Berufliche Schulen Witzenhausen

Acoustic measurements – final report

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Contents

Appendices

1 Introduction

Open plan schools require special acoustic conditions to obtain sufficient sound attenuation between groups and satisfactory speech intelligibility internally in groups. The ‘Berufliche Schulen Witzenhausen’ in Germany is an example of a semi-open school which is thoughtfully designed to obtain a good teaching and learning environment.

Despite the open plan layout, the users of the school (teachers and students) are very satisfied with their learning environment including the acoustics during their teaching and learning activities. For this reason it’s a very interesting school to study and understand more about the specific acoustic conditions. Therefore LBP|SIGHT performed several acoustic measurements in the school to get more knowledge of the acoustic performance.

The results of the measurements, findings and conclusions are presented in this report. The results are also compared with acoustic regulations for open plan schools.

2 Description

2.1 Situation

The two storey Upper Secondary of the ‘Berufliche Schulen Witzenhausen’ in Germany was completely renovated in 2011. In the new situation the school can be described as a semi-open plan school. There are still partition walls between the classrooms and glazed walls between classrooms and circulation, corridor and break-out spaces, however there are no doors between these different spaces. As a result of this all classrooms have offset openings between the partition walls and maintain an open physical connection with each other.

Both floors of the building are arranged with a central circulation area dissecting six classrooms with additional open multi-purpose learning areas and a staff room present on each floor. The size per floor is around 755 m^2, so 1.510 m^2 (ex. staircases) in total. With a occupancy of 360 students this results in 4,2 m^2 per student. The classrooms are 69-81 m^2 with 28-32 students per room.

Despite the open plan lay-out, due to the thoughtful design the users of the school (teachers and students) are very satisfied with their learning environment including the acoustics during their teaching and learning activities. The open connection and transparency allow some flexibility and connectivity between the variety of activities and an increased awareness and respect in their behaviour has been observed.

In appendix I the plans of the school are given. In appendix II some pictures of the school are presented to get a better idea of the situation.

2.2 Acoustic treatment

Open plan schools require additional acoustic design criteria as they are significantly more complex acoustic spaces than schools with enclosed classrooms. Intrusive noise arising from activities in adjacent class rooms and circulation spaces can increase the ambient indoor noise levels. If not properly controlled this decreases speech intelligibility and causes potential disturbance, annoyance and distraction form the teaching and learning tasks.

In Witzenhausen all classrooms, circulation, corridor and break-out spaces are fully covered with “Class A”(in accordance with ISO 11654) sound absorbing ceilings with around 25% ratio of “Class A” wall absorber / floor area. In addition, to compensate for the absence of doors, the offset and overlapping glass partitions, cupboards and walls were integrated in the design. These full height partitions overlap, creating barriers and sound traps to reduce the spread of sound whilst maintaining a good level of visual transparency. In addition, to counter the potential unwanted sound reflections from the glass partitions, wall absorbers and furniture bookcases were set directly opposite the glass to limit sound build up and spreading between spaces.

Figures 2.1 and 2.2 give an overview of the acoustic treatments.

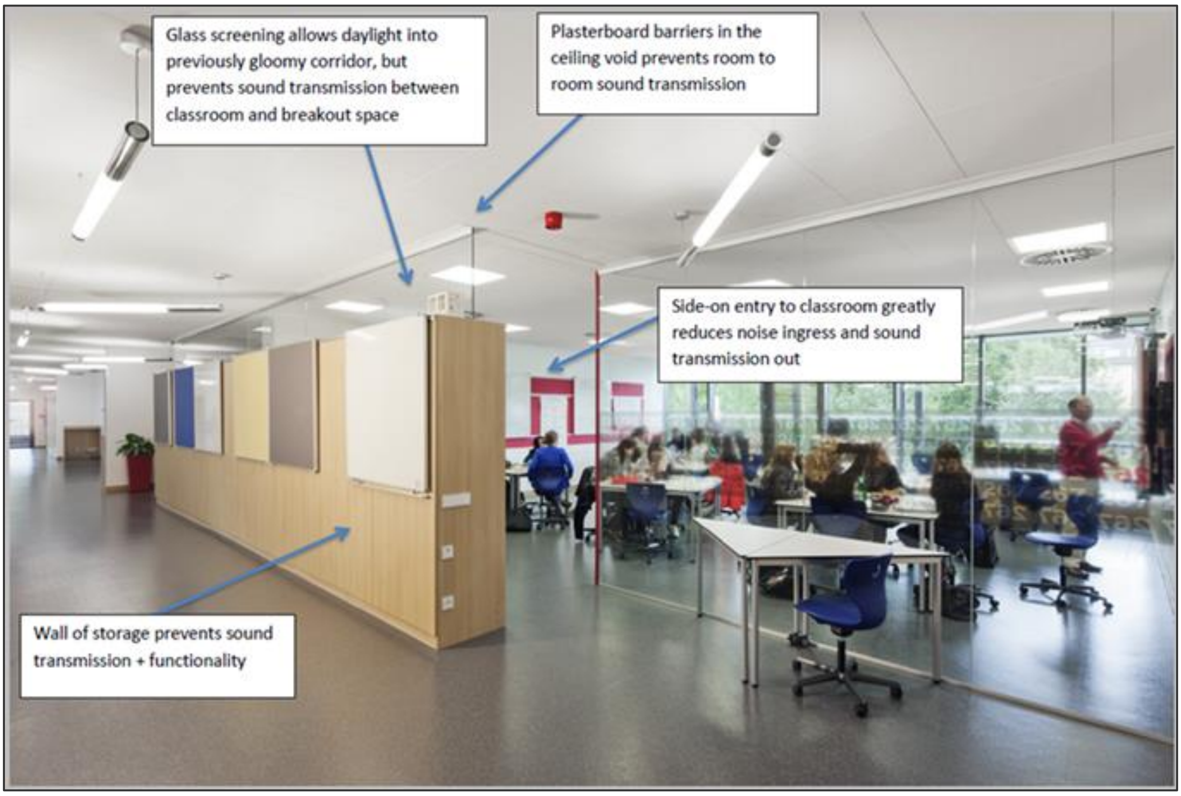

Figure 2.1
Overview of acoustic treatments

Figure 2.2
Overview of acoustic treatments

2.3 Objectives

To understand more about the specific acoustic conditions room acoustic measurements were made on January 17th, 2017. The purpose of these measurements is to get a better understanding of the acoustics of the school in terms of reverberation, sound attenuation, acoustic privacy and speech intelligibility. The results can be useful for further development or design of new schools.

Furthermore the results are compared with standards for traditional schools with enclosed classrooms (in terms of sound reverberation and sound insulation) and requirements for open plan schools.

2.4 References

The following reference documents are used by the measurements:

[1] ISO 3382-3:2012 ‘Acoustics – Measurement of room acoustic parameters – Part 3: Open plan offices.
[2] ISO 3382-2:2008 ‘Acoustics – Measurement of room acoustic parameters – Part 2: reverberation time in ordinary rooms.
[3] IEC 60268-16 Sound system equipment – Part 16: Objective rating of speech intelligibility by speech transmission index.
[4] Design drawings of the school form Pan B Architekturburo dated 26.01.10.
[5] ‘Programma van eisen frisse scholen 2015’, Netherlands Enterprise Agency.
[6] ‘Building Bulletin 93 ‘Acoustic design of schools: performance standard’ from the Department for Education dated February 2015.
[7] ‘Acoustics of Schools: a design guide’ by IOA/ANC dated November 2015.
[8] ‘Building Regulations 2010’, Danish Enterprise and Construction Agency, Danish Ministry of Economic and Business Affairs.
[9] ISO 3382-1:2009 ‘Acoustics – Measurement of room acoustic parameters – Part 1:Performance spaces.

3 Measurement procedure and parameters

3.1 Measurement procedure

The measurements were made according to ISO 3382-2&3 standards [1] [2], in furnished but unoccupied rooms. As both floors of the school are identically designed, all measurements were made on the first floor. The measurements were carried out using source and microphone positions on several positions. See also the figures in chapter 4.

An overview of the used measurement equipment is given in appendix III.

3.1.1 Impulse responses

To measure the impulse responses an omnidirectional sound source producing sweeps was used. The sound power source is verified before the measurements, with the sound source positioned at the height of 1,5 m. The measured sound level at 1 m from the source ($L_{p,A,Ls,1m}$) was 91,2 dB(A) for position S1 (room 167) and 91,6 dB(A) for position S2 (room 162).

The resulting sound pressure levels in each octave band at each microphone position were measured using an omnidirectional microphone at a height of 1,2 m above the floor.

The software used to measure the impulse responses is Dirac V6.0. The relevant acoustic parameters were derived from the measured impulse responses, also using Dirac V6.0. These parameters are reverberation time (RT), sound decay (D), speech transmission index (STI) and speech Clarity (C_{50}).

3.1.2 Sound power source

The sound attenuation between several positions is also measured using a reference sound source (type Norsonic Nor278).

The sound source was positioned in classroom 163 (position S3) to measure the sound decay in the room itself, the adjacent circulation area and the opposite classroom 164. The averaged sound pressure level ($L_{p,A,Ls,1m}$) at 1 m from the source at position S3 was 82,3 dB(A).

The measurements were also done with the source placed on a second position in classroom 163 (position S4) and measuring the resulting sound pressure levels in the adjacent circulation area and opposite classroom 164. The averaged sound pressure level ($L_{p,A,Ls,1m}$) at 1 m from the source at position S4 was 82,7 dB(A).

As a result of these measurements the sound propagation in the classroom (nearfield), circulation area (transition area) and opposite classroom (farfield) is derived.

3.2 Parameters

3.2.1 Reverberation Time (RT)

The reverberation time is a measure for the reverberation in a room. In fact it is the time in which a constant sound source in a room has a decay of 60 dB after the source is switched off. The longer this time, the more reverberant the room. The reverberation time is dependend of the volume of a room and the amount of sound absorption.

The results of the measurements can be compared with commonly used standards for the reverberation time in schools in the Netherlands [5], Great-Britain [6] and Denmark [8].

3.2.2 Absorption Area (A)

The absorption area is the amount of sound absorption in a room. The effective absorption area is calculated from the measured reverberation time RT according to formula A.6 in [9].

The results are compared with the Danish requirements [8]. The required absorption area according to [8] is $A \geq 1,3$*Floor area.

3.2.3 Sound levels (attenuation, reduction and propagation)

The decay of sound pressure levels is measured between different source-receiver configurations as shown in the figures in chapter 4. The spatial decay of sound pressure level gives an indication of the decrease of speech/noise from one position to other positions on increasing distance and indirectly around physical barriers.

The results of the measurements can be compared with commonly used standards for the sound insulation in traditional schools in the Netherlands [5], Great-Britain [6] and Denmark [8].

According to [5] the sound insulation $D_{nT;A}$ between groups/classrooms should be at least 39 dB and 27 dB between groups/classrooms and circulation areas. It is recommended to achieve higher values for the sound insulation. Between groups $D_{nT;A} \geq 43$ dB and between groups/classrooms and circulation areas $D_{nT;A} \geq 31$ dB is preferable.

According to [6] the sound insulation between rooms should be $D_{nT,w}$ = 45 – 50 dB. Between rooms and circulation areas the sound insulation R_w of the doorset should be 30 – 35 dB.

In Danish acoustic regulations [8] a sound reduction index $R'_w \geq 20$ dB (for flexible separating elements) is required. The recommended effective reduction of sound level (normal speech, A-weighted) between groups should be 15 – 20 dB.

3.2.4 Speech transmission STI

The speech transmission index (STI) is a measure of speech transmission quality. The STI measures some physical characteristics of a transmission channel, such as a room, electro-acoustic equipment, telephone line etc.). As we are interested in the acoustic conditions of the school, the room is the transmission channel.

In ISO 3382-3 the STI is used to describe acoustic distraction and privacy. The STI is therefore calculated according to the method in accordance with IE 60268-16 for each source-receiver combination. The STI is determined from the measured impulse responses and adjusted for the influence of the background noise.

Table 3.1 gives the qualification of STI according to IEC 60286-16.

Table 3.1
Qualification of STI

STI-value	Qualification	Description
0,75 – 1,00	Excellent	High speech intelligibility, even for complex messages and unfamiliar words
0,60 – 0,75	Good	Good speech intelligibility, even for complex messages with familiar context
0,45 – 0,60	Fair	Good speech intelligibility for simple messages in familiar context
0,30 – 0,45	Poor	Poor speech intelligibility. useful for simple messages and familiar words.
0,00 – 0,30	Bad	No speech intelligibility, even for experienced listeners and simple messages

According to ISO 3382-3 the distraction distance (r_d) is the distance to the source from where the STI is below 0,50. It can be described as the position at which speech can be heard, but is not distracting. The privacy distance (r_p) is the distance to the source from where the STI is below 0,2. From that point speech or conversations can't be heard and there's acoustic privacy.

The British design guide [7] also uses STI as measure to describe the acoustic performance in open-plan schools. In chapter 7 of [7] performance standards for STI in open plan spaces are mentioned. Within a group or classroom for instructions or critical listening activities the STI should be 0,6 or better. Between groups the STI should be less than 0,3.

In Danish acoustic regulations for open plan schools [8] a STI ≥ 0,6 inside working groups is recommended. Between working groups the STI should be less than 0,2.

3.2.5 Clarity (C_{50})

The Clarity is a measure for the perceived clarity of sound. It is an early-to-late arriving sound energy ratio between the early incoming sound at a position (the first 50 ms) and the late incoming sound (≥ 50 ms).

4 Results

4.1 Reverberation time (RT)

The reverberation time (RT) is measured in two rooms, classroom 167 and break out space 162. The results of these measurements are summarized in table 4.1 and shown in figure 4.1.

Table 4.1
Measured reverberation time

Room	Reverberation Time (T30) [s]						
	125 Hz	250 Hz	500 Hz	1.000 Hz	2.000 Hz	4.000 Hz	average[1]
Classroom 167	0,52	0,54	0,46	0,44	0,49	0,51	0,48
Open space 162	0,61	0,58	0,48	0,44	0,50	0,48	0,50

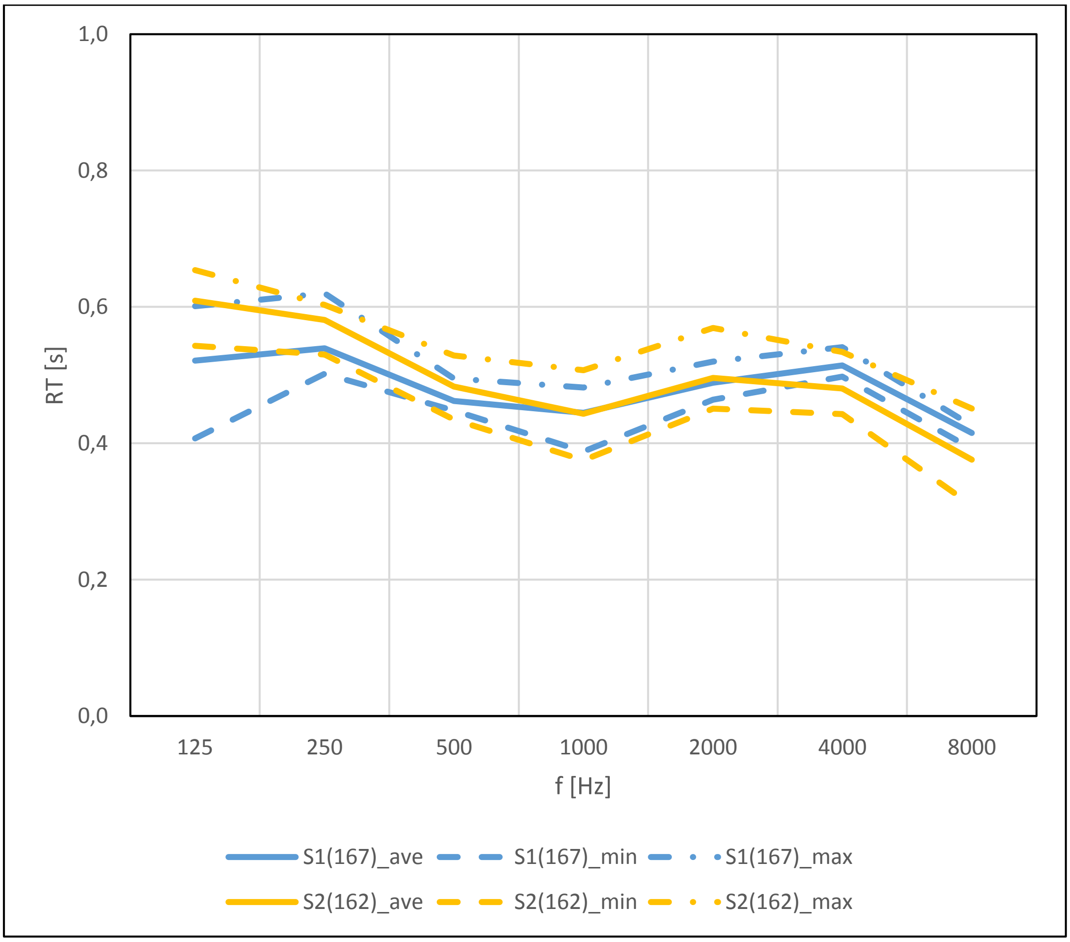

Figure 4.1
Measured reverberation time in classroom 167 and break out space 162

1 The arithmetic average of the reverberation times in the 250 Hz - 2.000 Hz octave bands

The measured reverberation time in the furnished classroom (167) is 0,48 s, in the break out room (162) the reverberation time is 0,50 s. For classrooms and/or teaching areas in open plan schools these values are a little longer than recommended for open plan schools (0,4 s) [8].

Despite this classrooms, break out space and circulation did not sound very reverberant.

4.2 Absorption Area (A)

The absorption area is calculated from the measured reverberation time and measures of both rooms. The height of the rooms is assumed to be 3,0 m. The results are given in tables 4.2 and 4.3.

Table 4.2
Calculated absorption area A

Room	Equivalent absorption area [m^2]						
	125 Hz	250 Hz	500 Hz	1.000 Hz	2.000 Hz	4.000 Hz	average
Classroom 167	71,5	69,1	80,6	83,7	76,2	72,4	75,2
Room 162	66,6	69,8	83,9	91,5	81,8	84,4	78,7

Table 4.3
Calculated absorption area A

Room	Floor area S [m^2]	Volume [m^3]	A [m^2]	A/m^2	A/m^3
Classroom 167	74,5	223,5	75,2	1,01	0,34
Room 162	81,4	243,4	78,7	0,97	0,32

4.3 Sound levels

Using different source positions (S1 and S2) the resulting sound pressure levels at multiple receiver positions in the school are measured. The measured sound levels are shown in tables IV.1 and IV.2 in appendix IV. The resulting sound reduction, attenuation and sound propagation are calculated and presented below.

4.3.1 Sound attenuation

Figure 4.1 shows the sound levels recorded at multiple receiver positions from the source S1 (classroom 167).

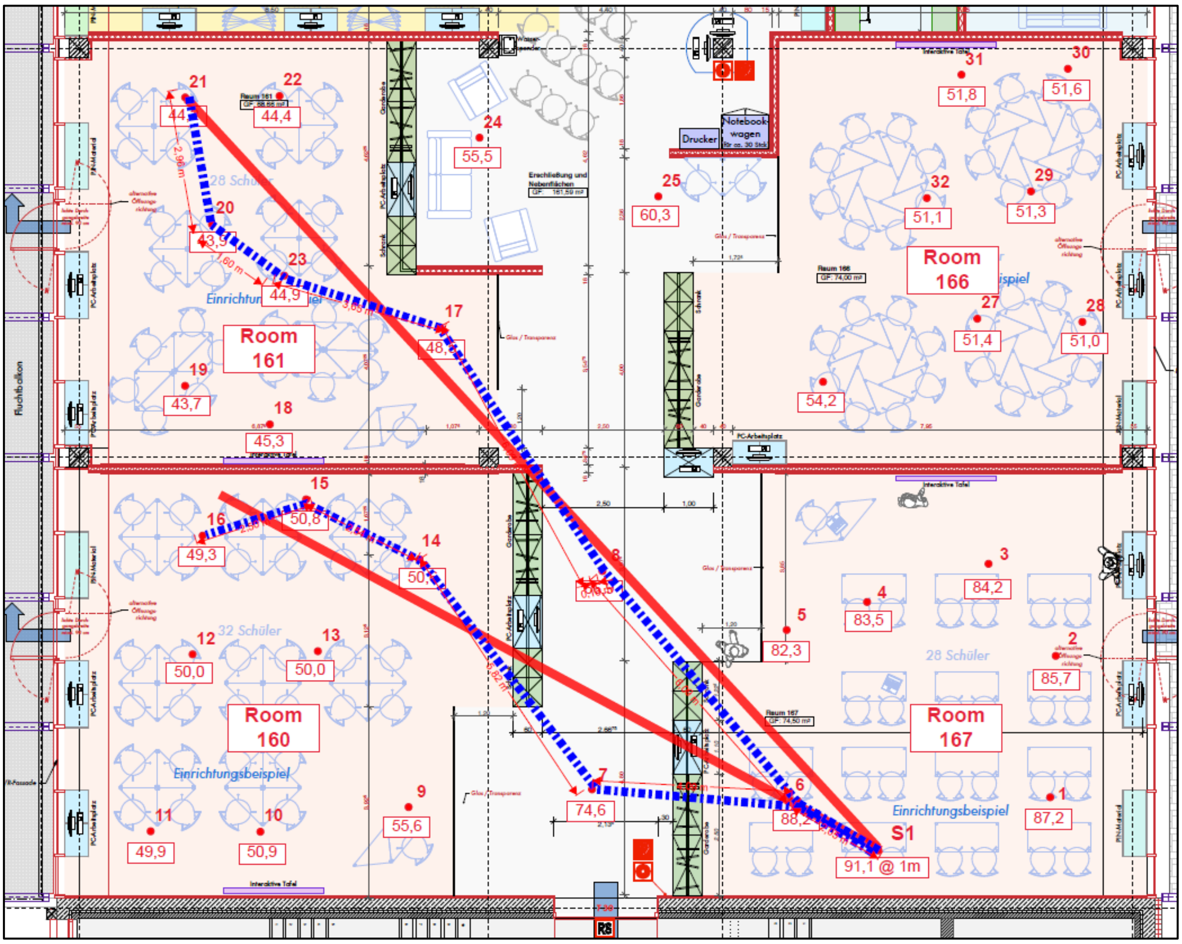

Figure 4.2
Sound level measurement positions between room 167 (S1) and adjacent rooms

Figure 4.2 shows the sound levels recorded at multiple receiver positions from the source S2 (break out space 162).

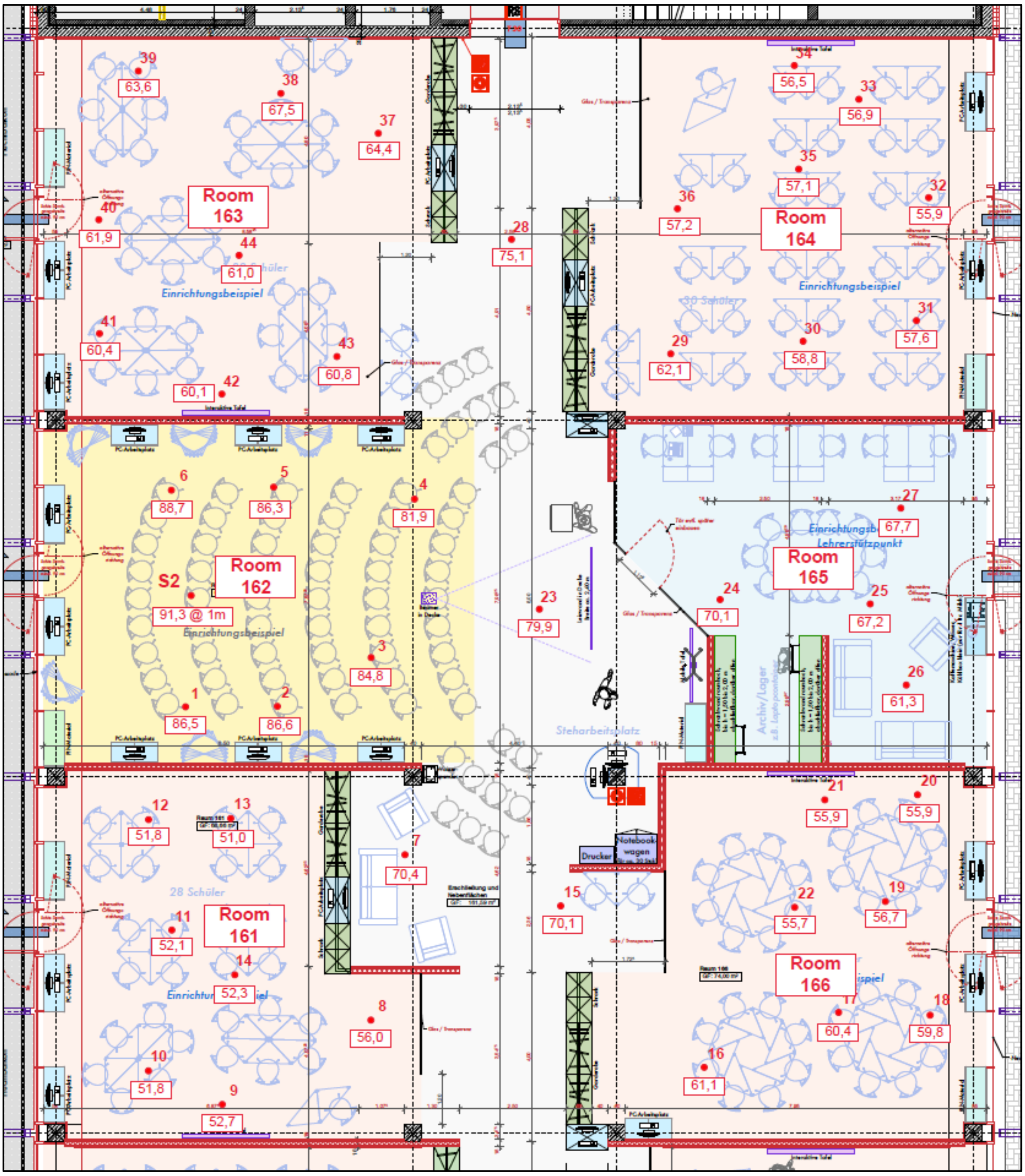

Figure 4.3
Sound level measurement positions between break out space 162 (S2) and adjacent rooms

4.3.2 Sound reduction index R'_w

The sound reduction is calculated between the enclosed classrooms. For the source and receiving levels the time-averaged sound pressure levels ($L_{p,Ls,n}$) are used. The sound absorption A is calculated using the measured reverberation time for enclosed classroom 167.

Table 4.4

Measured sound reduction index R'_w [dB]

Situation	Sound reduction index R' [dB] per octave					R'_w
	125 Hz	250 Hz	500 Hz	1.000 Hz	2.000 Hz	
Classroom 167 – Classroom 160	29,7	30,1	30,1	31,6	32,2	32
Classroom 167 – Classroom 166	22,1	25,6	28,9	32,5	35,8	33

4.3.3 Effective reduction of sound level between groups

The reduction of sound levels between enclosed classrooms is calculated using the spectrum for normal speech, A-weighted cf. NEN-EN 60268-16. For the source and receiving speech levels the time-averaged sound pressure levels ($L_{p,s,n}$) are used.

Table 4.5

Measured effective sound reduction [dB]

Situation	Sound reduction index R' [dB] per octave					Effective reduction of sound [dB]
	125 Hz	250 Hz	500 Hz	1.000 Hz	2.000 Hz	
Classroom 167 – Classroom 160	33,4	33,5	32,9	35,3	35,8	33,6
Classroom 167 – Classroom 166	26,8	30,1	34,1	37,9	38,2	34,4

4.3.4 Room amplification ($L_{p,A,S,4m}$)

The A-weighted SPL of speech at 4 m ($L_{p,A,S,4m}$) within classroom 167 and room 162 is determined using linear regression on a logarithmic distance axis. The measured speech levels in classroom 167 and room 162 are shown in figures 4.4 and 4.5. According to these results we find the following for the speech levels and excess of sound level re free field (DL_{fs}).

Table 4.6

Sound propagation

Room	$L_{p,A,S,4m}$ [dB]	DL_{fs} [dB]
Classroom 167	51,5	6,1
Room 162	53,3	7,9

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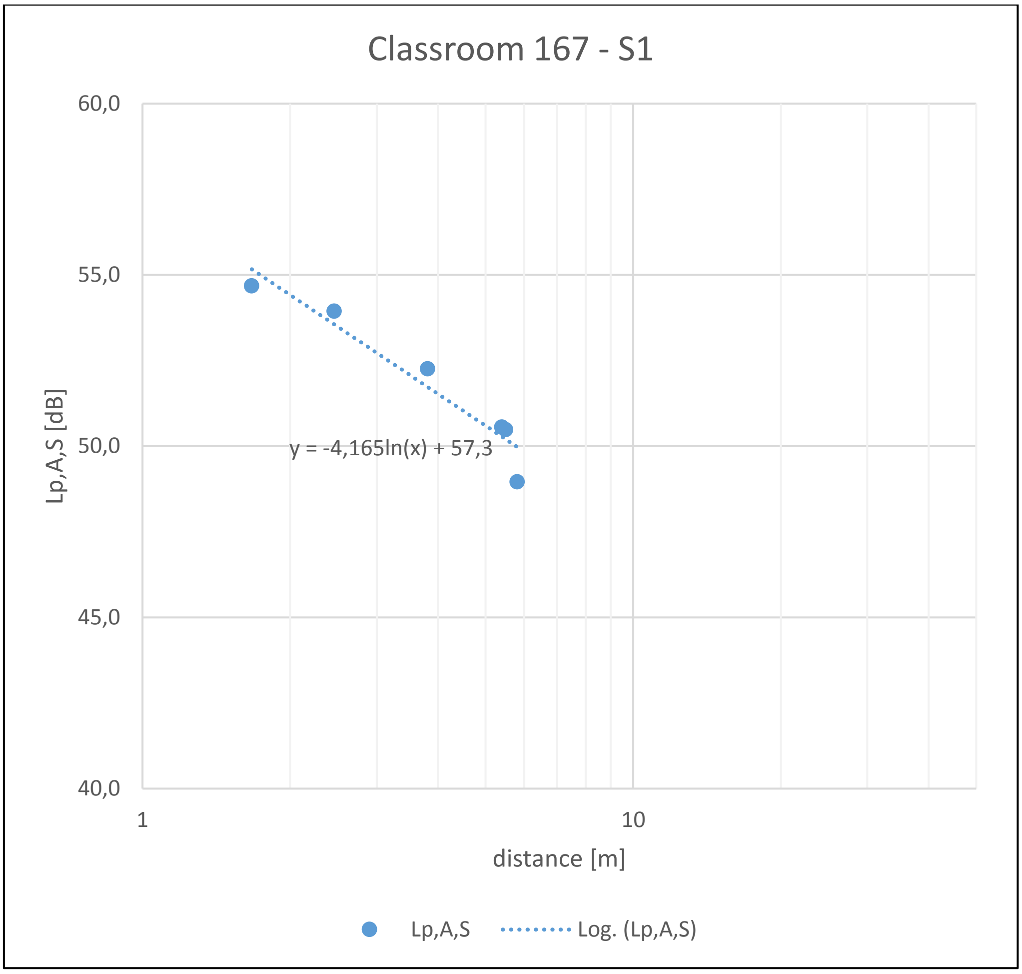

Figure 4.4
Measured speech levels in classroom 167 as a result of source at position S1

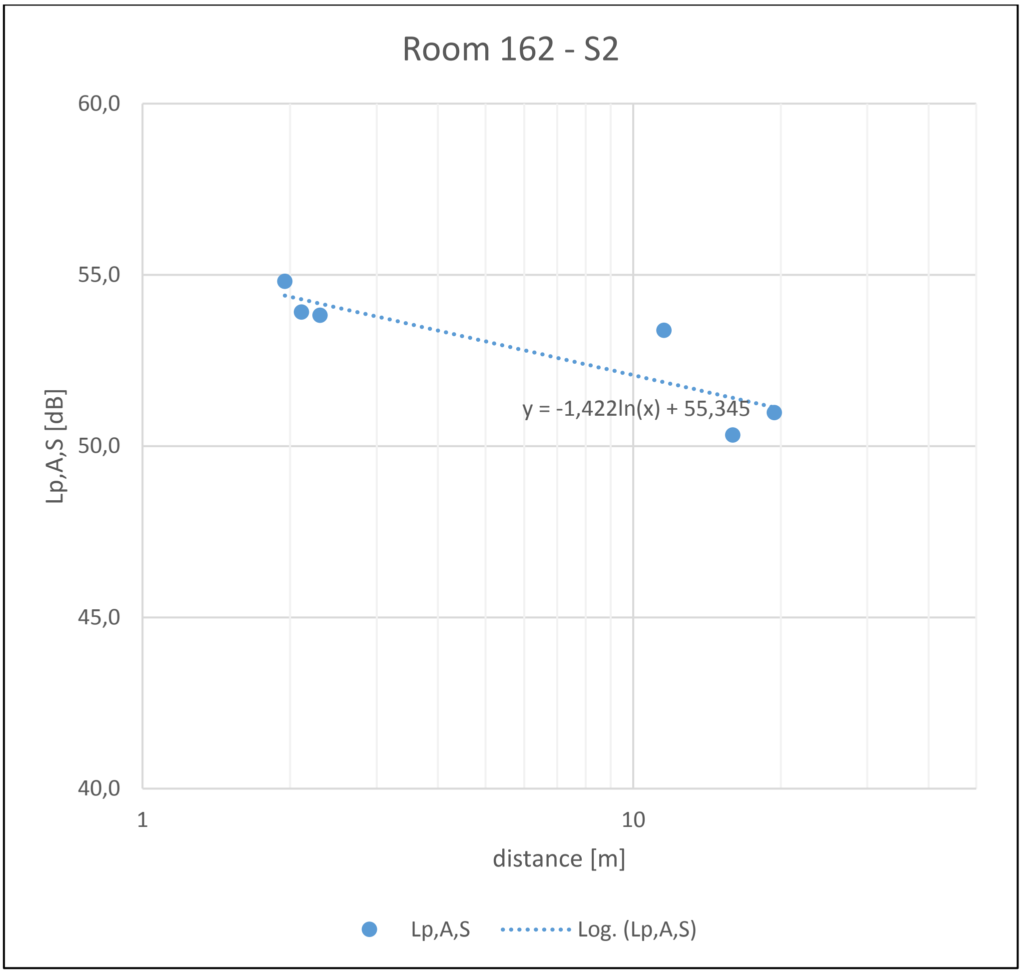

Figure 4.5
Measured speech levels in break out space 162 as a result of source at position S2

4.4 Speech intelligibility

4.4.1 Speech transmission index STI

The speech index is calculated out of the measured impulse responses in which a correction for the measured background noise levels is taken into account. As the measured background levels were not stable, the measured STI-values are also calculated with an estimated background noise level of 35 dB(A). Therefore the extended NC-25 curve cf ANSI S12.2:2008 is used.

A summary of the STI-values is given in tables 4.7 and 4.8. More detailed results are given in tables IV.1 and IV.2 in appendix IV.

Table 4.7

Measured STI, source S1 (classroom 167)

Position	STI (measured background noise)	STI (NC-25 as background noise)
Classroom 167	0,60 – 0,72	0,62 – 0,78
Circulation area	0,10 – 0,52	-
Classroom 160	< 0,10	-
Classroom 161	< 0,10	-
Classroom 166	< 0,10	-

- The measured STI in the classroom (167) is higher than 0,60, even with the relative high background noise level in this room. A value of at least 0,60 can be rated as good speech intelligibility. This background noise was caused by the beamer. With the beamer switched of the STI will be higher.
- In the adjacent classrooms (160, 161 and 166) the STI-values are all lower than 0,10 as a result of the sound source positioned in classroom 167. In accordance with [1] we can conclude that conversations in 167 can't be heard in these classrooms. Thus, acoustic privacy between the classrooms is achieved. The measured STI-values are also lower than the recommendations in [7] and [8].
- The STI in the circulation area depends on the distance to the (doorway) opening in the partition between classroom and circulation area. Close to this opening STI values of 0,5 are measured, which means that conversations can be heard on this short distances. Moving further away or behind the partition barriers, the STI-values decreases rapidly as a result of the presence of the sound absorbing ceiling and walls in the circulation area.

Table 4.8

Measured STI, source S2 (break out room 162)

Position	STI (measured background noise)	STI (NC-25 as background noise)
Break out room 162	0,75 – 0,86	0,67 – 0,82
Circulation area	0,45 – 0,70	-
Classroom 161	< 0,10	-
Classroom 166	< 0,10	-
Teachers room 165	0,31 – 0,53	-
Classroom 164	0,10 – 0,25	-
Classroom 163	0,19 – 0,38	-

- The measured STI in the open space is higher than 0,75 which can be rated as excellent. These high values are also due to the measured low background noise level. With a more ‘plausible’ background noise level (NC-25) the STI-values are still high.
- In the adjacent classrooms 161 and 166 the measured STI-values are lower than 0,10. This is caused by the absence of direct ‘soundlines’ between the open learning space and presence of high performing sound absorption.
- In the adjacent classrooms 163 and 164 the measured STI-values are lower than 0,30. In these rooms the measured background noise was about 10 dB(A) lower than in rooms 161 and 166. Despite the lower background noise levels, we can conclude that there’s still good acoustic privacy when there’s a conversation in the open learning space. Only the places closest to the open entrance of the classrooms are a bit worse than other positions.
- Toward the teacher room (165) higher values of STI are measured (> 0,30). This means that conversations in the open learning space can be heard, but hardly understood. These higher values are the effect of the direct sightline between both rooms.

4.4.2 Clarity C_{50}

The Clarity is measured in classroom 167 and room 162. The results are summarized in table 4.9 and 4.10. The shown Clarity is the arithmetical average for the octave bands 500 and 1.000 Hz.

Table 4.9

Measured C_{50}

Classroom 167	C_{50} [dB]	average
1	9,0	7,8
2	9,3	
3	6,8	
4	6,4	
5	6,1	
6	9,3	

The measured speech Clarity C_{50} in the classroom is ca. 8 dB which is similar to the value for speech clarity in classrooms deemed suitable for hearing impaired despite the RT being above 0,4 s at 0,48 s (table 4.1).

Table 4.10

Measured C_{50}

Room 162	C_{50} [dB]	average
1	12,3	11,1
2	11,5	
3	11,0	
4	7,9	
5	11,7	
6	12,2	

The measured speech Clarity C_{50} in the break out room is ca. 11 dB which is relative high. This is caused by relative high direct sound and very few late incoming sound/reflections as both ceiling and walls are highly absorptive.

4.5 Sound propagation

The sound propagation is measured between classroom 163 across the circulation space to the neighbouring class space 164 (S3). Then the same measurements from the same classroom 163 across the circulation space to the neighbouring classroom 164, but with a different source position (S4). Position S3 is a front and typical teaching position, S4 is a rear and typical student position.

The results for both sound paths are shown in figures 4.6 and 4.7.

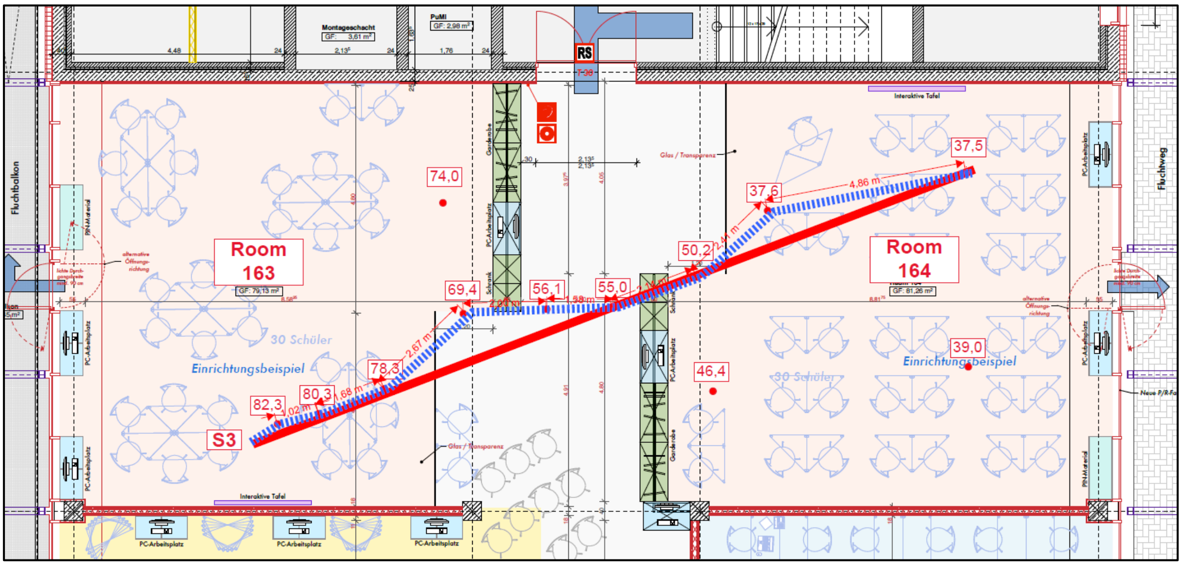

Figure 4.6
Sound level measurement positions between room 163 and room 164

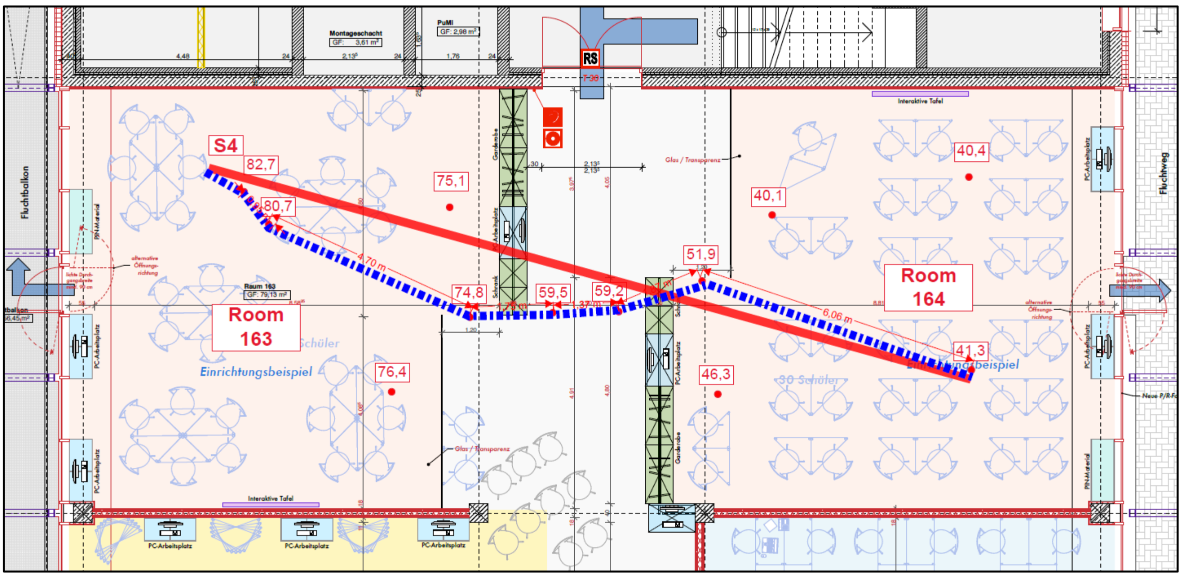

Figure 4.7
Sound level measurement positions between room 163 and room 164

As a result of the measured sound levels the sound propagation along the measurement path is derived. The results are compared with free field conditions. Figures 4.8 and 4.9 show the sound propagation between rooms 163 and 164 for both measurements paths.

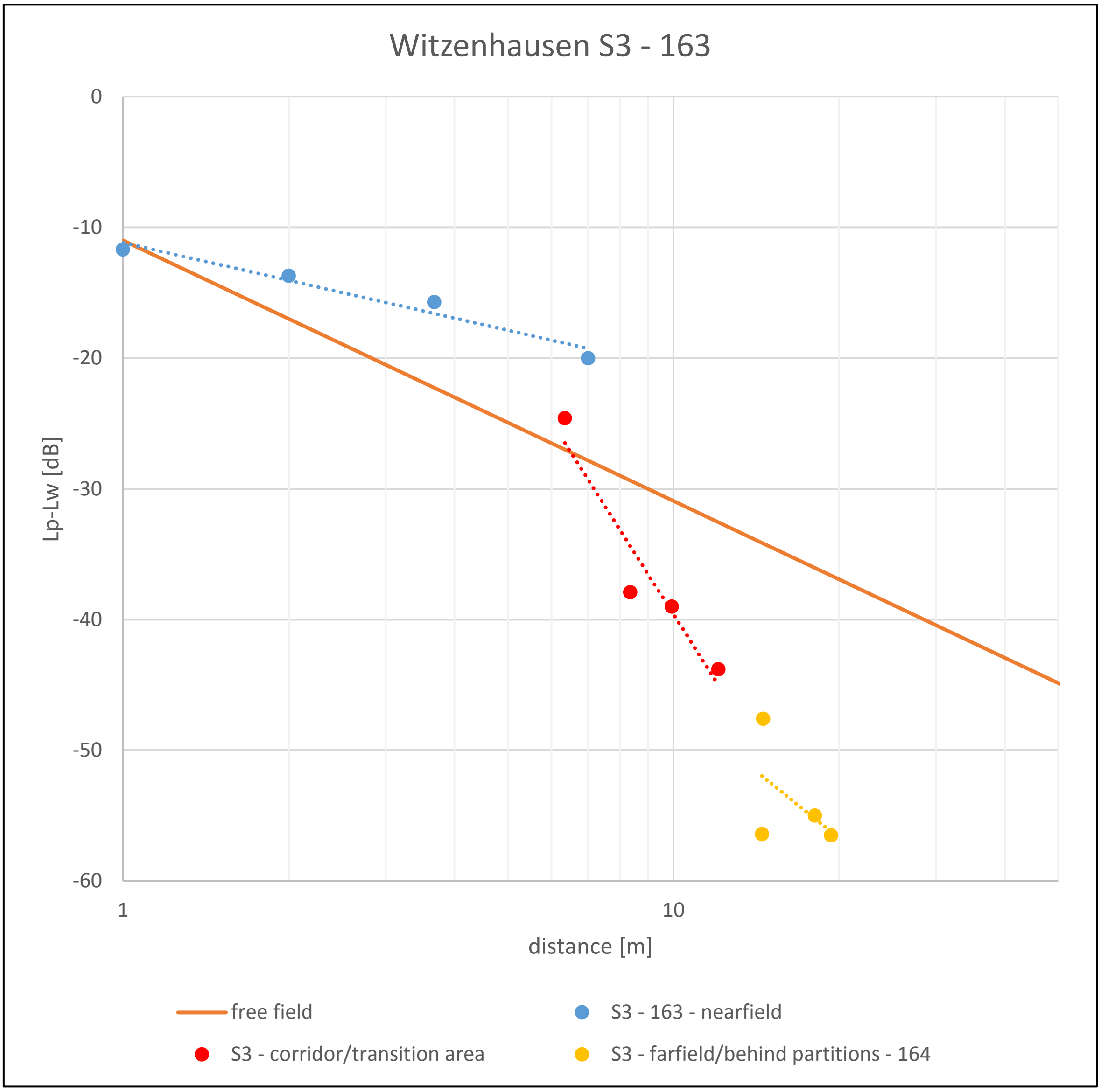

Figure 4.8
Sound propagation along measurement path S3.

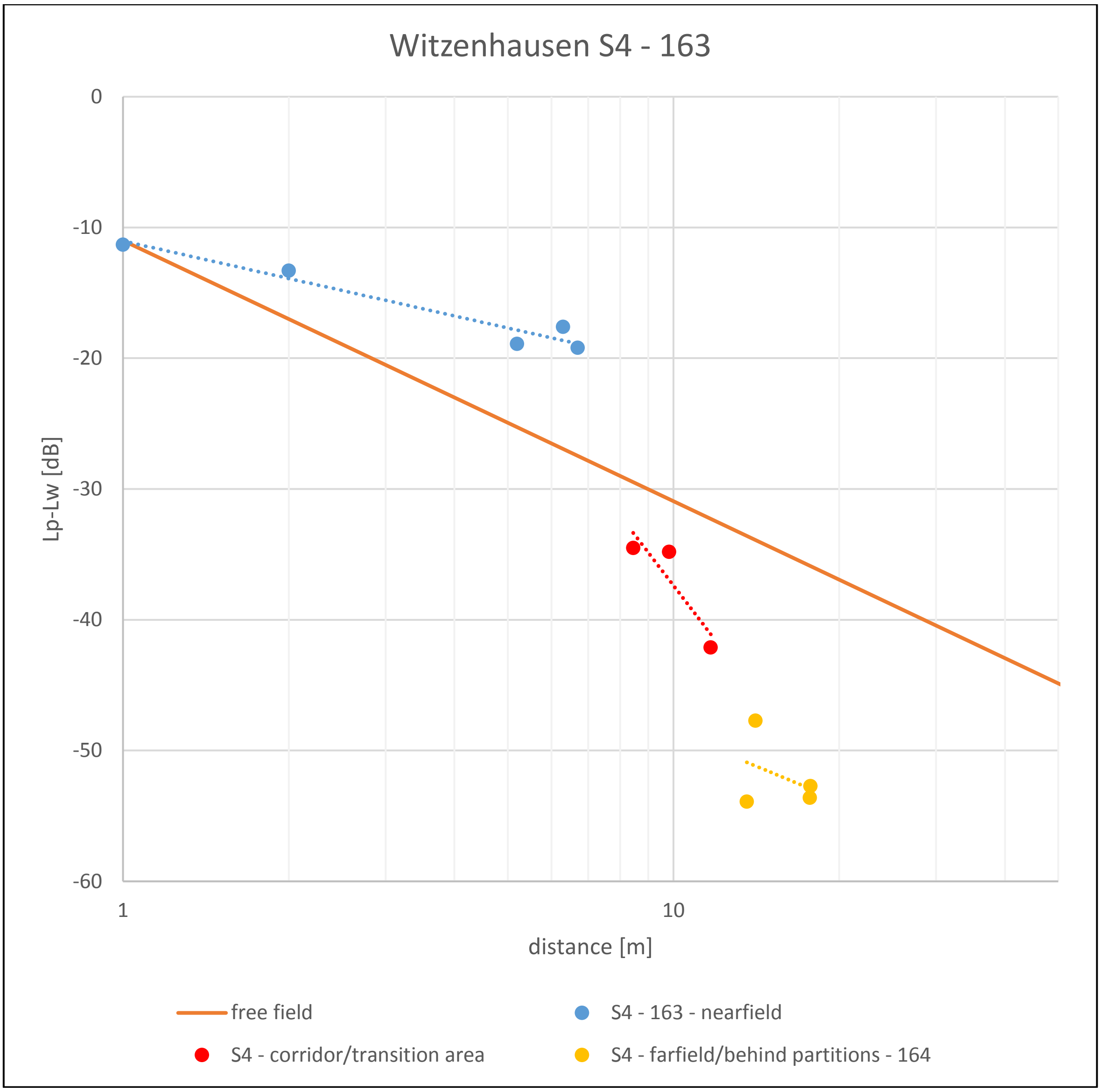

Figure 4.9
Sound propagation along measurement path S4.

An interesting aspect of these measurements is that it gives a clear insight into the sound level reduction in and between class spaces and multi-purpose open areas; over distance and due to high absorption materials, physical barriers and effectively designed sound traps.

5 Conclusions and discussion

5.1 Comparison with Danish regulation according to [8]

In table 5.1 the measured parameters/values are shown and compared with the Danish requirements/recommendations for open plan schools.

Table 5.1
Summary of measurement results compared to Danish regulations for open plan schools

Parameter	Measurement value	Measured values	
		Classroom 167	Room 162
A, absorption area	A ≥ 1,3 x Floor area	1,01	0,97
R'_w sound reduction index	R'_w ≥ 20 dB	32 (to classroom 160) 33 (to classroom 166)	29 (to classroom 161) 18 (to classroom 163) 23 (to classroom 164) 23 (to classroom 166)
T, Reverberation time	T ≤ 0,4 s	0,50	0,52
$DL_{2,S}$ rate of spatial decay of sound pressure level per distance doubling	$DL_{2,S}$ ≥ 5 dB	-	-
STI, Speech Transmission Index – inside working groups	STI ≥ 0,6	0,6 – 0,72[2]	0,75 – 0,86
STI, Speech Transmission Index – between working groups	STI ≤ 0,2	< 0,10 (to classroom 160) < 0,10 (to classroom 166)	< 0,10 (to classroom 161) < 0,27 (to classroom 163) < 0,53 (to classroom 165) < 0,25 (to classroom 164)
Effective reduction of sound level between groups	15 – 20 dB	33,6 dB (to classroom 160) 34,4 dB (to classroom 166)	32,3 dB (to classroom 161) 23,0 dB (to classroom 163) 23,0 dB (to classroom 164) 27,6 dB (to classroom 166)

5.2 Sound attenuation

S1 - Classroom 167

- The measured sound attenuation between classroom 167 and adjacent classrooms 160 and 166 is about 40 dB(A). Towards classroom 161 a sound attenuation of about 45 dB(A) is measured. If compared with guidelines for the sound insulation between classrooms in regular schools values of 40-45 dB are required to gain sufficient acoustic privacy.
- The measured sound attenuation towards the circulation area is 16 dB(A) close to the entrance and 30 dB(A) on greater distance. In comparison with guidelines for sound insulation this is less than recommended, as a result of the opening in the separation wall. However, the visual transparency seems to self-manage this.

2 As a result of the relative high background noise level, the calculated STI is relative low.

S2 - Open learning space 162

- The measured sound attenuation between the open learning space 162 and adjacent classrooms 161, 166 and 164 is about 35 dB(A). Towards classroom 163 a sound attenuation of about 30 dB(A) is measured.
- Towards the teachers room (165) the measured attenuation is more than 20 dB(A). For this situation with a direct opening between both rooms this can be judged as good. In [7] and [8] values for sound attenuation of 20 dB are recommended between class base areas in order to achieve sufficient privacy.

5.3 Sound propagation

- In the classrooms the sound levels are, as a result of inevitable reflections, little higher than in the free field. Together with a relative low reverberation time, this gives great speech intelligibility within the room itself.
- Towards the circulation zone we see a big drop in measured sound levels due to the sound barriers/glaze partitions.
- In the opposite classroom the measured sound levels are again lowered due cause of the presence of a second partition.

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Appendices: 4

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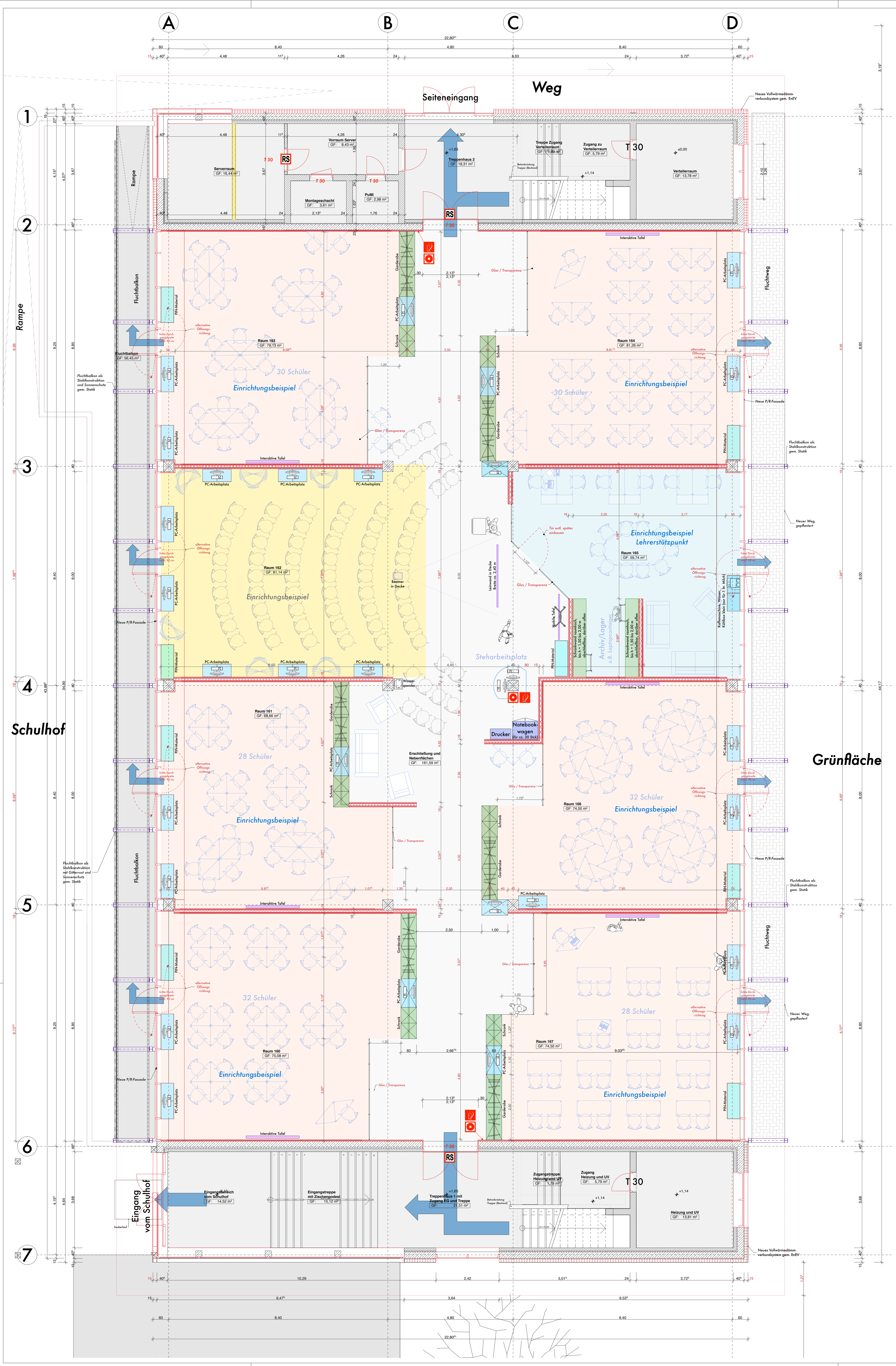
Appendix I

School plans Witzenhausen



1. SÄMTLICHE MASSE SIND VOR BEGINN DER ARBEITEN VON DEN AUSFÜHRENDEN FIRMEN VERANTWORTLICH ZU PRÜFEN. FESTGESTELLTE DIFFERENZEN SIND MIT DER ÖRTLICHEN BAULEITUNG ZU KLÄREN. ALLE FÜR DEN AUSBAU GRUNDLEGENDEN MASSE SIND AM BAU ZU NEHMEN. ÄNDERUNGEN NUR MIT ZUSTIMMUNG DES PLANENDEN ARCHITEKTEN.
2. DIE TÜRHÖHEN BEZIEHEN SICH VON OK FFB BIS UK STURZ (BEI TÜREN ZWISCHEN RÄUMEN MIT VERSCH. FUSSBODENHÖHEN WIRD DIE TÜRHÖHE VON DEM FUSSBODEN DES RAUMES ANGERECHNET, IN DEN DIE TÜRE AUFSCHLÄGT/DIN 4172)
3. ALLE AUSSPARUNGEN, DÜRCHBRÜCHE, SCHLITZE, ETC. SIND IM ARCHITEKTENPLAN IN FUSSBODENAUFSICHT DARGESTELLT.

LEGENDE

	MAUERWERK DIN cm	dB	kg/qm	kg/m
MAUERWERK	11,5 und 24			
STAHLBETON				
STB.-FERTIGTEIL				
DÄMMUNG				
SCHMUTZWASSERLEITUNG				
REGENWASSERLEITUNG				

HÖHENANGABEN

EG =+1,65 = OKFF

UK Roh · OK Roh · UK Fertig · OK Fertig · Höhe geplantes Objekt · Höhe vorhandenes Gelände

DS DECKENSPRUNG	WANDFLIESEN
DD DECKENDURCHBRUCH	WWS WAAGERECHTER WANDSCHLITZ
BD FUSSBODENDURCHBRUCH	WD WANDDURCHBRUCH
BA BODENAUSSPARUNG, BS BODENSCHLITZ, SV SOHLVERSPRUNG	WA WANDAUSSPARUNG; SWS SENKRECHTER WANDSCHLITZ

Nr.	Benennung	Datum	Name

Bauvorhaben: Sanierung und Umbau "Gebäude B"
Berufl. Schulen Witzenhausen
Südbahnhofstraße 33-35
37213 Witzenhausen

Bauherr: Eigenbetrieb Gebäudemanagement
Werra-Meißner-Kreis
Nordbahnhofsweg 1
37213 Witzenhausen

Planung: PLAN B
ARCHITEKTURBÜRO
DIPL.-ING. JÖRG-MICHAEL BRÜCKNER
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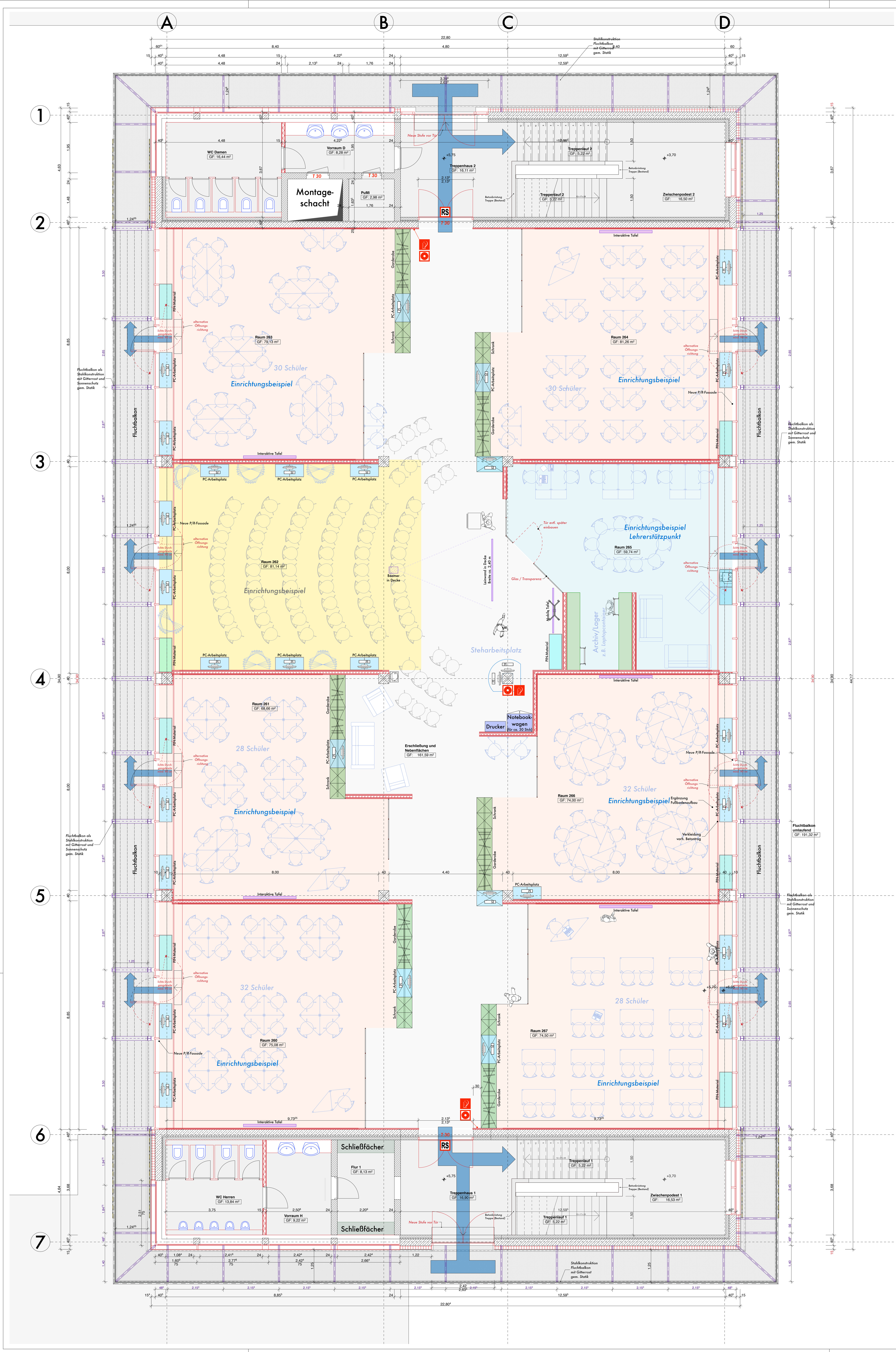
Bauteil:
Grundriss Erdgeschoss
VORABZUG

Maßstab	1:50	Projekt-Nr.:	09-01
Datum	26.01.10		
Gezeichnet	J-M.B./T.K.	Zeichnung-Nr.:	A-02.vorab
Datei	09-01-BSW_A-Planung.pln		

Achtung: Plan-Nr. angepasst!



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DD	DECKENDURCHBRUCH	WWS	WAAGERECHTER WANDSCHLITZ
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Nr.	Benennung	Datum	Name

Bauvorhaben
Sanierung und Umbau "Gebäude B"
Berufl. Schulen Witzenhausen
Südbahnhofstraße 33-35
37213 Witzenhausen

Bauherr
Eigenbetrieb Gebäudemanagement
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Planung
PLAN B
ARCHITEKTURBÜRO
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Bauteil
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VORABZUG

Maßstab	1:50	Projekt-Nr.:	09-01
Datum	26.01.10		
Gezeichnet	J-M.B./T.K.	Zeichnung-Nr.:	A-03.vorab
Datei	09-01-BSW_A-Planung.pln		

Achtung: Plan-Nr. angepasst!

Appendix II

Pictures

Figure II.0.1
Façade of the renovated building

Figure II.0.2
Overview of the circulation area

Figure II.0.3
Overview of the circulation area

Figure II.0.4
Overview of the circulation area

Figure II.0.5
Open entrance towards classroom

Figure II.0.6
Break out space

Figure II.0.7
Open connection

Figure II.0.8
Glass partition between circulation area and classroom

Figure II.0.9
Sound absorbing wallpanels in the break out space

Figure II.0.10
Glass partition between circulation area and teachers room

Figure II.0.11
Open connection between circulation area and class room

Figure II.0.12
Sound absorbing wallpanel on the side of the circulation area

Appendix III

Measurement equipment

The measurement equipment is given in table III.1.

Table III.1

Measurement equipment

Description	Fabricate	Type
Acoustic software tool	Acoustics Engineering	Dirac V6.0
USB Audio Interface	Acoustics Engineering	Triton
Omnidirectional source	Brüel & Kjær	4292
Sound level analyser	RION	NA28
Sound level calibrator	RION	NC73
Reference sound source	Norsonic	Nor278

Appendix IV

Overview of measurement results for S1 and S2

The measured sound levels ($L_{p,A,LS,n}$) and ($L_{p,A,S,n}$), sound decay (D), average background noise level ($L_{p,A,B}$) and determined STI are summarized in tables IV.1 and IV.2.

Table IV.1

Measurement results for source position S1 (classroom 167)

Position	Sound level $L_{p,A,LS,n}$ [dB]	Sound level $L_{p,A,S,n}$ for normal speech [dB]	Sound decay D [dB]	Back ground noise level $L_{p,A,B}$ [dB]	STI
167-1	87,2	53,9	3,5	39,1	0,72
167-2	85,8	52,3	5,2		0,70
167-3	84,2	50,5	6,9		0,64
167-4	83,5	50,6	6,9		0,64
167-5	82,4	49,0	8,5		0,60
167-6	88,2	54,7	2,7		0,64
Corridor-7	74,7	41,9	15,5	30,1	0,52
Corridor-8	66,9	33,6	23,8		0,36
160-9	55,6	23,2	34,2	36,5	< 0,10
160-10	50,9	18,8	38,7		
160-11	50,0	17,1	40,4		
160-12	50,0	17,3	40,1		
160-13	50,1	16,5	40,9		
160-14	50,7	17,2	40,2		
160-15	50,7	17,6	39,8		
160-16	49,3	16,6	40,8		
161-17	48,6	15,0	42,4	42,0	< 0,10
161-18	45,4	11,9	45,5		
161-19	43,7	11,3	46,1		
161-20	43,8	10,9	46,5		
161-21	44,2	10,9	46,5		
161-22	44,4	10,8	46,6		
161-23	44,8	11,6	45,8		
Corridor-24	55,6	22,1	35,3	30,1	0,10
Corridor-25	60,3	26,9	30,5		0,15
166-26	54,1	20,6	36,8	38,6	< 0,10
166-27	51,4	17,3	40,1		
166-28	51,1	17,1	40,3		
166-29	51,4	17,6	39,9		
166-30	51,6	17,5	39,9		
166-31	52,0	16,9	40,5		
166-32	51,2	17,2	40,2		

Table IV.2

Measurements results for source position S2 (open area 162)

Position	Sound level $L_{p,A,LS,n}$ [dB]	Sound level $L_{p,A,S,n}$ for normal speech [dB]	Sound decay *D* [dB]	Back ground noise level $L_{p,A,B}$ [dB]	STI
162-1	86,6	53,8	3,6	23,1	0,83
162-2	86,7	53,9	3,5		0,83
162-3	85,0	51,0	6,4		0,79
162-4	82,1	50,3	7,1		0,75
162-5	86,4	53,4	4,0		0,82
162-6	88,9	54,8	2,6		0,86
Corridor-7	70,4	38,4	19,1	30,1	0,47
161-8	56,1	23,2	34,2	42,0	< 0,10
161-9	52,9	20,4	37,0		
161-10	51,9	19,7	37,7		
161-11	52,2	20,8	36,6		
161-12	51,9	20,0	37,4		
161-13	51,0	19,3	38,1		
161-14	52,2	20,9	36,6		
Corridor-15	70,2	38,3	19,1	30,1	0,45
166-16	61,2	29,1	28,3	38,6	0,15
166-17	60,4	27,1	30,3		< 0,10
166-18	59,8	25,6	31,8		
166-19	56,7	24,2	33,2		
166-20	55,9	23,2	34,2		
166-21	54,6	22,2	35,2		
166-22	55,6	23,2	34,2		
Corridor-23	80,1	45,8	11,6	30,1	0,70
165-24	70,3	36,5	20,9	29,3	0,53
165-25	67,2	33,2	24,2		0,45
165-26	61,4	28,1	29,4		0,31
165-27	67,9	34,2	23,2		0,49
Corridor-28	75,1	41,8	15,6	30,1	0,54
164-29	62,2	29,0	28,4	30,7	0,25
164-30	58,9	25,4	32,0		0,14
164-31	57,7	24,9	32,5		0,13
164-32	55,9	24,0	33,4		0,11
164-33	56,9	24,8	32,6		0,12
164-34	56,6	24,0	33,4		0,12
164-35	57,1	23,9	33,5		0,10
164-36	57,3	25,2	32,3		0,13
163-37	64,5	32,6	24,8	32,2	0,27
163-38	67,6	32,8	24,6		0,38
163-39	63,7	29,7	27,8		0,26
163-40	62,0	29,3	28,2		0,22

Position	Sound level $L_{p,\mathrm{A,LS,n}}$ [dB]	Sound level $L_{p,\mathrm{A,S,n}}$ for normal speech [dB]	Sound decay *D* [dB]	Back ground noise level $L_{p,\mathrm{A,B}}$ [dB]	STI
163-41	60,5	28,1	29,3		0,19
163-42	60,1	27,3	30,1		0,19
163-43	60,9	29,3	28,1		0,20
163-44	61,1	28,3	29,1		0,20