "fit for purpose" for good speech communication. In a non-sabine, non-diffuse room with an imbalance of absorption we can clearly see that RT alone, is not a reliable measure. However, by having a more balanced acoustic design with sound absorption on both the ceiling and walls, optimal speech communication is possible to achieve. This study gives us measured outcomes, justifying the need to also consider and use strength / sound pressure levels and speech clarity, and to use wall surfaces actively for absorption. It seems, that looking at these room configurations that there is a triangulation of data - where researchers can hope to overcome the weakness or intrinsic biases and the problems that come from single method, single-observer and single-theory studies [18]. In addition, (Patton[19]) cautions that it is "a common misconception that the goal of triangulation is to arrive at consistency across data sources or approaches; in fact, such inconsistencies may be likely given the relative strengths of different approaches". In Patton's view, these inconsistencies should not be seen as weakening the evidence, but should be viewed as an opportunity to uncover deeper meaning in the data". While one separate acoustic parameter in all cases seems unaffected, the other two remaining parameters give us valuable information which helps to (*uncover deeper meaning*) describe the room acoustic differences (Patton[19]). In the long term it would be good to have more evidence from many rooms about how these parameters are actually perceived and appreciated, for and during speech communication activities and how we can find better ways to predict / model and measure more simply and accurately to secure good acoustic comfort in practice.

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