Title:

Good Acoustics in Classrooms

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Abstract

Acoustics/surfaces / The current German standard DIN 18041:2016 has strengthened the focus for the demands of inclusion of persons with impaired hearing ability and for non-native speakers in classrooms by giving an extra calculation formula for the planning. This raises the question of how these reverberation times can be achieved in a meaningful way. In a comprehensive study, measurements were performed with different surface treatments in a model classroom of Knauf. The study was supported by the Fraunhofer IBP in Stuttgart.

Article:

Introduction

The latest edition of the German DIN 18041 "Acoustic quality in rooms", published 2016, gives instructions and requirements of the acoustical design of various rooms, including classrooms. An essential component of the acoustic quality is that a good speech communication in a classroom is possible. The most important criterion in this respect is the **reverberation time,** for which different types of rooms requirements are given.

For the communication of non-native speakers and persons with hearing disabilities, denoted in the standard with the term "inclusive", an extra calculation formula is given for stronger emphasis on the demands of this group. In addition to the required values, the standard includes further instructions for achieving good room acoustics, which should be observed. For an optimized **speech intelligibility,** strong direct sound and many early sound reflections should reach the listener. This is possible when the surfaces near the speaker are reflective and the rear wall of the room is rather absorbing. Additionally, it is important to ensure that no flutter echoes occur.

A general statement of factors to be considered for classrooms is given in annex A2 (DIN 18041) for the verification of the calculated reverberation times. No room dimension should exceed the other dimension by a factor of more than 5, i.e. the rooms should not be planned to be too long or wide or too high. Furthermore, and of more practical relevance, the average sound absorption coefficient of the surfaces in the three room dimensions should not diverge by more than a factor of 3. If both of these requirements are regarded, it is possible to achieve an approximate **diffuse sound field.** Last but not least it should be pointed out that for good intelligibility of speech a low background noise level is needed. This requires for example a high level of sound insulation of exterior walls and building elements.

Requirements

The required reverberation times, especially for the inclusion of non-native speakers and persons with hearing disabilities, are sophisticated to achieve. The question arises how they can be achieved in practice in classrooms. Is it useful, for example, to implement constructions with high sound absorption coefficients and how does this affect the measured reverberation time in the room? On which surfaces of the room would acoustical treatment be useful, and are there other requirements important for the planning? To address these topics, Knauf constructed a model classroom and examined fundamental questions experimentally in the classroom by measuring the reverberation time in the room, equipped with different constructions and furniture. The measurement series was supported and analysed by the Fraunhofer IBP. The objective was to test practical measures and to demonstrate their consequences when considering the requirements of the standard.

Tests

The model classroom was specially constructed by Knauf to conduct these tests. The bare room had a length of 10 m, a width of 6.88 m and a height of 3.10 m. One longitudinal wall was given by the existing exterior wall of the industrial building, made of insulated lightweight metal construction with four windows. The other three walls were consisted of gypsum board stud partitions double-cladded on the inner side. The basic ceiling consisted of a concrete grid ceiling, clad between the ribs with gypsum boards. The room had a concrete slab floor. The bare surface of the unfinished room is shown in Figure 1.

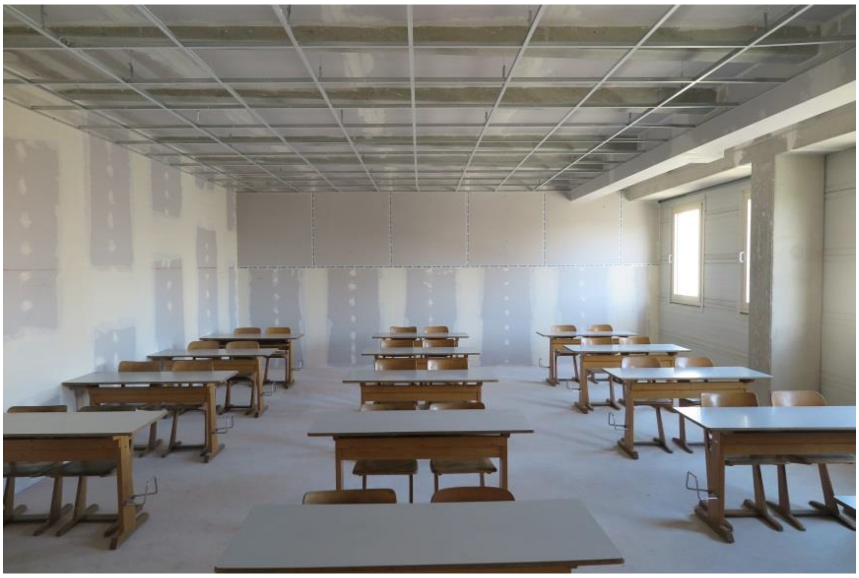

Figure 1: Room in unfinished state with installed ceiling grid and classroom furniture

Applying the requirements of the DIN 18041, the target reverberation time for this classroom in the frequency range from 125 Hz to 4 kHz is T=0.57 s for lessons/communication (room group A3) or T=0.46 s for lessons with inclusion (room group A4). The requirements for the reverberation time relate to an occupied room with an occupancy rate of 80% of the maximum number of persons in the room. The sound absorption by persons is to be included for the computational and technical measurement proofing of the room.

This is one of the **problematic areas of the standard,** as it provides varying degrees of absorption for different persons and scenarios, from which the planner has to choose. The room occupancy rate during use is also variable, so that the actual reverberation time in the room with a low level of occupancy may be significantly longer than intended by the standard. For planning purposes, the standard gives for the reverberation times a tolerance range of ± 20% in the mid-frequency range. For the classroom under examination this leads for room group A3 to a reverberation time between 0.68 s and 0.46 s and for inclusion (room group A4) to values between 0.55 s and 0.37 s. For the planning, it is therefore recommended to disregard the absorption of persons in the room and to target for the specified reverberation time in the standard, so that the tolerance range is reserved for deviations in the design of the room, the measurement tolerance and the rate of occupancy in the room. However, attention should be paid that the reverberation time does not fall below the tolerance range. The speech level would then unnecessarily reduce and the perception of the acoustics in the room might become unnatural if the acoustics develop toward some kind of “studio type acoustics.”

The measurement series incorporated a total of 18 different scenarios, of which the most informative ones are described hereafter. The starting point was the empty room without suspended ceiling, as shown in Figure 1. Subsequently, a closed suspended ceiling with an average suspended height of 250 mm was installed. Two acoustic suspended ceiling variants, a mineral-fibre ceiling with α_w = 1.0 (A absorber), and a perforated gypsum ceiling with α_w = 0.7 (C absorber) were measured. The differences in the reverberation times of the ceiling variants were examined by additionally including standard furniture of classrooms with wooden tables and chairs for 30 students and the use of supplementary wall absorbers.

Measurement results

The first measurement results for the room with closed suspended ceiling are shown in Figure 2.

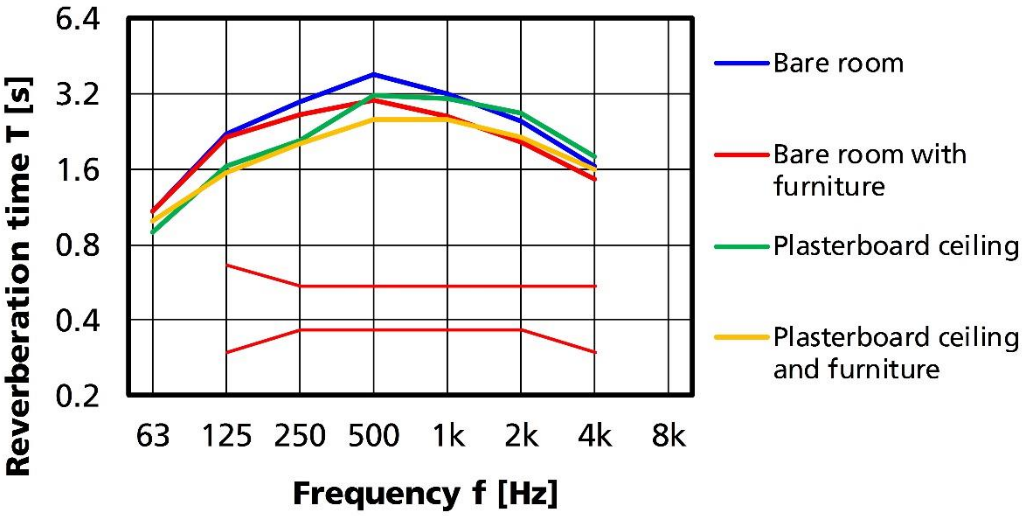

Figure 2: Measured reverberation time in a room with closed gypsum board suspended ceiling. The specified tolerance range is shown as red narrow lines for room group A4 (Lessons/communication inclusive). Note: The reverberation times are displayed on a double-logarithmic scale.

The results show maximum reverberation times at 500 Hz. At lower frequencies the reverberation times are shorter, due to a significantly higher sound absorption of the lightweight construction of the room in this frequency range. In solid room constructions, the reverberation times are generally similar or tend to higher values at low frequencies. The measurement results in figure 2 show that with furniture the reverberation times above 250 Hz are slightly lower, the furnishing itself results in minor additional sound absorption in the room. The frequency-dependent reverberation time in the room delivers values of about 3 s and above, which are much too long for a classroom.

The distribution of the average sound absorption coefficient $\overline{\alpha}$ for the surfaces in the three room dimensions (labelled z for the vertical direction, x for the length and y for the width) were less than the factor of 3 ($\overline{\alpha_z} / \overline{\alpha_x} = 1{,}0;\ \overline{\alpha_z} / \overline{\alpha_y} = 1{,}4$) in this case. Thus, the distribution of absorption is relatively uniform, but in total there is much too less sound absorption in the room. Therefore, the next step was to replace the closed suspended ceiling with an acoustical suspended ceiling. This room is shown in Figure 3.

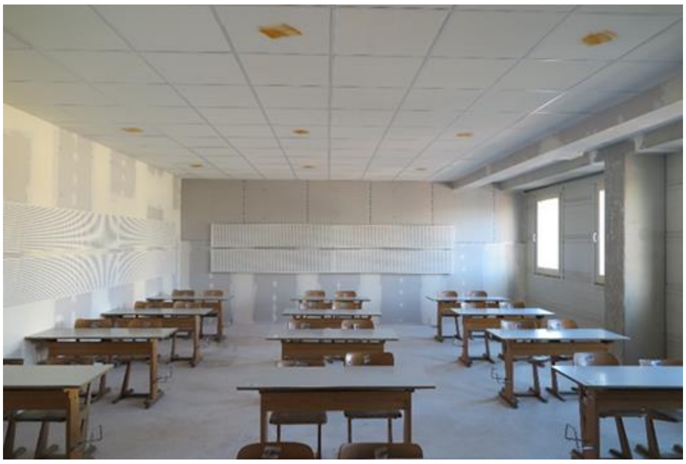

Figure 3: Classroom with acoustical suspended ceiling and classroom furnishing. Additionally shown are sound absorbers on the walls, which are installed in the middle of the wall surface at ear level of seated persons.

The first acoustical suspended ceiling was made of mineral fibre and had a rated sound absorption coefficient α_w = 1.0 (sound absorption class A). The measured reverberation times with different levels of furniture and absorbers are shown in Figure 4.

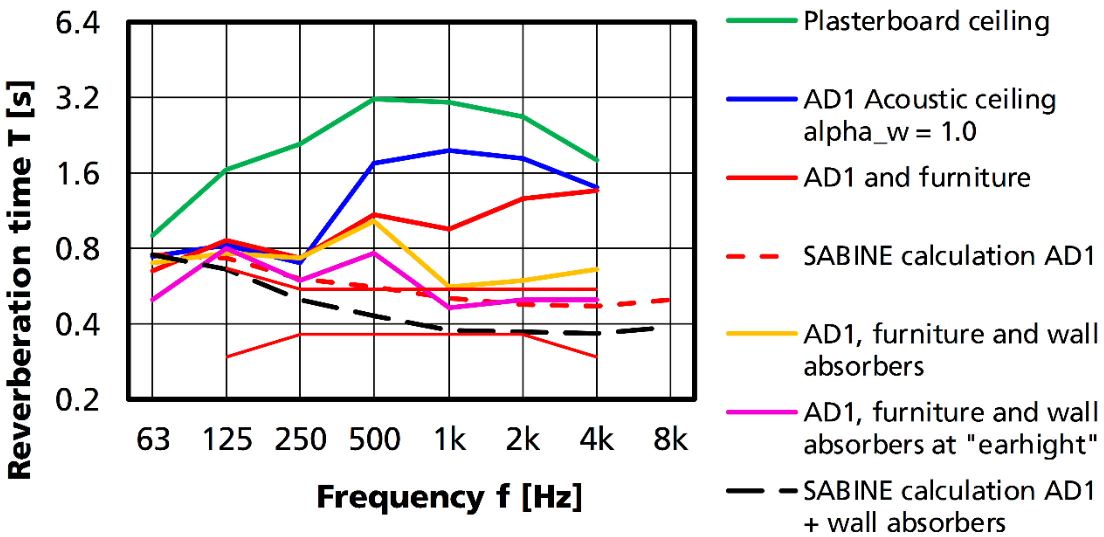

Figure 4: Measured reverberation time in the room with acoustical suspended ceiling AD 1 (mineral fibre, α_w = 1.0) and calculate reverberation times acc. to SABINE for a diffuse sound field. The specified tolerance range is shown as red narrow lines for room group A4 (Lessons/communication inclusive).

The measured reverberation times in Figure 4 have quite similar values for low frequency up to 250 Hz. Above 250 Hz the reverberation times, in particular in the empty rooms without furniture, exceed 1.6 s and are significantly higher than calculated acc. to SABINE, for which the values were close to the tolerance range. Thus, the measured reverberation times are much too high in comparison to the requirement.

The additional furnishing leads to a significant reduction of the reverberation time from 500 Hz to 2 kHz. This is mostly not caused by the additional absorption, which is low, see Figure 2, but primarily due to the scattering effect of the furnishings. The sound is partially scattered by it towards the ceiling, where it is absorbed. For both cases, the factor for the averaged absorption coefficient $\overline{\alpha_z} / \overline{\alpha_x} = 5{,}3;\ \overline{\alpha_z} / \overline{\alpha_y} = 7{,}7$ is significantly greater than factor 3, so that an irregular distribution of the absorption must be assumed.

The required reverberation time is significantly exceeded even with the furnishings in the room and the difference to the calculated reverberation times acc. to SABINE remains high. Measured values that come close to the requirement can only be achieved when additional wall absorbers are applied in the classroom. Reverberation times come close to the requirement range for individual frequencies (wall absorbers on the upper edge of the room) or lie partly in the requirement range (wall absorbers at ear level), if these wall absorbers are installed on the walls in the x- and y-direction of the room. The wall absorbers contribute by their additional absorption and their diffusion effect. With wall absorbers the factors are $\overline{\alpha_z} / \overline{\alpha_x} = 2{,}1;\ \overline{\alpha_z} / \overline{\alpha_y} = 1{,}2$. The increased reverberation time at 500 Hz are probably caused by the interaction of the acoustical ceiling with the sound field in the room, which does not occur for the measurement of the absorption coefficient in a reverberation room, see Figure 5.

Comparing measured values with calculated reverberation times, it becomes clear that additional scattering of furniture and persons can lead to an additional reduction of the reverberation time.

In a further step, the suspended ceiling was replaced by another acoustical suspended ceiling with lower sound absorption capacity, a perforated gypsum board ceiling with 50 mm mineral wool layer topping and α_w = 0.7 (sound absorption class C). The practical sound absorption coefficient of both acoustical suspended ceilings and the wall absorbers are shown in Figure 5.

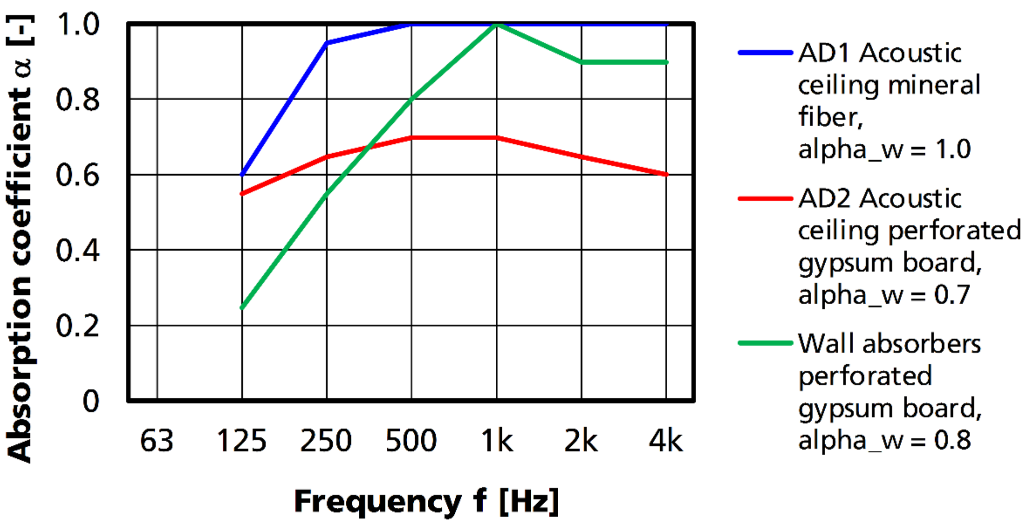

Figure 5: Practical sound absorption coefficients of the acoustical suspended ceilings and the wall absorbers from reverberation room measurements.

In the classroom, the same measurements were made under identical conditions with the acoustical suspended ceiling exchanged. The measured and calculated reverberation times for acoustical ceiling AD 1 and acoustical ceiling AD 2 are shown in Figures 6 and 7.

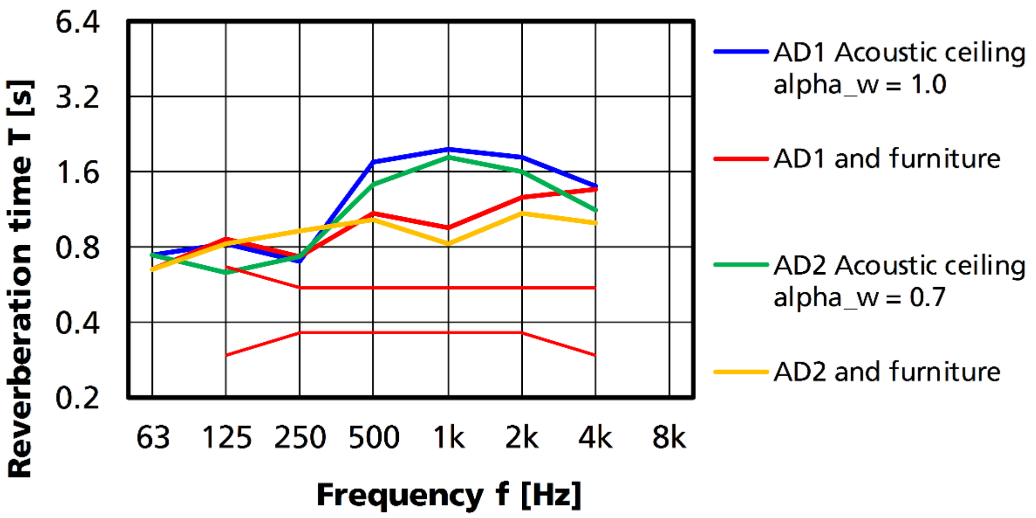

Figure 6: Measured reverberation time in the room with absorbing acoustical suspended ceiling AD 1 (mineral fibre, α_w = 1.0) and acoustical suspended ceiling AD 2 (perforated gypsum board, α_w = 0.7). Measurements without and with furniture. The specified tolerance range is shown as red narrow lines for room group A4 (Lessons/communication inclusive).

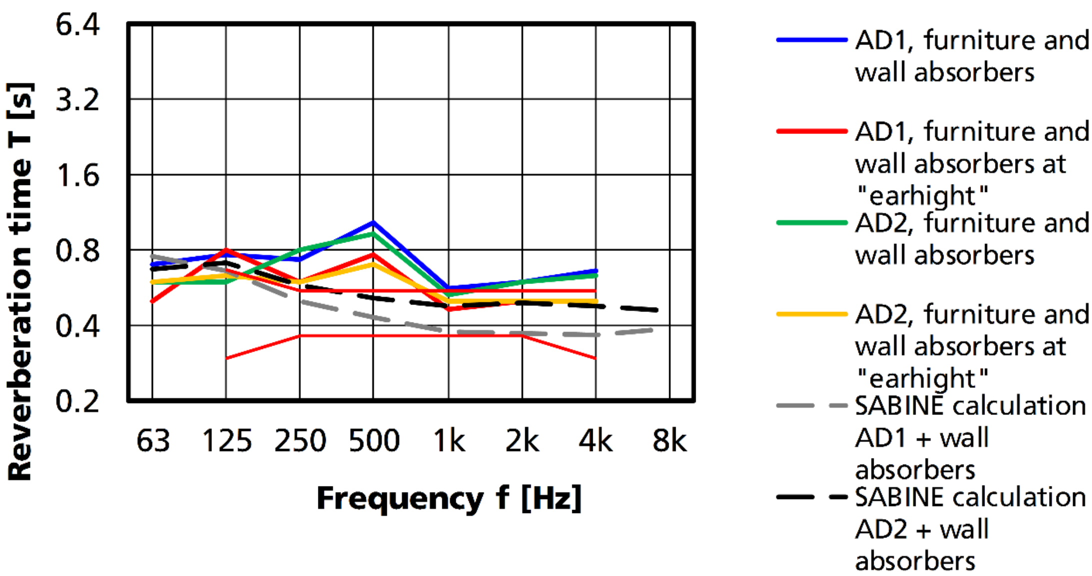

Figure 7: Measured and calculated reverberation time according to SABINE in the room with absorbing acoustical suspended ceiling AD 1 (mineral fibre, α_w = 1.0) and acoustical suspended ceiling AD 2 (perforated gypsum board, α_w = 0.7). Measurement with furniture and wall absorbers. The specified tolerance range is shown as red narrow lines for room group A4 (Lessons/communication inclusive).

The measured reverberation times in Figures 6 and 7 indicate very similar values for both acoustical suspended ceilings. The reverberation times measured for suspended ceiling AD 2 with α_w = 0.7 are even a little shorter than for suspended ceiling AD 1. The requirement values for room group A4 (Lessons/communication inclusive) are only achieved with both suspended ceilings from 1 kHz and above if the wall absorbers are installed at ear level, i.e. attached to the middle of the wall surface. When attached directly under the ceiling, the reverberation times are a little longer; at 500 Hz the values are slightly above 0.8 s. The calculations acc. to SABINE for both acoustical suspended ceilings with wall absorbers show for an assumed ideal diffused sound field reverberation times within the tolerance range for room group A4. The reverberation times in the low frequency range indicate that some absorption or scattering is still needed.

Influence of room occupancy

If an occupancy rate acc. to DIN 18041 of 80%, i.e. 24 persons, is included, the reverberation times in Figure 8 are calculated.

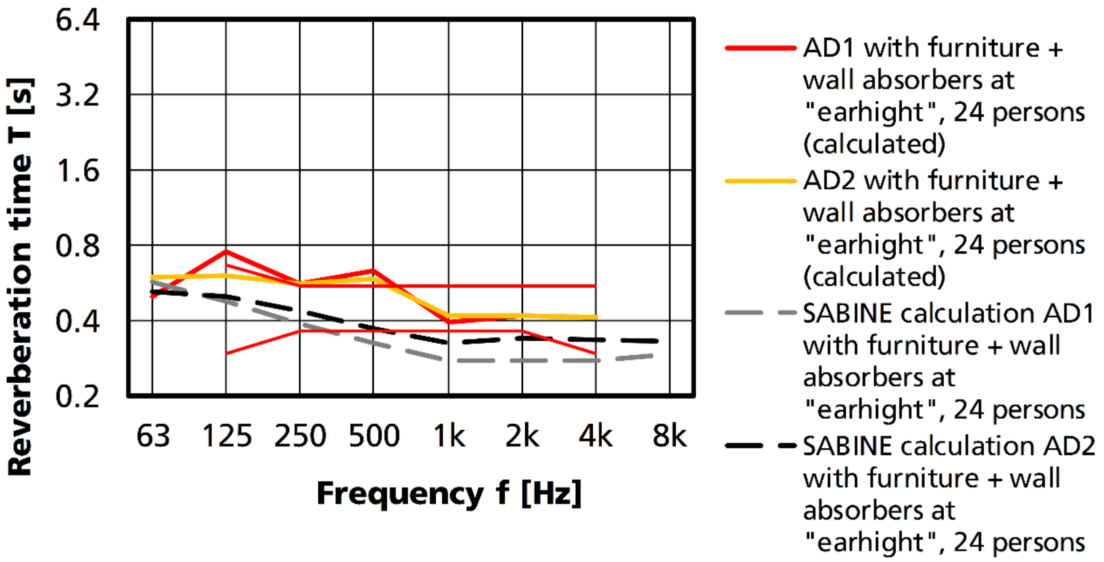

Figure 8: Reverberation time in the room with absorbing acoustical suspended ceiling AD 1 (mineral fibre, α_w = 1.0) and suspended ceiling AD 2 (perforated gypsum board, α_w = 0.7). Measurement with furniture and wall absorbers and inclusion of an occupancy of 80% with 24 persons and calculation according to SABINE. The specified tolerance range is shown as red narrow lines for room group A4 (Lessons/communication inclusive).

The reverberation times with occupancy in Figure 8 show that the upper limit of the tolerance range for A4 has almost been achieved in the low and mid frequency range. At higher frequencies, the reverberation times of 0.4 s are near the lower tolerance range. The calculation acc. to SABINE for a diffused sound field gives values below the tolerance range for both acoustical suspended ceilings, and particularly for acoustical suspended ceiling AD 1 with reverberation times under 0.3 s for the higher frequency range.

Summary

The tests show that an acoustical suspended ceiling is generally very helpful in bringing sufficient sound absorption into the room. If a highly absorbing product is selected, a calculation acc. to SABINE can give the impression that the requirements on the reverberation time have already been achieved. The calculation assumes a diffused sound field in the room, which is not present with this single acoustical treatment. Therefore, significantly longer reverberation times are often measured. Additional sound absorbers should be installed on the walls in both horizontal directions, and if possible, further sound scattering structures should be present, so that in all three room directions the averaged sound absorption differentiates by less than a factor of 3. This specification from DIN 18041 provides a good reference value in the acoustic design of the room.

The measurements show, that the difference in the reverberation times of different acoustical suspended ceilings with α_w = 1.0 and α_w = 0.7 can be minimal to negligible. The reason is that the real sound field in the room is often not sufficiently diffuse, so that the higher absorption potential is not utilized. Therefore, it is even more important to plan a balanced room design with sound absorbing acoustical ceiling and wall absorbers. A very high level of sound absorption on the ceiling should not lead to “excessive damping” of the room when many persons occupy it. Therefore, the acoustical suspended ceiling can be selected from a large range of products available when it is combined with corresponding wall absorbers in the room. An acoustic consultant should be involved during the planning phase, as the potential of the products applied can only be fully utilized with professional planning. This ensures that our children have good acoustics in classrooms, ultimately supporting a successful learning environment.