Balanced acoustics in class rooms of schools variation of ceiling properties and absorber dimensions

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Introduction

Architectural acoustics in class rooms of schools, an often discussed topic. Concerning the acoustical properties an accepted German standard exists for several years. Therein the most important requirements are stated. These are mainly reverberation time, speech intelligibility and background noise. The structural sound insulation is also treated, but it will not be discussed here. If reverberation is regarded as most important criteria, the local distribution of acoustical effective surfaces and elements has to be taken into account. In practice this can be affected by ceilings, in the entire concept with additional wall panels.

Actual measurements, amongst others in class rooms of the superior school located at Halle/Westfalia [1] were performed in the settings to compare reverberation times before and after interior modifications, and vary the surface of different acoustical properties of the new ceiling system. In Addition also wall panels were mounted. The question was, if different behaviour and dimension of absorbers can improve the acoustical conditions. Can ceilings with exposed grid systems be selectively used to regulate reverberation? The comparison between calculation and measurement and between laboratory results for absorption and the effect on site is looked at.

Requirements

In international standards and relevant literature requirements regarding the frequency-dependent reverberation time are enunciated. Volume and type of use result in the required reverberation time which, when kept to, leads to a good intelligibility. In the German standard DIN 18041 [2] reverberation time and additionally the tolerance range for different use are given.

The speech intelligibility in classrooms can be abstracted by the Speech Transmission Index *STI.* As per [4] the quality is entitled according to table 2. for teaching conditions *excellent* speech intelligibility has to be aspired.

STI	Description
0 – 0,30	unintelligible
0,30 – 0,45	poor
0,45 – 0,60	fair
0,60 – 0,75	good
0,75 – 1,00	excellent

Table 1: values and description of *STI*

Building structure details

In the reviewed object two similar rooms were observed regarding acoustics via forecasting calculation and measuring [1]. Both rooms U13 and U14 had identical dimensions $L \times W \times H =$ 9.30 m x 6.91 m x 3.17 m. The Volume of V = 204 m³ leads to a required mean value for the reverberation time for class rooms in schools, of $T = 0.57$ s according to equation (7) from DIN 18041 [2].

The rooms had the following equipment components, see image 1:

- Floor with linoleum on screed
- Walls: brickworks with plaster
- Windows with double glazing, wooden doors
- Furniture with wooden tables and wooden chairs
- Blackboard and teachers desk, open shelves
- ribbed concrete slab with suspended ceiling, *sound reflecting* before renovation

The rooms were modified as follows:

- New ceiling, suspension eight approx. 400 mm
- replacement of ceiling tiles
- U13: Wall panels as option, 1.200 mm high along back wall, 800 mm along corridor wall

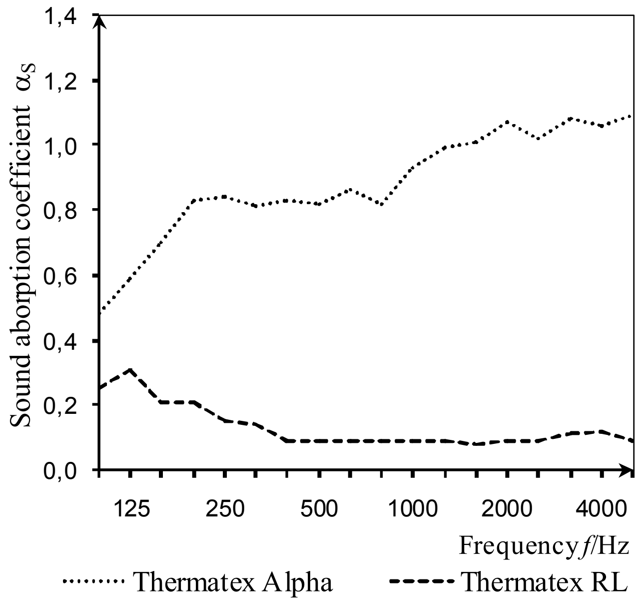
Image 1: view of class room U13

Ceiling tiles

The ceiling system in room U13 and U14 was equipped with different tiles.

The AMF Thermatex Alpha product is a highly absorbent tile with a weighted sound absorption coefficient according to DIN EN ISO 11654 [5] of $\alpha_w = 0.90$, the tile AMF

Thermatex Acoustic RL tile performs a value of $\alpha_w = 0.10(L)$. Due to rather low absorption coefficients of approximately $\alpha_s = 0.10$ in the frequency range of human speech AMF Thermatex RL was assembled as a sound reflecting ceiling zone. Sound absorption of Thermatex Acoustic RL with approximately $\alpha_s = 0.30$ at $f = 125$ Hz can (in calculation initially) be used to shorten reverberation at low frequencies. With $\alpha_s = 0.10$ at mid- and high frequencies excessive acoustical dampening should be reduced by an otherwise overall high absorbent ceiling. Sound absorption coefficients of both types of tiles are presented in graph 1.



Graph 1:
sound absorption coefficient acc. to EN ISO 354

Ceiling variation

Experience shows that an absorber for low frequencies is more effective if mounted along room edges and corners e.g. between ceiling and wall than in the centre of surfaces. The variations were done to take influence at low frequency reverberation and to improve speech intelligibility by the help of a sound reflecting ceiling central zone. The single surfaces were equipped with at least 3 x 3 tiles with dimensions of 600 mm x 600 mm. The tile's length of 3 number 600 mm matches the wave length at $f = 200$ Hz and below. In room U13 the reflecting tiles were in the ceilings centre as recommended in DIN 18041 [2], in room U14 different to that additionally in the rooms corners.

Both ceiling variations are shown in image 2 and 3.

Wall panels

Along the back wall and the corridor wall joining the ceiling of room U13 absorbing wall panels were assembled. The panels consist of 30 mm mineral-panels; fixed with a gap to the wall of up to 20 mm. Graph 2 shows the equivalent sound absorption area A_{eq} in m². The specimens surface was $S = 4.15$ m x 1.2 m, it was mounted in laboratory without air gap.

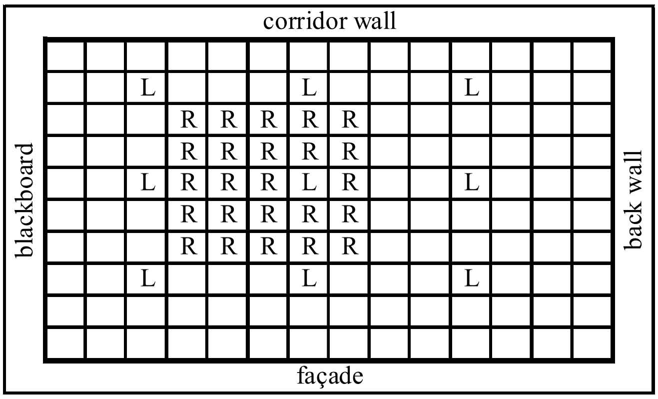


Image 3: variation of tile assembly in room U13

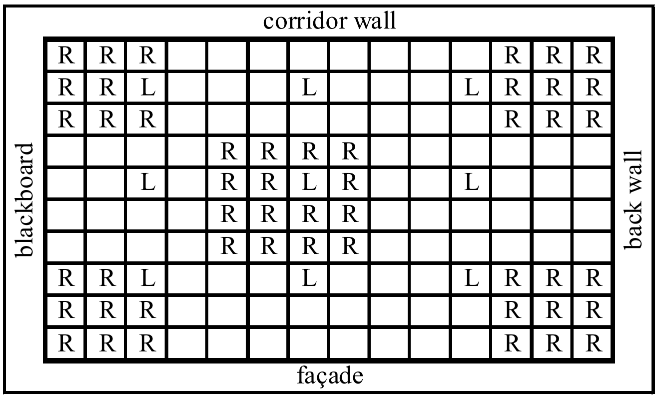
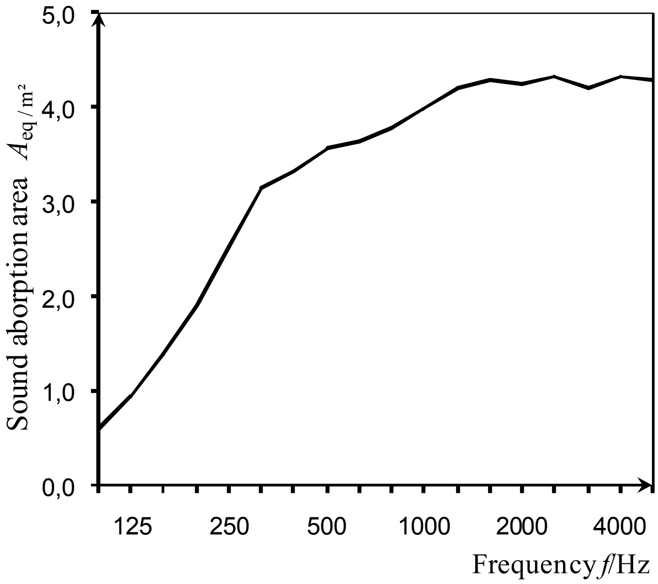


Image 3: variation of tile assembly room U14

Legend to image 2 and 3

R	reflective ceiling tile
L	Luminaire
not marked	high absorbent tile



Graph 2: 30 mm AMF Thermatex dB Acoustic equivalent sound absorption area - acc. to EN ISO 354

Measurement procedure

The measurements of reverberation time were executed and evaluated in respect of DIN EN ISO 3382 [3]. The speech transmission index *STI* was measured in 9 positions in the pupil's area of the class room. The sound source was situated close to the teacher's desk.

Results and assessment

Speech transmission index *STI*

The acoustical conditions in both rooms with the existing, sound reflective ceiling cladding, with furniture, but without persons, were classed as *fair*, according to table 1, with values of $0.47 \leq STI \leq 0.50$, an improvement was necessary.

First step was to replace the existing, reflective ceiling by a completely high absorbent ceiling system. Speech intelligibility in both rooms U13 and U14 then rises to *excellent* with values of $0.68 \leq STI \leq 0.80$, respecting different positions.

In a second step, in room U13 in the ceilings centre 5 x 5 reflective tiles type *RL* replaced the high absorbent tiles type *Alpha-* as shown in image 2. The variation in room U14 with reflective tiles in the rooms corners shown in image 3, leads to measured values of $0.65 \leq STI \leq 0.74$. This shows an acoustical advantage for the U13-solution, see image 2.

Third step was to mount wall panels along the back wall. Thereof results another improvement of speech transmission quality. Table 3 shows the change of the measured values, caused by adding back wall panels. The design of table 3 abstracts the class room's ground view plan.

Blackboard			corridor wall
0.0	+0.04	+ 0.01	
+ 0.05	+ 0.04	+ 0.04	
- 0.01	0.0	+ 0.02	
(wall panel)			

Table 3: change of *STI* – with/without back wall panel

When in fourth step additional wall panels were mounted along the corridor wall a further improvement of *STI* could be achieved.
There was an improvement of $\Delta STI = 0.13$ for the occupied situation, compared to the last results with all wall panels and ceiling equipment, shown in image 2.
Finally it can be stated that the variant with reflective centre, all other tiles high absorbent and wall panels on two walls offers the best acoustical solution.

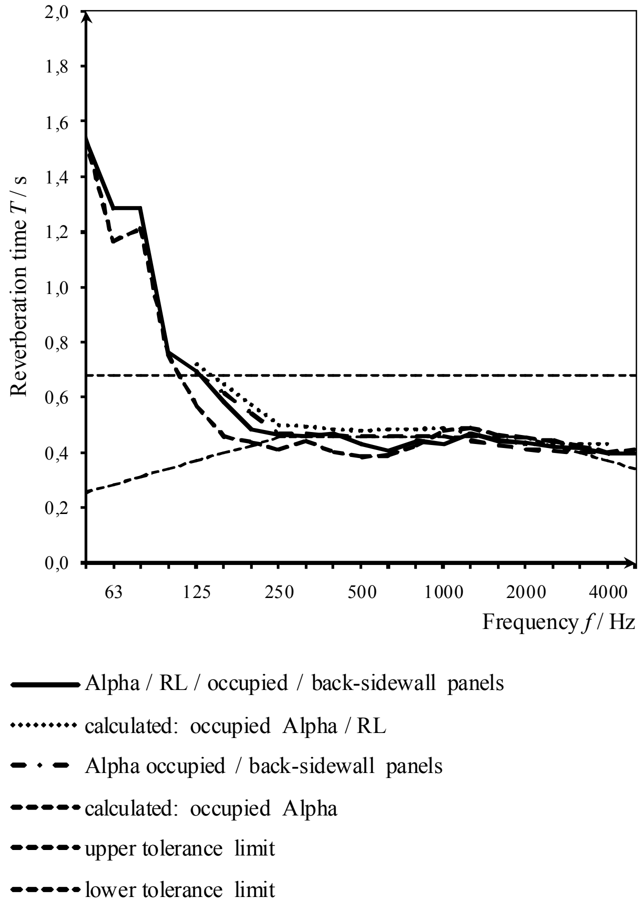
Reverberation time

Reverberation times in the room with existing, reflective ceiling are with $1.5 \leq T \leq 2.5$ far of any requirement. This was motivation for acoustical treatment of the class rooms.

Reverberation times in the examined rooms with absorbent ceiling were in all cases very close to and/or within the tolerances acc. to DIN 18041 [2] – occupied by 28 pupils even closer to the lower limits, see graph 3 to room U13.

It is of interest that the acoustical influence of 28 pupils is greater than to be expected by calculating with the sound absorption coefficients listed in table B.2 of DIN 18041 [2] for pupils including furniture.

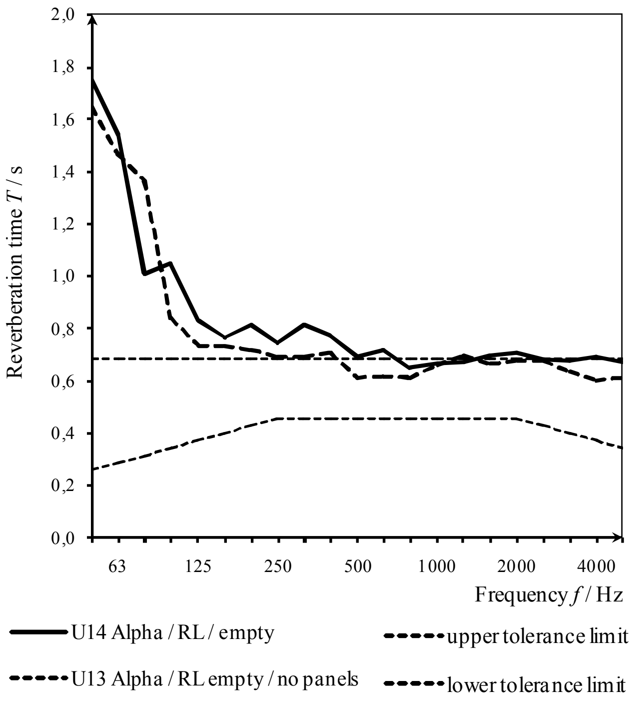
A good correlation between calculation using sound absorption coefficients acc. to DIN 18041 [2] and results of test certificates [6], and measured values was found, see graph 3. Even at low frequencies (f = 125 Hz for calculation) calculated and measured results correspond. Also for different ceiling layouts can be stated a good accordance between measurement and calculation.



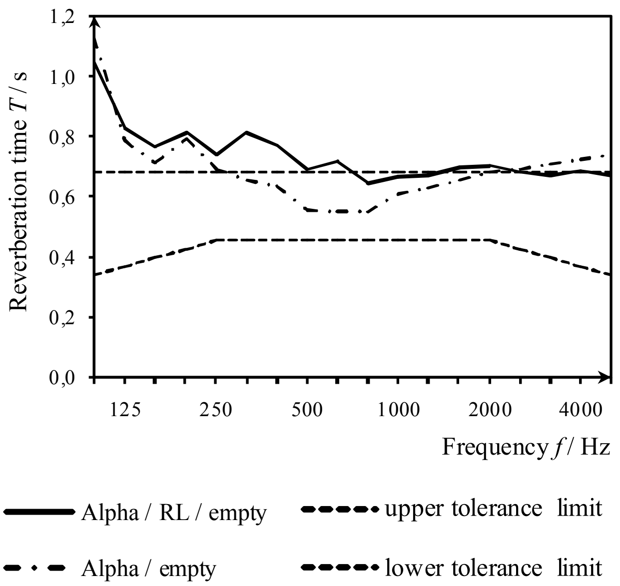
Graph 3:
Comparison – measurement and calculation

An acoustical advantage can be stated at low frequencies for the 5 x 5-tile zone in the ceiling centre (Img. 2), compared to a combination of smaller parts with 3 x 3 and 4 x 4 tiles (Img. 3). It would be of interest how bigger dimensions of e.g. 4 x 4 or 5 x 5 tiles in corners would behave. The comparison of reverberation in both modified rooms (Img. 2 and 3) are illustrated in graph 4.

Concerning the frequency dependence of reverberation time there was found an advantage for the combination of absorbent/reflective tiles, in graph 5 for a constellation as in image 3, if compared to the situation with completely high absorbent ceiling only. This also shows that ceiling systems with single tiles can be helpful for acoustical adjustment.

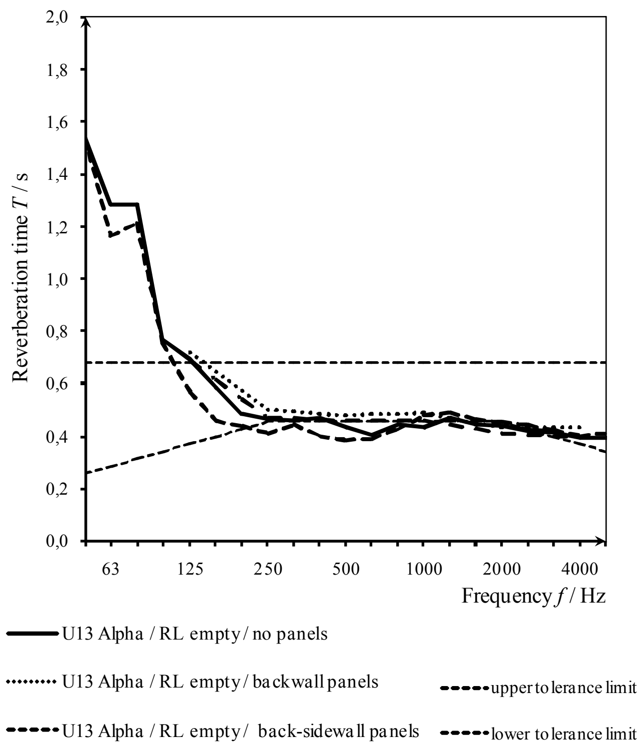


Graph 4:
Comparison – ceiling variation acc. to img.1 and img. 2



Graph 5: Comparison room U14 – Alpha and Alpha / RL

Finally the influence of wall panels was examined. Graph 6 compares 3 different situations, first without, second with back wall panel, third with back- and side wall panels. To achieve an even frequency dependence of reverberation time wall panels are helpful. The effect of an additional side wall panel is rather poor, if there is already a back wall panel. Given an influence on low frequent reverberation by rather thin wall panels (see graph 2) is suspected to be caused by the panel's position along a room's edge.



Graph 6: Comparison – influence of wall panels

Summary

Using calculation and measurements of reverberation time and speech transmission index it could be found that by variation of ceiling tiles of different acoustical behaviour improvements can be achieved, in comparison to an overall high absorbent ceiling. The examined ceiling system with rather small tiles behaves like it is to be expected for theoretical calculations. Additional wall panels are of benefit. The test results for sound absorption, given by test certificates, can be applied for calculation and prognosis.

References

[1] Acoustical measurements at KGH Kreisgymnasium Halle / Westfalia, August 2008

[2] DIN 18041 Acoustic quality in small to medium-sized rooms 12-2004

[3] DIN EN ISO 3382 Acoustics - Measurement of the reverberation time of rooms with reference to other acoustical parameters 03-2000

[4] DIN EN 60268-16 Sound system equipment - Part 16: Objective rating of speech intelligibility by speech transmission index 01-2004

[5] DIN EN ISO 11654 Acoustics - Sound absorbers for use in buildings - Rating of sound absorption 07-1997

[6] Technical data sheets Knauf AMF GmbH & Co. KG Thermatex Alpha, Acoustic RL, 30 mm dB Acoustic