The effect of acoustic absorbing wall panels in classrooms

Carsten Svensson[1], Erling Nilsson[2]

[1] Saint-Gobain Ecophon, Sweden (corresponding author)
[2] Saint-Gobain Ecophon, Sweden

Corresponding author's e-mail address: carsten.svensson@ecophon.se

ABSTRACT

A wall-to-wall acoustic ceiling is a common solution in many buildings today. But this may not be enough to create good acoustics – there can be a need for more sound absorption on the vertical surfaces. Different acoustic qualities are important in different situations. In some cases the sound level is the main issue and in other cases it can be speech clarity, such as in classrooms. In this paper we discuss the results of room acoustic field measurements and calculations on how vertical absorbing wall elements affect human and acoustic qualities. Wall panels give a larger effect than expected using the Sabine formula, due handling horizontal grazing sound energy. The more vertical absorbers installed in a room with a full absorbent ceiling, the more will the speech clarity increase and the reverberation time decrease. Results also show that you only need to add a fairly small vertical absorption area to improve speech clarity and reverberation time. The sound strength was not as easy to improve. To reduce it you need to add a fairly large area of vertical absorbers.

1. INTRODUCTION

A wall-to-wall absorbing ceiling is a common acoustic component in buildings today. But a wall-to-wall ceiling sometimes just is not enough to create good room acoustics – there may be a need for additional sound absorption, placed vertically on walls. Combining ceiling mounted acoustical solutions (both modular and free-hanging) with vertical sound absorbing elements can further add to the room acoustic quality of a space. A number of trends make acoustic absorbing wall panels more important in acoustic design:

- The awareness of the importance of good acoustics is growing. As a result there are stronger demands for acoustic treatment beyond the standard acoustic ceiling
- Current design trends with minimal furnishing and a lot of glass and hard surfaces increase the need for more acoustic absorbers. An acoustic ceiling may not be enough
- More and more workplaces are built as open-plan spaces to increase flexibility. These premises almost always require vertical absorbers

- Buildings with TABS (Thermally Activated Building Systems) exist and then it is not possible to fully cover the concrete soffit due to thermal aspects, thus a need to apply vertical absorbers as an important complement

Acoustic standards are generally met with full covering high performing acoustic suspended ceilings, sometimes with a small amount of wall absorption. One of the reasons suspended ceilings perform well, is due to much of the sound being effectively trapped (particularly the low frequency sounds) within the ceiling void which can vary from 200 mm to 1000 mm [1]. In this paper we will discuss the acoustic benefits and objective outcomes of adding vertical wall absorption in order to positively affect the holistic room acoustic qualities.

2. ACOUSTICS

2.1 Human activities, human response and applications

Human activities and the people performing them must be the starting points when designing acoustics. Supporting people and optimizing the outcome of their activities in buildings such as schools, offices, hospitals, etc. is the core. Measurable objective parameters below will be discussed. 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. For example, one effect is that in a well-treated room (like a 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” [2, 3]. Regarding TABS buildings, the benefits of "thermal mass" in stabilizing temperature for thermal comfort and reducing building energy consumption for sustainable green buildings are well documented. However, when exposing the concrete soffit for thermal purposes it is then not possible to have a fully covered sound absorbing suspended ceiling in rooms for acoustic comfort. In turn, this potentially compromises the achievement of good acoustic comfort while still utilizing the thermal mass of the exposed soffit. [1] Thus, working with wall absorbers may to some extent compensate for the lack of ceiling coverage.

2.2 Characterizing sound

Normally, the acoustic treatments of a room consist of a suspended absorbent ceiling. The non-uniform distribution of the sound absorbing material makes the sound field non-diffuse and measured reverberation times generally deviates from what is expected from diffuse field theory. The non-diffusivity is a reason why several parameters are needed showing relations between early and late arriving sound energy [4]. Traditionally the use reverberation time as a measure of the room acoustics in a space is still common. But to create a good acoustic environment more than one parameter is needed to characterize an acoustic experience. The following four acoustic qualities are suitable for common rooms:

Table 1: The acoustic qualities used for common spaces

Acoustic quality	Acoustic parameter	Unit	Explanation
Sound Strength	G	dB	How much a room affects the sound level from a sound source, compared to measuring the sound level from the same sound source in a free field at 10 m distance. The higher the sound strength, the more the “echoes” / sound reflections in the room add to the general sound level.
Speech Clarity	C50 D50	dB %	The ratio between the early reflections (< 50 ms) and late reflections. Late reflections make it hard to interpret speech and a high value indicates good speech clarity.
Sound propagation	D2,S and Lp,A,S,4m	dB	D2,S / Rate of spatial decay of A-weighted sound pressure level of speech per distance doubling. (ISO 3382-3) Lp,A,S,4m / Nominal A-weighted sound pressure level of normal speech at a distance of 4.0 m from the sound source. (ISO 3382-3)
Reverberance	T20	s	The reverberation time, T20, is the time it takes for the sound level to drop by 60 dB after turning off the sound source.

Reverberation time: The most common acoustical treatment of a room is a suspended absorbent ceiling. A consequence of this non-uniform distribution of the absorption is a degeneration of the sound field during the decay process from a fairly diffuse to a non-diffuse sound field. This circumstance also means that the late reverberation time is not very well related to the statistical absorption coefficient of the ceiling absorber as given by ISO 354 [5]. The late reverberation time will mainly be determined by the ceiling absorbers efficiency for grazing sound incidence as well as the amount and scattering effect of furniture and other equipment, especially along the walls [6].

Sound strength: The sound Strength G (dB) (ISO 3382-1) [7] is defined as the logarithmic ratio of the total sound energy in the impulse response compared to the sound energy at 10 m in a free field measured with the same sound source and the same sound power output. Sound Strength quantifies how much the reflected sound in a room contributes to the direct sound from a sound source. It is a very useful parameter that measure how the sound pressure level in a room will be affected by the absorbing surfaces and can be used as a design parameter in the same way as the reverberation time. In rooms with non-diffuse sound fields, as a room with ceiling treatment, the late reverberation time T20 is not a good predictor of the noise level since it ignores the early part of the impulse responses [6].

Speech clarity: The speech clarity C50 (dB) (ISO 3382-1) [7] is given by the logarithmic ratio between the early arriving sound energy to the late arriving sound energy. The limit between early and late energy is set to 50 ms after the arrival of the direct sound. The direct sound is included in the early part.

Different acoustic qualities are important in different situations and this is why it is crucial to use activities and people as a starting point when advising on room acoustics.

2.3 Sound and how to affect it

In a room with a continuous sound source, for example a speaker emitting noise or a large group of people in a canteen, the sound level is largely affected by the total absorption in the room. In an empty room with hard surfaces the absorption is minimal and the sound level is high. Adding a lot of absorbing material in the room causes the sound level to drop since part of the sound is continuously absorbed. Installing a wall-to-wall acoustic ceiling is an efficient way to get a large, absorbing area into a space and it reduces both the sound level and shortens the reverberation time. Sometimes a wall-to-wall acoustic ceiling is not enough to create optimum acoustic comfort. One reason may be that the ceiling can be far from the activity noise, and another that the sound level in the space needs to be reduced even more, for example in a sports hall or an open-plan office. Then you could also install absorbers on the walls, and if possible free-standing absorbing screens.

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 absorbent ceilings, the sound is more or less diffuse at steady state [8]. If we switch off the sound source in a room, we will see that the sound waves hitting the acoustic ceiling will disappear first and the sound waves that are reflected off the hard walls will remain longer. The result is a sound field where the sound waves predominantly travel horizontally, almost parallel to the ceiling. Even if the vertical part of the sound field is quickly absorbed, the horizontal persists. The horizontal waves are referred to as grazing waves since they hit the ceiling at a very grazing angle of incidence. In many rooms with absorbent ceilings, the reverberation time is very much determined by grazing sound waves. 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.

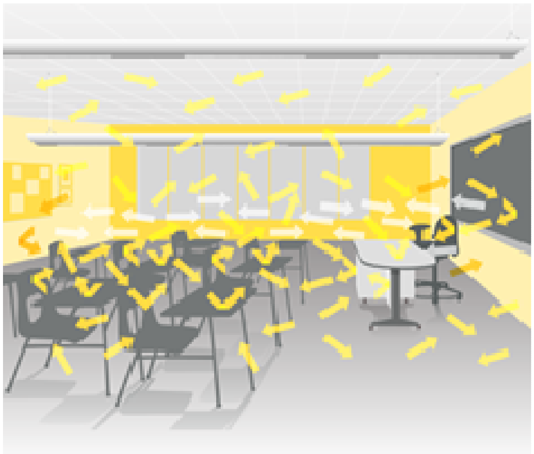

Figure 1: Sound fields at steady-state in a room with absorbent ceiling and sound scattering objects.

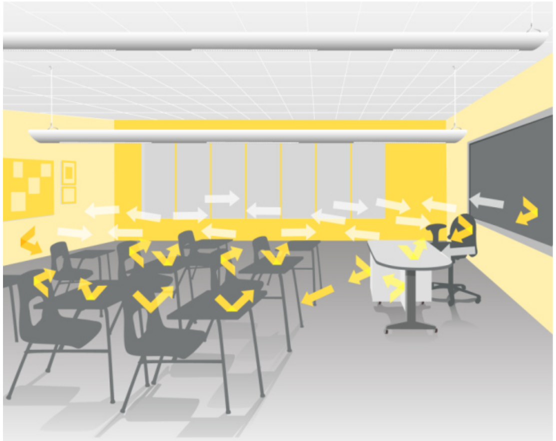

Figure 2: Sound fields during sound decay in a room with absorbent ceiling.

2.4 The effect of wall absorbers and absorbing screens

By mounting wall absorbers and/or putting up absorbing screens, the grazing sound waves are effectively absorbed and the total sound field decays faster, i.e. the reverberation time becomes shorter. In addition, introducing vertical absorbers also improves speech clarity, reduces sound propagation and eliminates disturbing flutter echoes. Speech clarity is impeded by late echoes or reflections, for example from a distant wall in a lecture hall. The unwanted late sound reflections from the wall muddle the direct speech from the lecturer. By absorbing the grazing sound waves in a room, unwanted late echoes/reflections are removed and speech clarity boosted. Sound propagation can be very disturbing, for example in an open-plan office where the grazing sounds waves spread without being absorbed by the acoustic ceiling. By using absorbing standing screens and installing wall absorbers the situation will improve. Flutter echoes arise between two parallel walls and can effectively be eliminated with properly placed wall absorbers.

3. TESTING THE EFFECT OF WALL ABSORBERS

To get a clear view of the effects of acoustic absorbers on walls, a series of acoustic measurements were carried out. The test was performed in a typical meeting room (31 m2) with a wall-to-wall acoustic ceiling. Acoustic measurements were performed with 15 different configurations of wall absorbers (different number of absorbers and location), and compared to a measurement when no wall absorbers were present (the acoustic ceiling was unaltered in all cases).The results confirm that even a relatively small area of wall absorbers has a significant positive effect on the acoustics, even in a space with a wall-to-wall acoustic ceiling.

Figures 3, 4 and 5 show the results of a test series where the number of absorbers was gradually increased. Four measurements with no, one, three and five wall absorbers (W x H = 0.6 x 1.2 m.) installed on one of the walls were performed. The soffit was covered by a wall-to-wall 20 mm sound absorption class A ceiling.

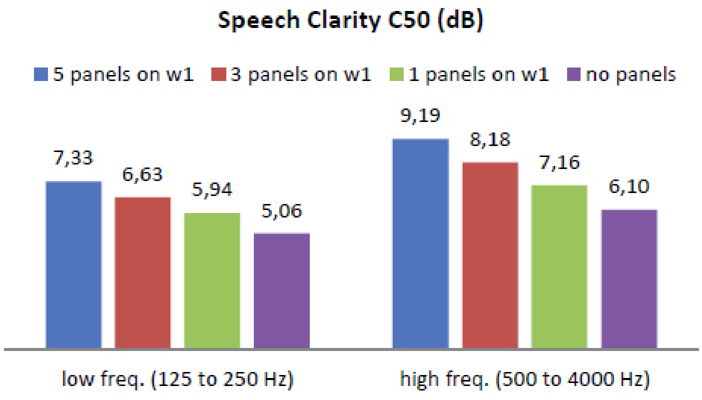

Figure 3: There is a clear increase in speech clarity when wall absorbers are added, the more the better. However, there is a significant positive effect even when just one wall absorber is added. (Values for C50 and Strength, G, onwards, should have been rounded off to the first decimal place. The Just Noticeable Difference, JND, is 1 dB for C50 and G according to ISO 3382-1)

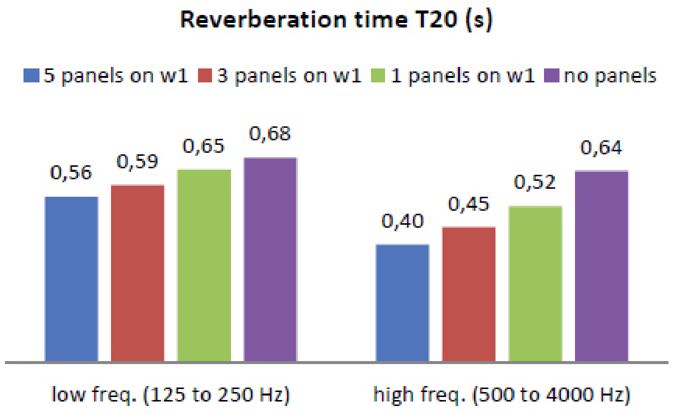

Figure 4: Reverberation time clearly decreases with the number of wall absorbers. Even adding just one wall absorber has a significant positive effect.

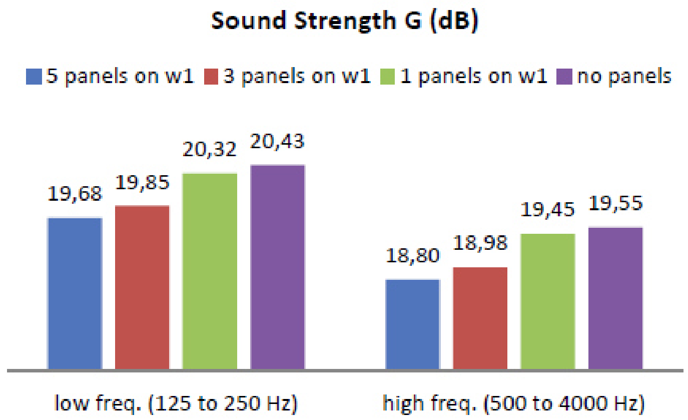

Figure 5: To affect the sound strength large absorbing areas are needed to make a difference. Adding one or a few wall absorbers has little effect.

4. COMPARISON OF MEASUREMENTS AND CALCULATIONS FOR A CLASSROOM WITH CEILING TREATMENT AND WALL PANELS

Let us take a closer look at a case, a classroom (volume: 2.7 x 7.3 x 7.6 = 150 m3, ceiling absorber is a 15 mm porous absorption class A absorber, mounted 0.80 m below the soffit). When we look at the results and comparing Sabine calculations with room acoustic measurements we can see rather large differences in the outcome.

Figure 6: The classroom that was calculated and measured

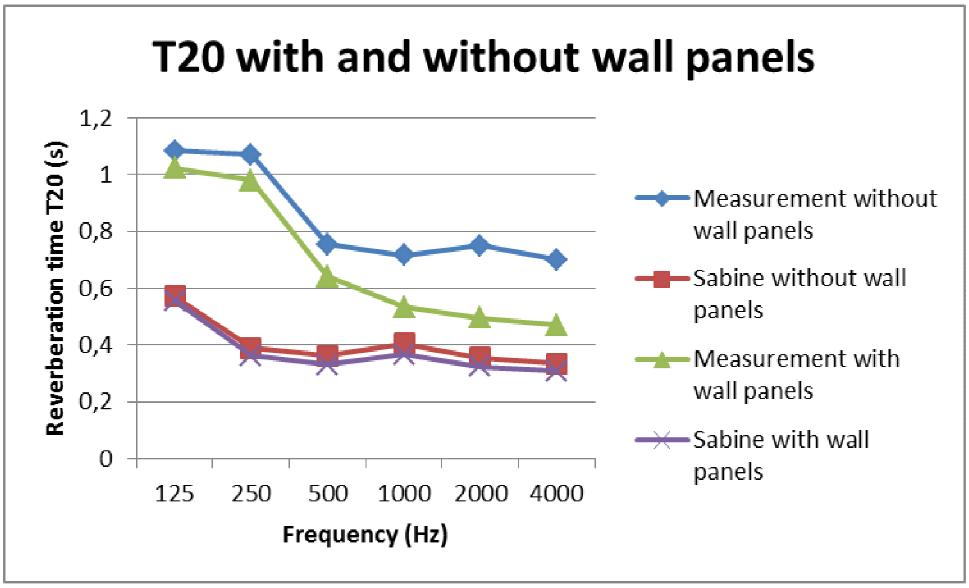

Figure 7: Comparison of measurements and calculations for a classroom with ceiling treatment and wall panels, Reverberation Time (T20)

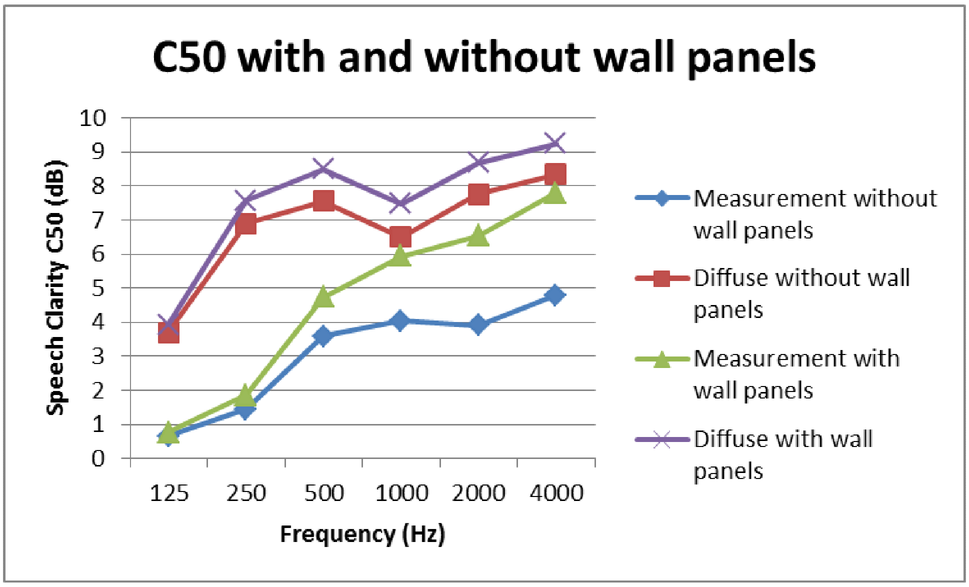

Figure 8: Comparison of measurements and calculations for a classroom with ceiling treatment and wall panels, Speech Clarity (C50)

Looking at the differences between Sabine calculations and room acoustic measurements we can clearly see that calculations do not correspond with the measured reality, due to low sound diffusion. As you see in the Reverberation Time and Speech Clarity figures above, Sabine calculations without and with wall panels (red and purple curves) are very similar, whereas you see clear differences between the measurement curves (green and blue). Three scenarios can be described and highlighted:

- There is a large difference between Sabine calculations and measurements due to low diffusion
- You do not notice the effects of the wall panels (vertical absorbing acoustic elements) in the Sabine calculations as you do in the measurements
- Sabine calculations clearly overrate, for example, the absorption/reverberation time, which often is the only acoustic descriptor used in national acoustic standards.

So, this could mean that, if you fully lean upon and use Sabine calculations fulfilling the requirements in for example any national acoustic standards, guidelines or even regulation, it may be so that the classrooms (like the above example) will qualify according to the acoustic requirements using Sabine calculations, but actually not in real life and when you carry out room acoustic measurements. Thus, the end-users, in this case teachers and students, would not get the room acoustic comfort they deserve and should have according to acoustic standards.

5. SUMMARY

From the tests we can draw a number of conclusions regarding the optimum use of wall absorbers. The most important is that the more vertical absorbers installed in a room, the more will the speech clarity increase and the reverberation time decrease. But the results also show that you only need to add a fairly small vertical absorption area to improve the acoustics in terms of speech clarity and reverberation time. Adding just one wall absorber in the room resulted in a significant improvement. Again, results improved with the total absorption area in the room. Preferably the absorbers should be placed as close to the sound source and activities as possible, and at the height of the listeners' heads. As expected, the sound strength was not as easy to improve. To reduce it you need to add a fairly large area of vertical absorbers.

- Sound strength – Add as many vertical absorbers as possible in the space. You need a lot of absorption area to make a difference
- Speech clarity – Add vertical absorbers in the room and place them close to the sound source and/or where they eliminate late reflections or flutter echoes. The more absorbers that can be fitted the better clarity, but even a minor vertical absorption area has a significant positive effect
- Sound propagation – Add absorbing screens and wall absorbers to stop grazing sound waves propagating across the room. In some cases you may even need to add a few free-hanging absorbers below the wall-to-wall acoustic ceiling. In a typical open-plan office this means installing wall absorbers, using screen absorbers as room dividers throughout the office and placing any free hanging units over the desks
- Reverberation time – Add vertical absorbers in the room. Even a minor vertical area has a significant positive effect

Larger absorbers: If it is possible to install larger wall absorbers, they should preferably be placed on two adjacent walls to eliminate grazing sound waves.

Smaller absorbers: The size of the total absorption area is important, so the more vertical absorbers you can fit in a room the more you will affect the room acoustic qualities. But even with a smaller vertical absorption area you can improve reverberation time and speech clarity.

The distances between absorbers, the distribution of the absorbers on the walls and the orientation of rectangular absorbers have a minor effect on the room acoustics. However, the tendencies are:

- Increasing the distance between absorbers increases absorption efficiency (up to 0.5 m apart)
- Distributing the absorbers over different walls is more effective than putting them on only one wall
- Rectangular absorbers work slightly better when placed horizontally, provided they cover the listening/speaking zone

Generally it's preferable to position vertical absorbers as close to the sound sources and activities as possible. There should be a distance of about 1 meter between a vertical absorber and any individuals sitting close to it. If you sit too close to an absorber there is a risk of feeling unbalanced. When using smaller absorbers, they should be placed with the centre of the absorber at the height of the speakers'/listeners' heads. The effect of wall panels is often much larger than could be expected by Sabine calculation, especially regarding reverberation and speech clarity, since Reverberation Time and Speech Clarity is very depending on the placement of the wall panels. Sound Pressure Levels will not differ too much from the diffuse field calculation.

Moreover, when you compare Sabine calculations with room acoustic measurements for rooms with and without wall absorbers (vertical absorbing elements) you can see clear differences in outcomes, due to low sound diffusion. Sabine calculations, especially in rooms with poor sound diffusion, will overrate the reverberation time for instance, and may risk that fulfilment of requirements in national acoustic standards will be jeopardized when executing room acoustic measurements.

REFERENCES

[1] Campbell, C., & Svensson, C., & Nilsson, E. (2014). *The challenge of meeting both acoustic and thermal comfort in 21st century school classrooms*. Paper presented at Internoise 2014, Melbourne, Australia

[2] Campbell, C., & Svensson, C., & Nilsson, E. (2014). *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.* Paper presented at Internoise 2014, Melbourne, Australia

[3] Canning, D. & James, A. (2012). *Essex Study Final Report – "Optimising classroom acoustics"*, 2012

[4] Nilsson, E. (2013). *Calculations and measurements of reverberation time, sound strength and clarity in classrooms with absorbing ceilings*. Paper presented at Internoise 2013, Innsbruck, Austria

[5] ISO 354: *Acoustics – Measurement of sound absorption in a reverberation room.* 2003

[6] Nilsson, E. (2006). *A reverberation time formula for rooms with ceiling treatment*. Paper presented at Joint Baltic-Nordic Acoustics Meeting *2006*, 8-10 November 2006, Gothenburg, Sweden

[7] ISO 3382-1: *Acoustics – Measurement of room acoustic parameters – Part 2: Reverberation time in ordinary rooms.* 2008

[8] Nilsson, E., & Svensson, C. (2008). *Room acoustic evaluation of different room types*. Paper presented at Joint Baltic-Nordic Acoustics Meeting, August 2008, Reykjavik, Iceland