# The challenge of meeting both acoustic and thermal comfort in 21st century school classrooms

Colin Campbell [1]; Carsten Svensson [2]; Erling Nilsson [3]

[1 2 3] Saint-Gobain Ecophon AB, Sweden

**ABSTRACT (836)**

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 classrooms for acoustic comfort. In turn, this potentially compromises the achievement of good acoustic comfort while still utilizing the thermal mass of the exposed soffit.

For this paper we measured a classroom configuration with free hanging sound absorbing units and wall absorbers instead of a fully covering traditional suspended ceiling. We looked into solving the low frequency imbalance - a potential negative consequence of not having a full suspended ceiling - with an enclosed void which can trap the low frequency sound (125Hz) which can build up and interfere with the important speech frequencies. We looked at the challenge of optimizing the acoustic coverage range without affecting the thermal comfort. We also wanted to improve the balance of the potentially negative low frequencies to achieve good speech communication and acoustic comfort for all students and teachers, while also providing an inclusive acoustic environment for sensitive listeners.

Keywords: Thermal Mass, Sound, Absorption, Classrooms, Reverberance, Speech Clarity, TABS, Sustainability

## 1. INTRODUCTION

It is clear that understanding of the importance of classroom acoustics has increased steadily. In recent years the benefits for teaching and learning have been well documented and the required acoustic performance has also increased in many classroom acoustic standards. These 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 200mm to 1000mm.

However there is an increasing trend towards exposing the structural thermal mass of the school buildings

[1] colin.campbell@ecophon.se
[2] carsten.svensson@ecophon.se
[3] erling.nilsson@ecophon.se

(without a fully covered suspended ceiling; to help to stabilize the temperature via night cooling etc.) which has traditionally been utilized by “high spec” HQ office buildings where the expectation is to occupy the building for many decades and the focus on reducing the energy costs is often prioritized even if the capital costs are increased. This move is generally driven by governments who want to reduce the burden on energy costs for their school stock although the capital costs are likely to be increased. In England, the PSBP (Priority School Building Programme) is pushing for this in all future new build schools and in Germany increasing numbers of Federal States are insisting on the same for new build schools.

While it is to be commended that governments and Green Building Councils are striving for more sustainable buildings with reduced energy needs being prioritized, it is vital that these buildings also function for those who occupy them. Accordingly whilst thermal comfort is important, it is also important to make sure that any drive for thermal efficiency is not detrimental to the acoustic comfort of teachers and students.

To this effect we need to make sure that acoustics are now given an even greater standing when it comes to Thermally Activated Building Systems (TABS buildings). In a traditional school building, a fully covering (100%) sound absorbing suspended ceiling is a basic and fundamental starting point for reducing the sound level and supporting good speech clarity and overall communication quality. In addition there should be wall panel absorbers to take out late reflections starting with the back wall. Additional low frequency absorption can balance the sound environment where there are unwanted and disturbing low frequencies (125Hz) and may be necessary for inclusion of children who are sensitive or vulnerable listeners. A wide range of students can be described as sensitive listeners including; permanent hearing impaired, temporary hearing impaired, partially sighted, autistic, ADHD, non-native language speakers or even the more introverted students.

## 2. Background

**School design and classroom acoustic conditions**

When it is not possible to have a full covering suspended ceiling due to TABS (Thermally Activated Building Systems) in classrooms, this tends to be addressed by combining free hanging / raft sound absorbing panels and wall absorbing panels which of course can greatly improve the acoustic environment whilst allowing thermal convection and radiation to and from the exposed thermal mass of the structural soffit. This works where the thermal capacity of the structural mass is utilized (often through purge / passive night cooling of the soffit or actively via cooled water embedded in pipes in the soffit) to control the temperature in the building in a more efficient and embedded way than traditional heating (HVAC), cooling and ventilation systems.

However, we need to be aware that as there may be little or no enclosed void (ODS - overall depth of system between the ceiling and the soffit), then there may be little low frequency absorption (125Hz) which can give rise to an imbalance for speech clarity where low frequency sound can build up and interfere with the speech frequencies. This makes it harder to hear the necessary consonants which give the words their meaning and thus the information. This makes understanding speech harder as the consonant sounds are overpowered or masked by the vowels and other low frequency sounds which can build up due to the lack of appropriate absorption.

**Sound and the learning environment**

Teachers and students spend most of each day in a school environment. It is vital that they can teach, learn, and socialise etc. in a place where speech communication is efficient as increasingly, more student engagement and broader pedagogic approaches are actively encouraged.

It has been acknowledged in several studies[16] 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. 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.[1,5,6] 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 complement to the RT.

In Bradley[10] the use of the room acoustic parameters $C_{50}$ and Strength are examined both experimentally and theoretically. In Nilsson[12] a model is presented for calculating $C_{50}$ and G. Special effort is focused 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[12] 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[2]. 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: 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.

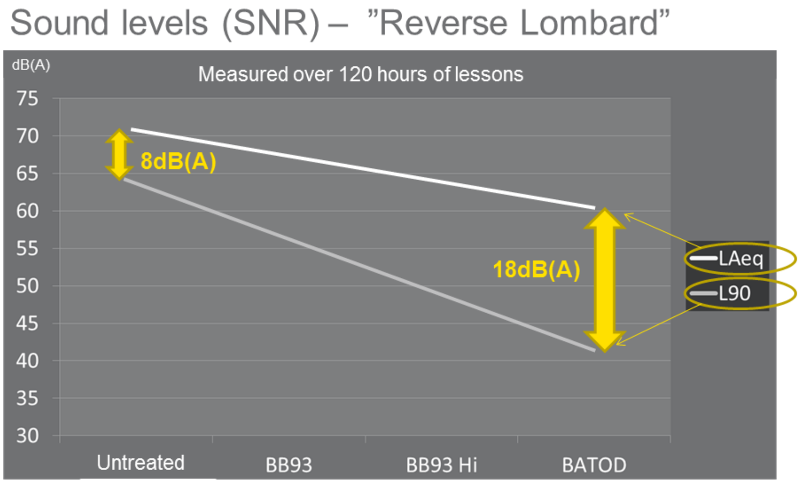



Figure 1: Sound levels of rooms with different acoustic treatment (The Essex Study)

When we look beyond reverberance / RT's, we can illustrate and understand the room acoustic characteristics better 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 types of rooms, by considering 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 they will actually be fit for purpose in reality.

The diffuse sound field is a theoretical situation which is very often not achieved in a classroom in reality, 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 having large flat surfaces. Hard flat surfaces like plasterboard and glass are also more prevalent; 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. However for TABS classrooms which do not have full covering suspended ceilings we thought it would be interesting to see if we would observe a more diffuse soundfield and if the three parameters values would correlate well.

In non-diffuse rooms with full covering acoustic ceilings as found by Nilsson[12]. 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 measure T20, commonly used which begins recording 5dB below the initial sound source. This is significant as the first 10dB (EDT) Nilsson[12], 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 (Sabine) and measuring the room characteristics. However we should not be surprised if in a more diffuse TABS classroom the RT correlates better with speech clarity ($C_{50}$) and sound strength or room gain (G), and how the sound is actually be perceived compared to a non –TABS classroom.

Increasing changes in teaching and learning approaches mean we need to re-evaluate if the single number RTs indicate whether a classroom is “fit for purpose” or not. Teaching methods are moving increasingly from a more traditional teacher centred approach, where speech from one person (teacher) dominates, to include 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 included 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 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 i.e.

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 characterizing 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 a 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.

## 3. Outline objective

In order to balance the acoustics in a TABS school building classroom we need to understand what we are missing when it comes to the absence of a fully covered suspended ceiling and define what we can do to optimize acoustics in these situations. It is of particular importance for sensitive listeners as we know the low frequencies are compromised in order to try to match optimized thermal efficiency with optimized acoustic efficiency. We also want to see if it is possible to match the acoustic comfort achieved by traditional / existing acoustic suspended ceilings and the highest performing classroom acoustic standards in Europe for classrooms, sensitive listeners and group work.

We thought it would also be good to suggest how this can be achieved in practice so that practical solutions can be provided with expected acoustic outcomes and values. In this way we hoped to be closer to being able to provide guidance on the requirements for acoustically socially sustainable school buildings which perform well and complement the increasing TABS school buildings. Meeting this challenge of further increasing the low frequency absorption performance and improving the room acoustic balance for speech and hearing activities in these TABS schools may also inform us as to how to improve acoustics in school buildings in hot climates where there is little or no existing sound absorption but the structural soffit cools the classroom passively and might reduce the need or requirements for mechanical cooling systems e.g. Mediterranean countries.

In this study our aim was to collect objective measurement data which corresponded as closely as possible to how building users subjectively perceive room acoustics. This will enable us to identify the most effective acoustic configurations for TABS classrooms and in the long term provide data for guidance for target values in standards and recommendations to support optimal acoustic condition for the classrooms in TABS school buildings.

The objective of this study was to investigate different acoustic conditions and establish the acoustic configurations for optimal acoustics in TABS classroom 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 sound 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[14,15]. In general these additional parameters $C_{50}$ and G outlined in ISO 3382-1[15] 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].

The purpose of this intervention study was to show the beneficial effect of using several parameters and acoustic configurations together with the RT for optimizing acoustics in TABS classrooms. Optimal acoustic conditions should be specified by a balance of objectively measureable parameters related to speech clarity, sound strength and reverberation time. The data collected will be useful input to establish what recommendations are possible concerning optimal acoustic conditions for TABS classrooms to be used in future standards, since, alongside political initiatives and recommendations from Green Building Councils, like general modern learning environments, TABS classrooms will increasing have to fit a broader pedagogic approach.

## 4. Methodology (intervention study)

The main part of this intervention study was to measure and analyse room acoustic data from different acoustic configurations which are relevant for TABS classrooms. In the data collection of room acoustic measurements (impulse response measurements), the room was furnished but unoccupied. Our approach covered the following topics below:

*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.

*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 measurement 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 a typical non-TABS classroom. This will serve as potential input for the acoustic design guidance for future TABS classrooms.

## 5. TABS classroom configurations [18]:

The size of the Ecophon Solaris laboratory room is length x width x height = 7.25m x 7.25m x 3.5m. 184m3.

Although the room is minimally furnished to simulate a “worst case scenario” it has typical furniture and surfaces for a TABS classroom. A full suspended ceiling grid system has been installed with a ceiling height of 3.2m and 300m (ODS) overall depth of system in the ceiling void. This is to provide the support frames for the absorption panels and allow efficient changeovers of the many different acoustic configurations.

Image 1

Image 2

Image 1: Bare room with no sound absorbing rafts and wall absorbers installed.

Image 2: Sound absorbing rafts and wall absorbers installed for testing.

**Solaris classroom layout with 8 different room configurations for 8 different acoustic measurements:**

| Configuration / Group number | Raft Absorbers: Master E | Above Raft Absorbers ExtraBass | Rear Wall Absorber Akusto | Rear Wall Absorbers ExtraBass | Side Wall Absorber Akusto (Bonus) |
|---|---|---|---|---|---|
| 1 | O | O | O | O | O |
| 2 | X | O | O | O | O |
| 3 | X | X | O | O | O |
| 4 | X | O | X | O | O |
| 5 | X | O | X | X | O |
| 6 | X | X | X | X | O |
| 7 | X | X | X | O | O |
| 8 | X | X | X | O | X |

Table 1: Summary of acoustic configurations. X=absorbing panels. O = No absorption.

**The temperature and humidity conditions could influence the acoustic results.**

| Conditions | 16/06/2014 | 17/06/2014 | 18/06/2014 |
|---|---|---|---|
| Temperature (°C) | - | 19 | 18,5 |
| | - | 19 | 18.8 |
| Relative Humidity (%) | - | 42 | 48 |
| | - | 42 | 56 |

Table 2:

### Configuration 1

Bare room (no acoustic treatment on the ceiling or walls) with existing empty grid to be moved up to 300mm ODS and with Ceiling Height of 3.2m, to simulate a typical TABS senario. (Instead of the existing 800mm ODS and CH of 2.7m which is a typical non-TABS senario).

The adjusted grid height should remain installed throughout all 6 different configurations and measurements.

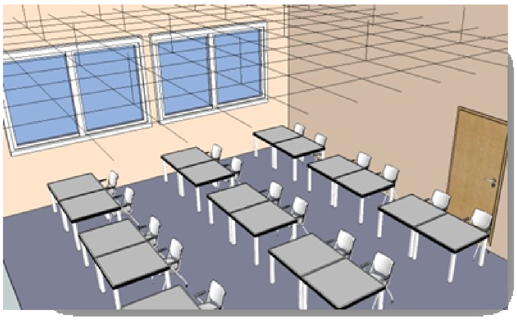
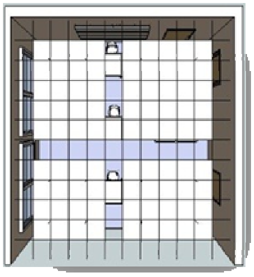


Image 3: Bare classroom with no absorbers.

Image 4: Bare classroom with no absorbers.

The results of this configuration measurement are presented in blue.

### Configuration 2



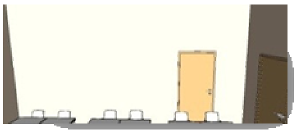


Image 5: Raft absorbers. Image 6: No wall absorbers. Image 7: No low freq. absorbers

After measuring the basic room conditions, untreated with any sound absorbing materials in our classroom, we started with a basic configuration:

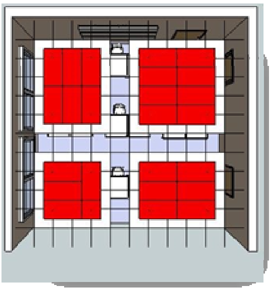
The ceiling consists of raft absorbers 600x600 40mm high density "Class A" sound absorbing panels in the existing grid. Split in 4 separate rafts with 1 tile (600mm) gap between the rafts and surrounding at the perimeter (4x5 full size panels in the grid). This configuration is likely to be a typical solution for TABS classrooms giving a coverage ratio of approx. 60% of the total ceiling or floor area.

Raft Absorbers Surface = 29,16 $m^2$

Coverage ratio = 56% of the total ceiling or floor plan.

The result of this configuration measurement will be presented in red.

**Configuration 3.**



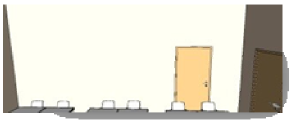
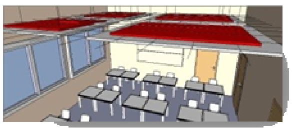


Image 8: Raft & LF absorbers. Image 9: No wall absorbers. Image 10: LF absorbers.

Same installation as number 2 with low frequency sound absorbing panels (1200x600) 50mm lower density "Class A" sound absorbing panels installed above the raft absorbers 7.2m2 rafts.
Six low frequency sound absorbing panels to be laid over the tiles and grid.
Total extra Low frequency panels above the Raft Absorbers = 19 $m^2$

The result of this configuration measurement will be presented in green.

**Configuration 4**



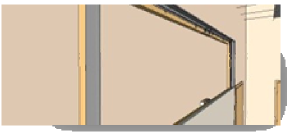
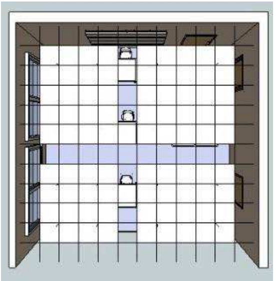


Figure 11: Raft & low frequency absorbers. Image 12: Bespoke 90mm frame.

Same configuration as 2 with sound absorbing wall panels 40mm high density "Class A" sound absorbing wall panels in a bespoke double frame (90mm frame) on the back wall.
Three 2700x600mm wall absorbers direct mounted on the back wall, spaced in the middle.

The result of this configuration measurement will be presented in yellow.

**Configuration 5**



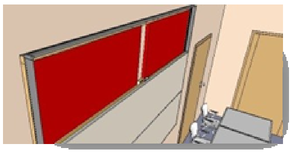
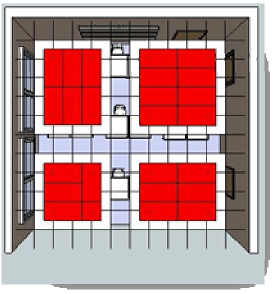


Image 13: Raft absorbers. Image 14:LF wall absorbers. Image15:Wallpanels covering LF panels

Same as 4. Plus additional low frequency sound absorbing panels (1200x600) mounted behind the wall absorbers in the 90mm bespoke frame.
Six (1200x600) Low frequency panels fitted between support battens.

The result of this configuration measurement will be presented in black.

**Configuration 6**



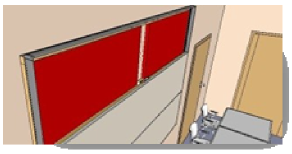
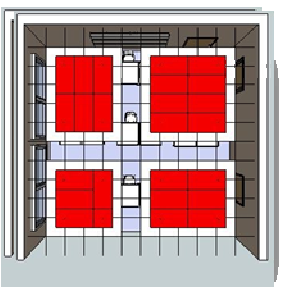


Image 16: Raft & LF absorbers. Image 17: LF wall absorbers. Image 18: Wallpanels covering LF panels

Same as 5. , Plus 3.
Plus installing additional low frequency panels (1200x600) above the sound absorbing rafts) 7.2m2 rafts. Six low frequency panels laid over the tiles and grid.

The result will be presented in pink.

**Configuration 7**



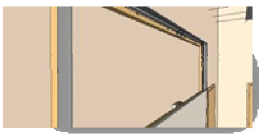


Image 19: Raft & LF absorbers. Image 20: No additional LF panels. Image 21:Wall absorber without LF.

Same as 3.
Plus installing additional low frequency panels above the sound absorbing rafts.

**Configuration 8**

Image 22: Four panels resting against the wall. Image 23: Panel resting against the wall.

Same as 7. Plus four sound absorbing wall panels 2700x600mm resting against the adjacent wall.

ISO testing of Absorption materials:

The ceiling panel installed is an (Ecophon Master E) 40mm panel, “Absorption Class A” glass wool absorber, the additional low frequency absorber is a lower density (Ecophon Extra Bass) 50mm panel “Absorption Class A” glass wool absorber and the wall panel absorber an (Ecophon Akusto) 40mm ,“Absorption Class A” glass wool absorber are all measured in accordance with ISO 11654.

## 6. Results:

The Ecophon Solaris (TABS classroom) laboratory acoustic measurements[18].

For this test we decided to use a simple room as possible without wall elements to simulate the worst acoustic configuration possible. The furniture inside the room was just 11 tables and 19 chairs. (see images below)

12 tests for each position (6 microphone positions x 2 Loudspeaker positions)

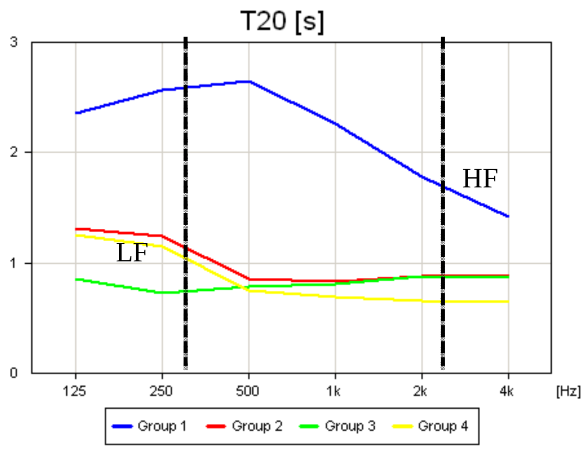
- Height microphone: 1,25m
- Height loudspeaker: 1,4m

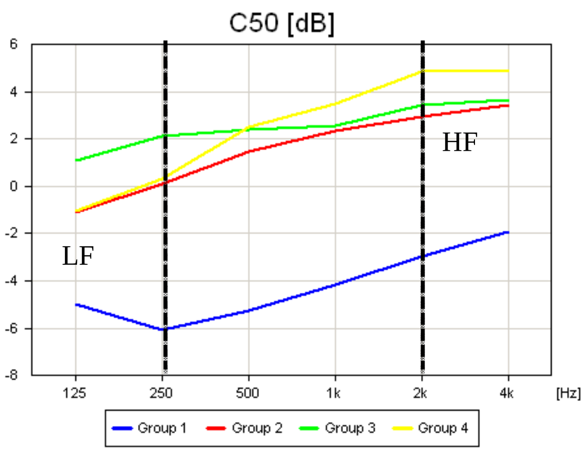
We calibrated our Sound Pressure Level meter (94dB (± 0.2 dB) - 1000 kHz frequency) with a sound calibrator type 4231:

We measured impulse responses with a multidirectional MLS (maximum length sequence) internal signal. The Software that we used is Dirac. To describe Sound Levels we used the Leq method resulting in a single decibel value which takes into account the total Sound Energy over the period of time of interest.

The acoustic measurements were recorded using an impulse response in order to evaluate the following room acoustic descriptors; T20, $C_{50}$ and G in accordance with ISO 3382-1.

To begin with we compared the first four configurations:



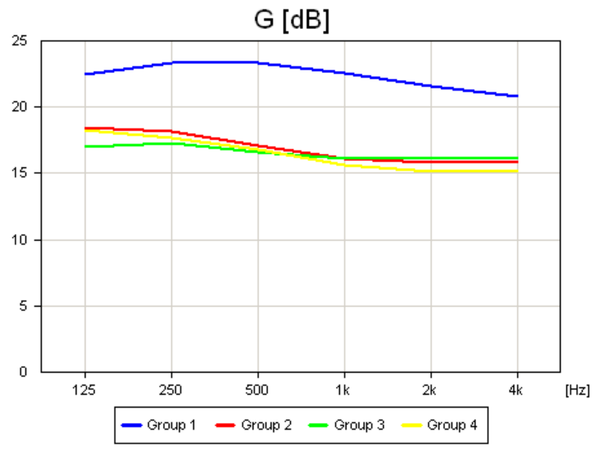



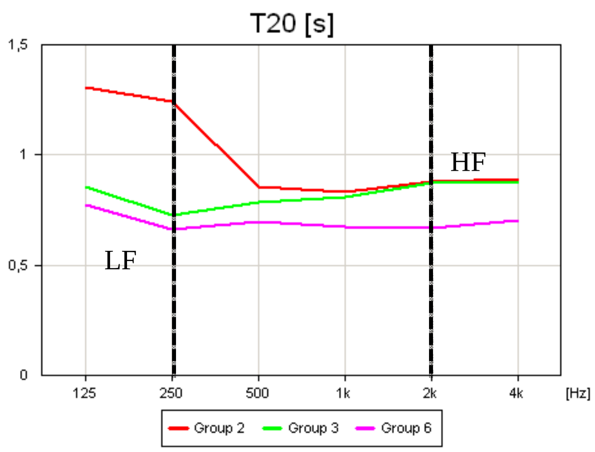

Figure 2: configuration / group 1-4; T20, $C_{50}$ & G

Average values for all Rooms: values across broad frequency range (125-4000Hz).

| Configuration / Group number | Raft Absorbers: Master E | Above Raft Absorbers | Rear Wall Absorber | Rear Wall Absorbers | Side Wall Absorber |
|---|---|---|---|---|---|
| | | ExtraBass | Akusto | ExtraBass | Akusto (Bonus) |
| 1 | O | O | O | O | O |
| 2 | X | O | O | O | O |
| 3 | X | X | O | O | O |
| 4 | X | O | X | O | O |

Table 3: X - Absorption configuration / group 1-4.

## Result 2



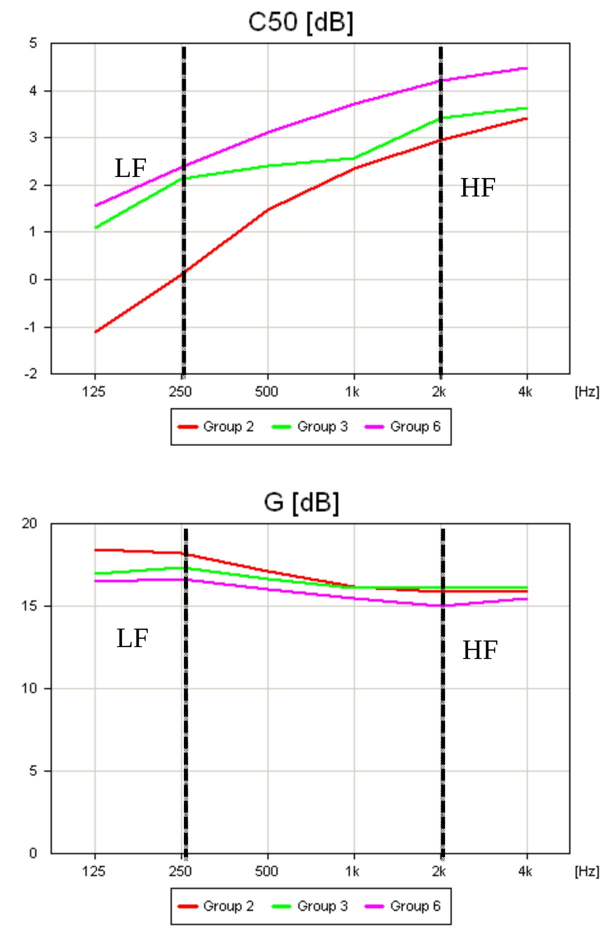



Figure 3: configuration / group 1-4; T20, $C_{50}$ & G

Average values for all rooms: values across broad frequency range (125-4000Hz).

| Configuration / Group number | Raft Absorbers: Master E | Above Raft Absorbers<br>ExtraBass | Rear Wall Absorber Akusto | Rear Wall Absorbers<br>ExtraBass | Side Wall Absorber Akusto (Bonus) |
|---|---|---|---|---|---|
| 2 | X | O | O | O | O |
| 3 | X | X | O | O | O |
| 6 | X | X | X | X | O |

Table 4: X - Absorption configuration / group 2,3 & 6.

**Result 3**

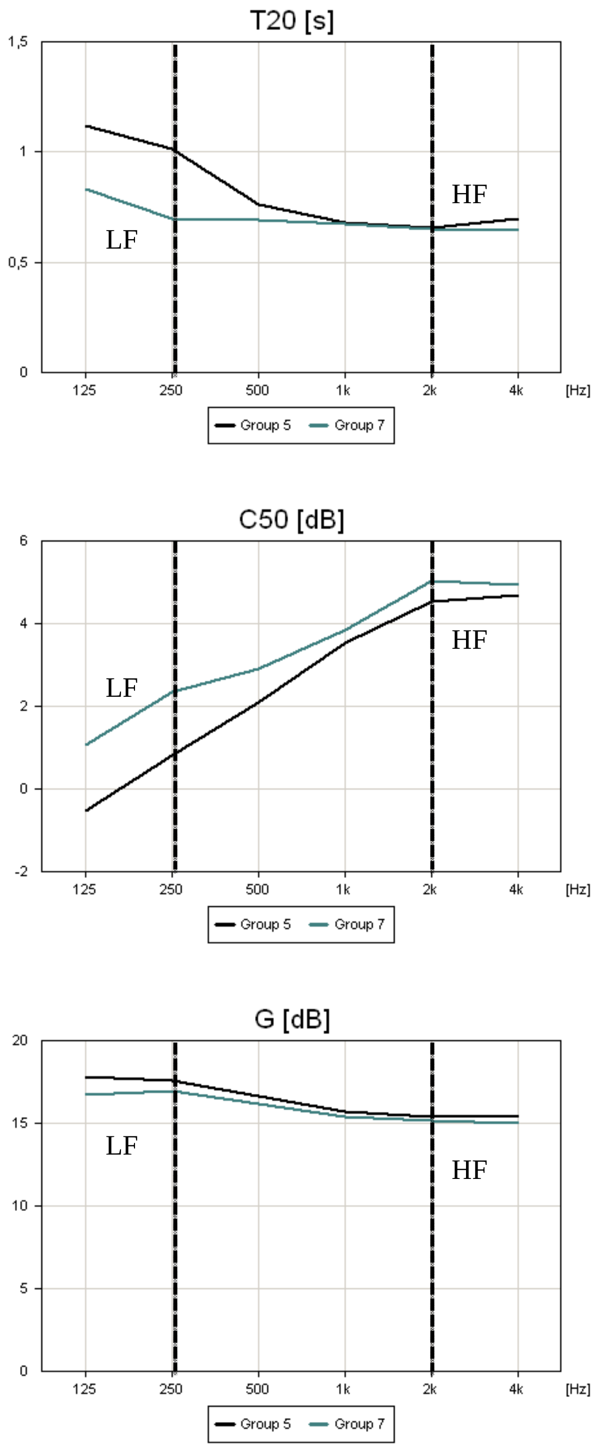



Figure 3: configuration / group 5 & 7; T20, $C_{50}$ & G

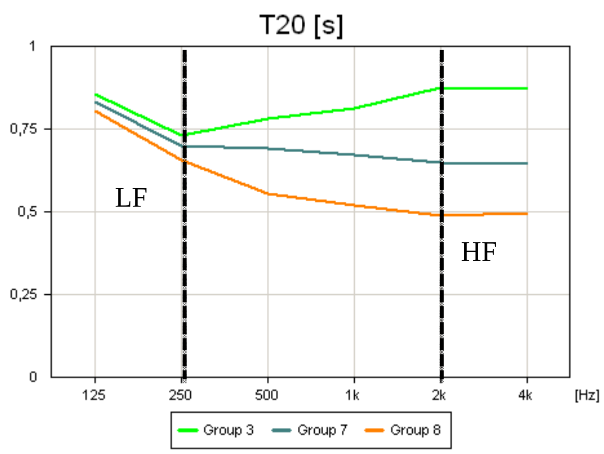
Average values for all rooms: values across broad frequency range (125-4000Hz).

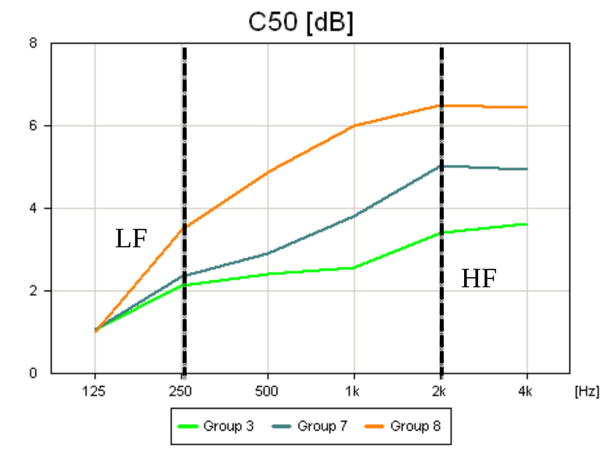
| Configuration / Group number | Raft Absorbers: Master E | Above Raft Absorbers | Rear Wall Absorber Akusto | Rear Wall Absorbers | Side Wall Absorber Akusto (Bonus) |
|---|---|---|---|---|---|
| | | ExtraBass | | ExtraBass | |

| | | | | | |
|---|---|---|---|---|---|
| 7 | X | X | X | O | O |
| 5 | X | O | X | X | O |

Table 5: X - Absorption configuration / group 5&7.

Results 4



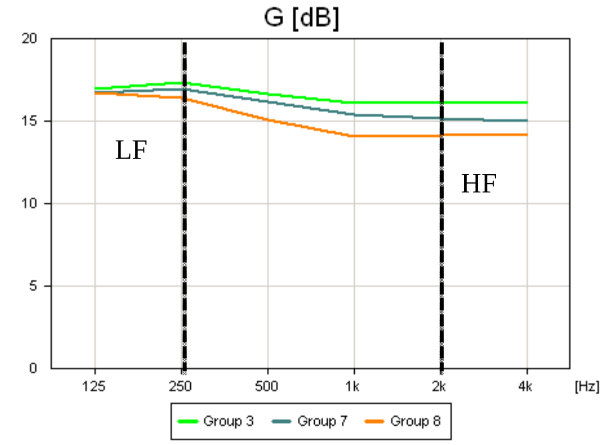


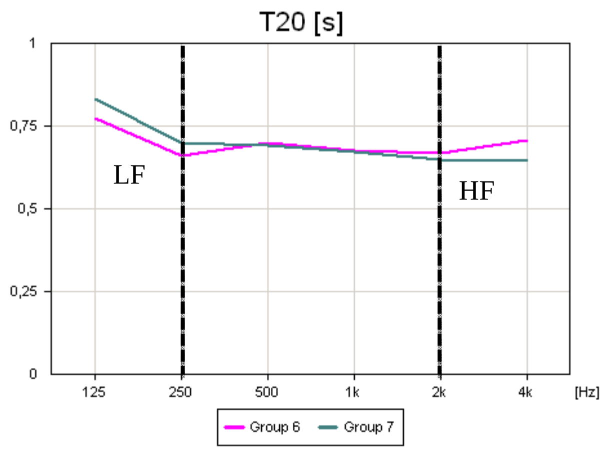

Figure 3: configuration / group 3,7 & 8; T20, $C_{50}$ & G

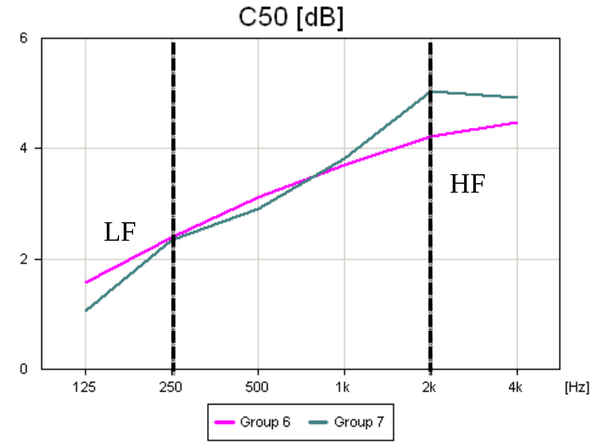
Average values for all rooms: values across broad frequency range (125-4000Hz).

| Configuration / Group number | Raft Absorbers: Master E | Above Raft Absorbers ExtraBass | Rear Wall Absorber Akusto | Rear Wall Absorbers ExtraBass | Side Wall Absorber Akusto (Bonus) |
|---|---|---|---|---|---|
| 7 | X | X | X | O | O |
| 8 | X | X | X | O | X |
| 3 | X | X | O | O | O |

Table 6: X - Absorption configuration / group 3,7 & 8.

Results 5





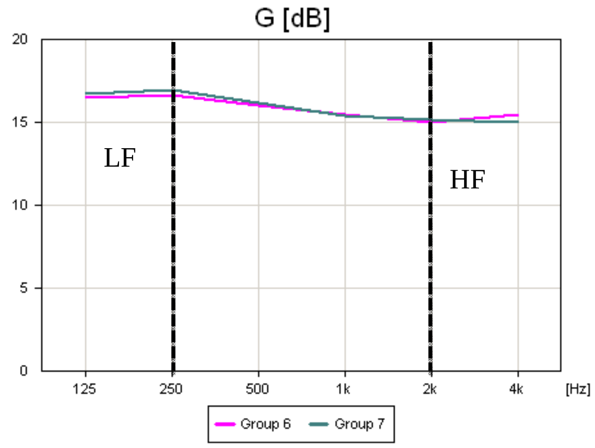




Figure 3: configuration / group 6 & 7; T20, $C_{50}$ & G

Average values for all rooms: values across broad frequency range (125-4000Hz).

| Configuration / Group number | Raft Absorbers: Master E | Above Raft Absorbers ExtraBass | Rear Wall Absorber Akusto | Rear Wall Absorbers ExtraBass | Side Wall Absorber Akusto (Bonus) |
|---|---|---|---|---|---|
| 7 | X | X | X | O | O |
| 6 | X | X | X | X | O |

HF

LF

Table 7: X - Absorption configuration / group 6 & 7.

**Summary of average values of all the configurations from the measurement data:**

| Room number | T20 (s) | $C_{50}$ (dB) | $D_{50}$ (%) | G (dB) |
|---|---|---|---|---|
| 1 | 2,2 | -4,2 | 28 | 22,4 |

| | | | | |
|---|---|---|---|---|
| 2 | 0,99 | 1,6 | 59 | 16,9 |
| 3 | 0,8 | 2,6 | 64 | 16,6 |
| 4 | 0,85 | 3 | 66 | 16,4 |
| 5 | 0,82 | 2,6 | 64 | 16,6 |
| 6 | 0,7 | 3,2 | 68 | 15,9 |
| 7 | 0,7 | 3,3 | 68 | 16 |
| 8 | 0,7 | 4,7 | 74 | 14,9 |

Table 8: Average values of all the acoustic configurations from the measurement data. Values across broad frequency range (125-4000Hz).

| Configuration / Group number | Raft Absorbers: Master E | Above Raft Absorbers ExtraBass | Rear Wall Absorber Akusto | Rear Wall Absorbers ExtraBass | Side Wall Absorber Akusto (Bonus) |
|---|---|---|---|---|---|
| 1 | O | O | O | O | O |
| 2 | X | O | O | O | O |
| 3 | X | X | O | O | O |
| 4 | X | O | X | O | O |
| 5 | O | O | X | X | O |
| 6 | X | X | X | X | O |
| 7 | X | X | X | X | O |
| 8 | X | X | X | X | X |

Table 9: Summary of acoustic configurations. X=absorbing panels. O = No absorption.

## 7. Discussion and conclusion

In this paper the aim was to look at how we can optimize the acoustic conditions for TABS school buildings where it is not possible to have a fully covered high performance acoustic suspended ceiling. By using alternative free hanging sound absorbers and wall panels we wanted to see how good an acoustic environment is possible, when we have to compromise and expose large areas of the concrete ceiling soffit for thermal purposes.

We also wanted to obtain relevant acoustic data which would help us match the technical data with human qualities and let us assess how the human user perception of room acoustics would be in reality to enable us to come closer to defining the appropriate conditions which are possible for TABS classrooms as we believe this will have a significant impact on the conditions for speech communication, not just for the inclusion of sensitive listeners but for all teachers and all students and their teaching and learning activities.

We measured relevant acoustic parameters in addition to RT, which we believe have a closer correspondence to the subjective human qualities. Measuring these room acoustic parameters ($C_{50}$ / $D_{50}$ and the difference in SPL's) is likely to have given us a better indication as to how occupants would perceive the room acoustics.

In Table 8. we can see that Configuration 3 and Configuration 2 look the same when we average the values but it would be interesting to know if the differences we see across the frequencies in Figure 2. Might be perceived by users. This would help with fine tuning across the frequencies to identify when there is a significant difference which would be missed if only the average values are presented. Also this might reinforce the need to look across all frequencies and not just mid frequencies as is often done.

However, if we compare the best values achieved here to the most stringent documented classroom target values corresponding to optimal room acoustics for typical classrooms, we can see that we don't achieve the requirements.

So while it is apparently still best to have a traditional fully covering suspended ceiling it might be that these values can be improved with additional sound absorbing furniture, however it might also be worth noting that for the inclusion of hearing impaired occupants and for more intensive speech activities which is often the case for interactive group work, then unless everything possible is done to create a good sound environment, these TABS classrooms may not be "fit for purpose". Meeting this challenge of further increasing the low frequency absorption performance and improving the room acoustic balance for speech and hearing activities in these TABS schools as mentioned in the outline may also inform us as to how to improve acoustics in school buildings in hot climates where there is little or no existing sound absorption but the structural soffit cools the classroom passively and might reduce the need or requirements for mechanical cooling systems e.g. Mediterranean countries.

Looking beyond the practice of using only 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 for TABS classrooms so that they are "fit for purpose" for good speech communication and the inclusion of hearing impaired and for more intensive speech communication activities like group work which are an increasing feature of educational approaches to encourage student engagement and collaboration.

This is indeed a challenge, however, we are closer to giving constructive guidance to improve the acoustics, for socially sustainable school buildings and to complement the increasingly energy based performance criteria for TABS school buildings. This study gives us measured outcomes, justifying the need for additional low frequency absorption and wall absorption. In the long term it would be good to have more evidence gathered from many rooms to inform us about how these parameters are actually perceived in what we believe are optimized acoustic conditions for TABS classrooms, for and during more intense speech communication activities to that we can secure good acoustic comfort in practice and know if this is good enough for the inclusion of sensitive listeners.

## References:

[1] M. Oberdörster, G. Tiesler, "Akustiche Ergonomie der Schule", Schriftenreihe der Bundesanstalt für

Arbeitsschutz und Arbeitsmedizin, Forschung Fb1071, Universität Bremen, 2006.

[2] D. Canning. Essex Study, “Impact of different acoustic standards in School Buildings on teaching and learning” 2008 UK.

[3] D. Canning and A. James, Essex Study Final Report – “Optimised classroom acoustics for all” 2012.

[4] C. Campbell, C. Svensson, E. Nilsson “Classroom acoustic research on speech behaviour of teachers and students” Internoise 2013.

[5] E. Nilsson, P. Hammer; “Subjective evaluation of speech intelligibility for normal hearing persons and for persons with simulated minimal degrees of hearing loss”. Report TVBA-3083, Engineering Acoustic, Lund University, Sweden, 1994.

[6] R. Ljung, K. Israelsson & S. Hygge; (2013). Speech Intelligibility and Recall of Spoken Material Heard at Different Signal-to-noise Ratios and the Role Played by Working Memory Capacity. Applied Cognitive Psychology, 27 (2), 198-203.

[7] J. Harvie-Clark, N. Dobinson, R. Hinton, “Acoustic response in non-diffuse rooms”, Euronoise 2012, 10 – 13 June, Prague.

[8] J. S. Bradley, H. Sato, M. Picard, “On the importance of early reflections for speech in rooms”, J. Acoust. Soc. Am. 113 (6), June 2003.

[9] L. G. Marshall, “Speech intelligibility prediction from calculated C50 values”, J. Acoust. Soc. Am. 98 (5), November 1995.

[10] J. S. Bradley, “Review of objective room acoustic measures and future needs”, Applied Acoustics 72 (2011) 713 – 720.

[11] J. S. Bradley, H. Sato, “The intelligibility of speech in elementary school classrooms”, J. Acoust. Soc. Am. 123 (4), April 2008.

[12] E. Nilsson, “Simple formulas for estimation of room acoustic parameters”, Euronoise 2012, 10 – 13 June, Prague.

[13] B. Rasmussen, J. Brunskog, D. Hoffmeyer, ”Reverberation time in class rooms – Comparison of regulations and classification criteria in the Nordic countries”, Joint Baltic – Nordic Acoustics Meeting, June 18th – 20th, 2012 Odense, Denmark.

[14] ISO 3382 – 1: Acoustics – Measurement of room acoustic parameters – Part 1: Performance spaces.

[15] ISO 3382 – 2: Acoustics – Measurement of room acoustic parameters – Part 2: Reverberation time in ordinary rooms.

[16] Hygge, S., Kjellberg, A., Nöstl, A., Keus, M., Hurtig, A., Ljung, R. & Sörqvist, P. (2013). Acoustical conditions in the classroom II: Recall of spoken words in English and Swedish heard at different signal-to-noise ratios. InterNoise 2013, Innsbruck, Sept 15-18, 2013.

[17] Pierre Lombard;Windsor conference 2014.”Measure and model of free hanging sound absorbers impact on thermal comfort” Saint Gobain Recherche, 39 quai Lucien Lefranc, 93330 Aubervilliers Cedex.

[18] Ecophon Solaris Acoustics Report - Free hanging units and low frequency investigation from measurements of different classroom acoustic configurations in Solaris Laboratory. E.Nilsson, H.Sallenhag, V.Malemanche.