Influence of the Amount and Distribution of Absorbers on the Room Acoustic Properties of School Sports Halls

Joachim Zander[1], Frank Schnelle[2], Roland Kurz[3]

[1] *Kurz u. Fischer GmbH, 71364 Winnenden, E-Mail: joachim.zander@kurz-fischer.de*

[2] *Kurz u. Fischer GmbH, 06110 Halle, E-Mail: frank.schnelle@kurz-fischer.de*

[3] *Kurz u. Fischer GmbH, 71364 Winnenden, E-Mail: roland.kurz@kurz-fischer.de*

Introduction

In school sports halls high noise levels due to activities with values of $L_{AFeq} \geq 80$ dB(A) and $L_{AF,max} \geq 90$ dB(A) are often measured, in particular for ball sports. According to the general experience in practice, complaints from teachers about the acoustics in school sports halls are mostly related to high noise levels [1].

In consideration of the practical use of a school sports hall primary demands on room acoustics should relate to a sufficient noise reduction and sufficient speech intelligibility for the near and middle distance range.

In contrast, the German standard DIN 18041 [2] gives requirements for the reverberation time (RT) for planning the acoustical design of school sports halls without an audience. It is assumed that appropriate room acoustics conditions for the use as school sports hall are given when those specific requirements for RT are met. In this context RT can be seen as a room acoustics indicator. It is well known from earlier investigations that both, the amount of sound absorption and the way in which absorbers are distributed on the room planes, show influence on RT in sports halls [3].

By means of computer simulations, the influence of these quantities has been examined with respect to the size of box-shaped school sports halls. The effects on RT as a room acoustics indicator and on the primary parameters noise reduction and speech intelligibility have been examined and will be discussed as follows.

Requirements of DIN 18041

In DIN 18041 sports halls are classified into “group A” with requirements for the acoustical quality in middle and farer distances between speaker and listener of ≥ 5 m. For school sports halls without audience this standard gives requirements for RT in the frequency range from f = 250 Hz – 2000 Hz, depending on the volume and the type of use (“Sport 1” - one class or sports group at the time with similar communication content and “Sport 2” - several classes or sports groups at the same time with different communication content).

General Acoustical Properties

Typically school sports halls are box-shaped rooms with opposed parallel walls in pairs and with low diffusivity. Because of the required protection from impacts diffuse reflecting surface structures can’t be fixed at the low parts of the walls. The floor is a flat reflecting surface.

Usually the room width and length is much bigger than the height. Thus from an acoustical point of view school sports halls constitute flat spaces.

Multiple-field sports halls where the room volume can be subdivided into several room sections using partition curtains can also be used as several single-field sports halls.

Method

Investigations on the influence of the room’s acoustical configuration (amount and distribution of sound absorbers in the room) were carried out as a parameter study with computer simulation calculations (CATT-Acoustics v9.0c) for typical school sports halls without audience.

To study the influence of the sports hall’s size a typical large size (V1) and a typical small size (V2) have been considered:

V1: triple-field sports hall with geometric dimensions of 45,0 m x 27,0 m x 7,15 m (V = 8.687 m³, 4V/S = 10,0 m)

V2: single-field sports hall with geometric dimensions of 27,0 m x 15,0 m x 5,65 m (V = 2.288 m³, 4V/S = 7,1 m).

In DIN 18032-1 [4] the minimal geometric dimensions of sports halls are defined. For these dimensions to meet requirements for RT according to DIN 18041 from calculation of the Sabine’s formula an equal value for the mean absorption coefficient of the total room surface ($\alpha_{m,B}$) is given of $\alpha_{m,B}$ = 0,16 for „Sport 1“ and $\alpha_{m,B}$ = 0,20 for „Sport 2” in each case for triple-, double- and single-field sports halls. In addition to these values for $\alpha_{m,B}$, that describe the amount of sound absorption in a sports hall, a reverberant case (without absorbers) with $\alpha_{m,B}$ = 0,07, a case according to ÖN B 8115-3 [5] with $\alpha_{m,B}$ = 0,25 and a high absorption case with $\alpha_{m,B}$ = 0,30 have been investigated.

To investigate the influence of the distribution of the total equivalent sound absorption area (A) on the 3 room planes for the different values of $\alpha_{m,B}$, two extreme cases have been examined.

Case A: Maximal non-uniform distribution with reflecting floor (α = 0,07) and reflecting walls (α = 0,07) and concentration of the sound absorption for $\alpha_{m,B}$ on the ceiling. This case represents the usual room acoustics design of sports halls where sound absorbers are mounted only on the ceiling.

Case B: Maximal uniform distribution with reflecting floor (α = 0,07) and distribution of the absorbers on the ceiling, sidewalls and end walls to fulfil the condition A(x) = A(y) = A(z) for the 3 room axes x, y and z.

The scattering factor for all surfaces in the simulations was set to 10 %.

The 18 simulated cases and attributed short terms and symbols are listed in Table 1.

$\alpha_{m,B}$	V1		V2	
	case A	case B	case A	case B
0,07	● V1_0 *)		● V2_0 *)	
0,16	◆ V1_A1	▲ V1_B1	◆ V2_A1	▲ V2_B1
0,20	◆ V1_A2	▲△V1_B2	◆ V2_A2	▲△V2_B2
0,25	◆ V1_A3	▲ V1_B3	◆ V2_A3	▲ V2_B3
0,30	◆ V1_A4	▲ V1_B4	◆ V2_A4	▲ V2_B4

*) reverberant case with α = 0,07 for every room plane (for comparison purposes, neither case A nor case B)

Table 1: Simulated cases and attributed short terms

Following the practice for flat spaces, which does not comply with the conditions for a diffuse sound field (such as workrooms or open-plan offices), the calculations for the considered room acoustics parameters were done for measurement paths along the 2 crossing space diagonals parallel to the floor [6]. The height of the source and receiver positions was h = 1,50 m. Figure 1 shows the geometrical model for the computer simulations.

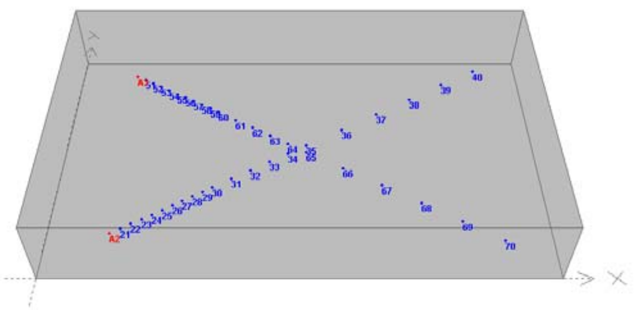

Figure 1: Geometrical model of the triple-field sports hall with source (A2, A3) and receiver positions (r = 1, 2, … 10, 12, 14, …32, 36, 40 m)

With regard to the primary objective of noise reduction, the sound pressure level (SPL) decrease per distance-doubling (DL_2) was calculated according to VDI 3760. For the speech intelligibility the "Deutlichkeitsgrad" (D_{50}) was considered. In both cases the middle distance range of r = 5 – 16 m has been considered. The receivers were located with distances of r = 5, 6, 7, 8, 9, 10, 12, 14 and 16 m to the sound source.

Results

The following results are for the 1 kHz octave band.

Reverberation Time RT

Figure 2 shows results for the reverberation time T_{30} for different $\alpha_{m,B}$ and the required RT according to DIN 18041 „Sport 2" and "Sport 1" for the regarded sports halls.

Consistently higher values of T_{30} result for case A with sound absorbers only mounted on the ceiling. Depending on the distribution of the sound absorbers the values of T_{30} can differ by a factor of 2-4 for identical values of $\alpha_{m,B}$. The larger the sports hall and the more absorption the bigger is the variation.

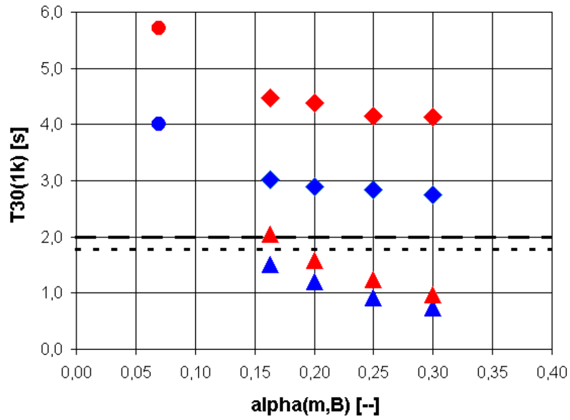

Figure 2: T_{30} for different $\alpha_{m,B}$ and distribution of absorbers for:
triple-field sports hall: ● V1_0, ◆ V1_A1-4, ▲ V1_B1-4,
single-field sports hall: ● V2_0, ◆ V2_A1-4, ▲ V2_B1-4,
required RT 'Sport 2'for triple-field sports hall (▬ ▬),
required RT 'Sport 1'for single-field sports hall (······)

It is well-known that there won't be a diffuse sound field in rooms with one-sided placement of absorbers on the ceiling (case A). In such rooms RT is mainly determined by the wall reflections and calculation of RT based on statistical theories as from Sabine generally leads to an underestimation of RT.

Here it is remarkable that even for values of $\alpha_{m,B}$ = 0,30 the requirements for RT according to DIN 18041 can not be achieved when the sound absorption measures are restricted to the ceiling. Additional sound absorption measures on the walls are clearly required to meet requirements for RT.

Sound Decay Curves and DL_2

Figure 3 shows results for the sound decay depending on the sports hall's size and on $\alpha_{m,B}$. For the triple- and single-field sports halls the results for $\alpha_{m,B}$ = 0,07 and for $\alpha_{m,B}$ = 0,20 with uniform distribution are shown exemplarily. In addition the theoretical SPL decay for a point source radiating into a semi free-field is shown.

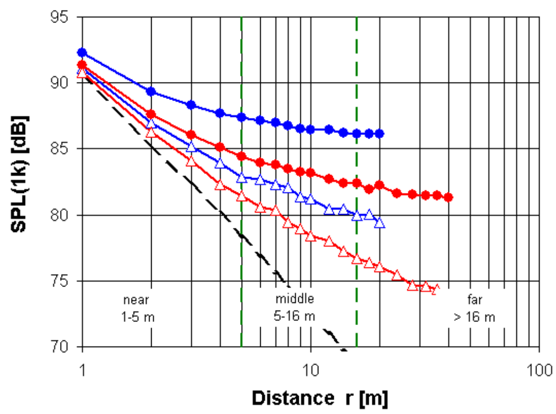

Figure 3: Sound decay curves along the paths in Figure 1 with uniform distribution of absorbers for $\alpha_{m,B}$ = 0,07 and $\alpha_{m,B}$ = 0,20
single-field sports hall: ●V2_0 (0,07), △ V2_B2 (0,20),
triple-field sports hall: ●V1_0 (0,07), △ V1_B2 (0,20),
semi free-field (▬ ▬)

As expected, the values of SPL decrease with rising $\alpha_{m,B}$. Furthermore a strong influence of the hall's size is observed.

For equal values of $\alpha_{m,B}$ the damping is much higher for the triple-field than for the single-field sports hall. The main reason for this is the bigger distance of the receiver positions to the room surfaces in the larger sports hall.

For all cases the values for DL_2 for the middle distance range were calculated from the sound decay curves. Figure 4 shows results as a function of T_{30}. In addition the requirements on RT according to DIN 18041 are shown.

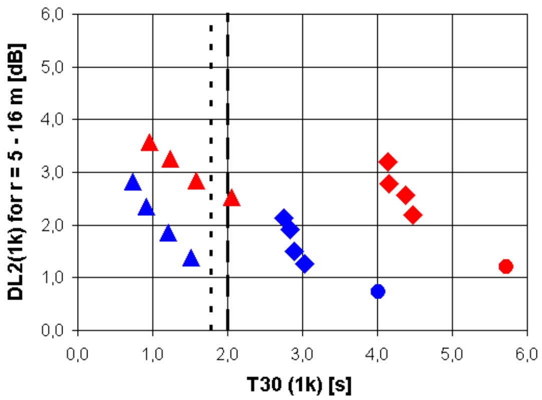

Figure 4: DL_2 as a function of T30 and distribution of absorbers for:
triple-field sports hall: ● V1_0, ◆ V1_A1-4, ▲ V1_B1-4,
single-field sports hall: ● V2_0, ◆ V2_A1-4, ▲ V2_B1-4,
required RT 'Sport 2' for triple-field sports hall (– –),
required RT 'Sport 1' for single-field sports hall (······)

The graph shows that equal values of DL_2 can occur for entirely different values of T_{30}. The reverberation time is not a suitable parameter to indicate the sound damping of a sports hall.

However Figure 5 shows that DL_2 correlates distinctly with $\alpha_{m,B}$. Thus $\alpha_{m,B}$ is an appropriate parameter to describe the sound damping of sports halls.

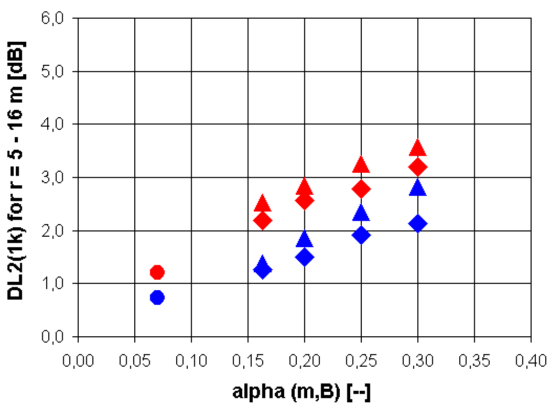

Figure 5: DL_2 as a function of $\alpha_{m,B}$ and distribution of absorbers for:
triple-field sports hall: ● V1_0, ◆ V1_A1-4, ▲ V1_B1-4,
single-field sports hall: ● V2_0, ◆ V2_A1-4, ▲ V2_B1-4

Furthermore, Figure 5 shows the influence of the distribution of absorbers on the room planes. For $\alpha_{m,B} = 0{,}15 - 0{,}25$ and uniform distribution an almost equal DL_2 is obtained as by increasing $\alpha_{m,B}$ by $\Delta\alpha_{m,B} \approx 0{,}05$ for the case of non-uniform distribution.

For cases with $\alpha_{m,B}$ in accordance to the requirements for RT in DIN 18041 for the triple-field sports halls ($\alpha_{m,B} = 0{,}20$) results $DL_2 \approx 2{,}5$ dB and for the single-field sports hall ($\alpha_{m,B} = 0{,}16$) results $DL_2 \approx 1{,}4$ dB.

Deutlichkeitsgrad D_{50}

D50 was calculated as arithmetic average for the middle distance range (r = 5 -16 m). In Figure 6 D_{50} is shown as a function of T_{30}. In addition the requirements on RT according to DIN 18041 and the criteria for D_{50} for "good" and "very good" speech intelligibility are shown.

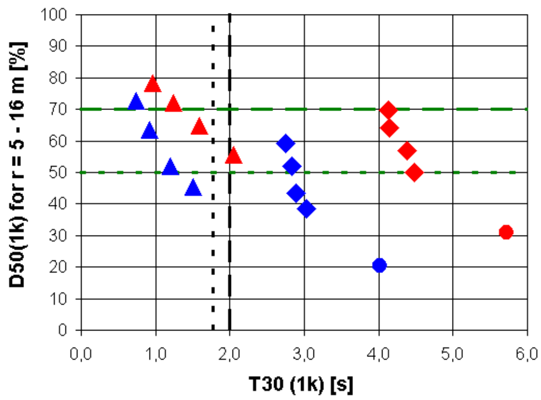

Figure 6: D_{50} as a function of T_{30} and distribution of absorbers for:
triple-field sports hall: ● V1_0, ◆ V1_A1-4, ▲ V1_B1-4,
single-field sports hall: ● V2_0, ◆ V2_A1-4, ▲ V2_B1-4,
required RT 'Sport 2' for triple-field sports hall (– –),
required RT 'Sport 1' for single-field sports hall (······),
very good speech intelligibility $D_{50} \geq 70$ % (– –),
good speech intelligibility $D_{50} \geq 50$ % (······)

For the large triple-field sports hall a value $D_{50} \geq 50\%$ for good speech intelligibility is obtained for any case when the requirement on RT according to DIN 18041 is met. On the other hand, a value of $D_{50} \geq 50$ % can be obtained even with reverberation times higher than the standard requirements on RT according to DIN 18041. Furthermore it can be seen that for the single-field sports hall a value $D_{50} \geq 50\%$ cannot be achieved securely by meeting the standard requirements on RT according to DIN 18041.

As in Figure 4, Figure 6 shows that the reverberation time is not a suitable parameter to evaluate the speech intelligibility in a sports hall.

Figure 7 shows that D_{50} correlates distinctly with $\alpha_{m,B}$. Therefore $\alpha_{m,B}$ can also be used as parameter for the speech intelligibility in sports halls.

The influence of the distribution of absorbers on the room planes for D_{50} is similar as for DL_2 (see Figure 5). For $\alpha_{m,B} = 0{,}15 - 0{,}25$ and uniform distribution of absorbers a similar D_{50} can be obtained as by increasing $\alpha_{m,B}$ by $\Delta\alpha_{m,B} \approx 0{,}05$ for the case of non-uniform distribution.

Furthermore, it can be seen that for the single-field sports hall a value of $\alpha_{m,B} \geq 0{,}25$ is required for securely reaching a value of $D_{50} \geq 50$ % for good speech intelligibility, independent from the kind of distribution for the absorbers on the room planes. It is remarkable that $\alpha_{m,B} \geq 0{,}25$ is the requirement in ÖN B 8115-3 for sports halls.

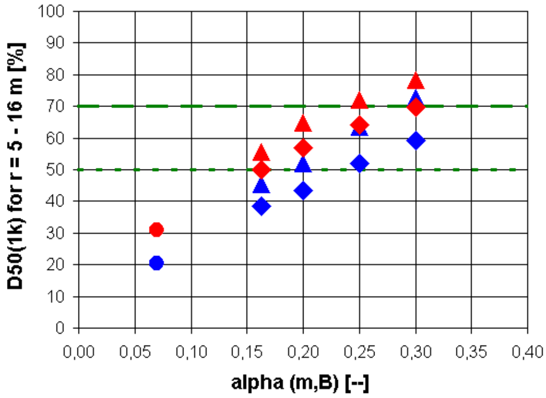

Figure 7: D_{50} as a function of $\alpha_{m,B}$ and distribution of absorbers
triple-field sports hall: ● V1_0, ◆ V1_A1-4, ▲ V1_B1-4,
single-field sports hall: ● V2_0, ◆ V2_A1-4, ▲ V2_B1-4,
very good speech intelligibility D50 ≥ 70 % ( ),
good speech intelligibility D50 ≥ 50 % ( )

Summary and Conclusions

The reverberation time in sports halls is highly dependent on the distribution of sound absorbers on the room planes.

A sufficiently high equivalent sound absorption area A does not guarantee that requirements for RT according to DIN 18041 for sports halls are met. Concentration of absorbers only on the ceiling is not adequate, effective broadband absorbers are also clearly required at the walls (see also [7]).

The investigations show that DL_2 (as a parameter for the sound damping behaviour) and D_{50} (as a parameter for the speech intelligibility) correlate with $\alpha_{m,B}$, but do not correlate with RT in school sports halls without audience. Again, RT is not an appropriate parameter for the evaluation of the primary room acoustical targets of noise reduction and speech intelligibility for sports halls. This is because RT is highly determined by the late reflections in a room (e. g. the evaluation time range for T_{30} in a sports hall with RT = 2,0 s would be 1.000 ms). In contrast, SPL and D_{50} are dominated by the early high-energetic room reflections (direct sound and first early reflections for SPL, time reference value 50 ms for D_{50}).

The noise reduction and speech intelligibility in sports halls improve with increasing values of $\alpha_{m,B}$.

From identical values of $\alpha_{m,B}$ for single-field sports halls result lower values for DL_2 and D_{50} as in triple-field sports halls due to the bigger influence of wall reflections. According to the results of the parameter study it seems to be advisable, especially for smaller school sports halls, to realize an acoustical standard with $\alpha_{m,B} \geq 0,25$ as in ÖN B 8115-3.

In addition to $\alpha_{m,B}$, the noise reduction and speech intelligibility in sports halls depend on the kind of distribution of the absorbers on the room planes. Therefore both $\alpha_{m,B}$ and the distribution of the absorbers have to be considered for the room acoustical design of a sports hall. A distribution of the absorbers on the 3 room planes is most suitable.

Complaints about acoustics in school sports halls are mostly related to high noise levels. For the evaluation of the sound damping behaviour and assessment of potentially required improvements, measurements of the sound decay in the sports hall are required. This is similar to the usual measurement analysis method in flat spaces such as workrooms or open-plan offices. DL_2 for the middle distance range (or similar parameters) can be determined from measurements in a simple manner.

When carrying out acoustical measurements with pulse-type excitation or by hand-clapping in empty school sports halls late reflections and flutter echoes can often be heard. This occurs mainly in box-shaped sports halls where sound absorbers are mounted only at the ceiling. Also this behaviour can occur in a middle part of a triple-field sports hall with reflective partition curtains on both sides. In the results of our simulations, the influence of late echoes on D50 (as a parameter for the speech intelligibility) is included. Further critical effects of late echoes in sports halls (e. g. psychoacoustic effects) have not been reported yet (see also [8]). For an evaluation of a special further acoustical disturbance due to late echoes additional studies for typical pulse-type excitation signals in school sports halls would be necessary.

References

[1] M. Luykx, M. Vercammen: Evaluation and measuring procedure for strength in sport halls, Euronoise Prague 2012

[2] DIN 18041: 2004-05 Hörsamkeit in kleinen bis mittelgroßen Räumen, Beuth-Verlag Berlin

[3] L. Nijs, M. Rychtáriková: Auralization examples to discuss the reverberation time as a standard for sports facilities, NAG/DAGA Rotterdam 2009

[4] DIN 18032-1: 2003-09 Sporthallen; Hallen und Räume für Sport- und Mehrzwecknutzung; Teil 1: Grundsätze für die Planung, Beuth-Verlag Berlin

[5] ÖNORM B 8115-3:2005-11 Schallschutz und Raumakustik im Hochbau - Teil 3: Raumakustik, Austrian Standards Institute Wien

[6] VDI-Richtlinie 3760: 1996-02 Berechnung und Messung der Schallausbreitung in Arbeitsräumen, Beuth-Verlag Berlin

[7] F. Schnelle, J. Zander, R. Kurz: Raumakustik in Sporthallen – Einfluss der Diffusität und der Schallabsorption von Wandbekleidungen auf Nachhallzeiten, NAG/DAGA Rotterdam 2009

[8] V. Chmelik, M. Rychtáriková et. al.: Reduction of noise levels in sport halls by geometrical optimization, Euronoise Prague 2012