New techniques in the planning of open space offices
(extended english version of the paper presented at DAGA 2015 in Nürnberg)

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Introduction

Acoustically based requirements can play an important role if extended open plan offices are planned. Differently to the planning of other working areas with noise relevant machinery and other technical facilities it is not the main target to avoid high noise levels and the danger of hearing impairment, but to ensure satisfying acoustic conditions especially with respect to the understandability of speech. These preferred conditions can be quite different and even contradictory - while in some areas a relaxed communication with low speaking effort is required, a reduced or even impossible understandability and a certain confidence is needed between different working groups in other areas.

To ensure these wanted acoustic properties for open plan offices, it is advantageous to predict the relevant acoustic parameters in the planning process. In the following the most important steps in the software based acoustic planning of interior spaces, the selection of acoustically relevant furniture and fixtures and in the optimization of layouts is presented. Taking these aspects into account, some new approaches in standardization are critically discussed.

Calculation methods and software strategies

The procedures described in the following are performed applying the software CadnaR [1]. A hybrid strategy is used that is based on a deterministic ray tracing for the direct sound propagation including screening effects and on a statistically based particle method for propagation with reflections up to high orders or up to a defined propagation time dependent on the required accuracy of the results determined.

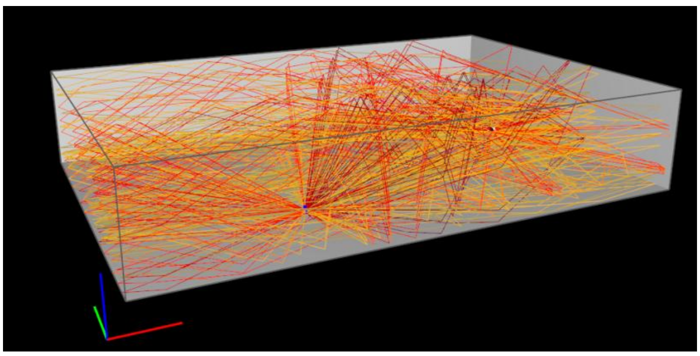

Figure 1: Sound rays calculated with the mirror image method

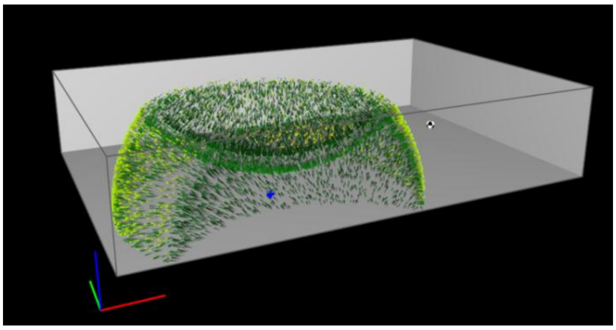

Figure 2: The distribution of propagating particles after a first reflection at ceiling and floor with the particle method applied

With the particle method the acoustically relevant volume is subdivided in smaller counting volumes - the so called voxels - and for each of these voxels the particles crossing them are summed up weighted with their path length inside the voxel to determine the contribution to the final energy density at this position. The size of the voxels define the possible "acoustical" resolution but influence also the necessary calculation time to keep the statistical uncertainty below certain target limits .

The acoustic properties of furniture and fixtures

It is sufficient to include in the "virtual" model only furniture and fixtures acoustically relevant due to their size and to describe these with the parameter values for absorption, scattering and transmission in the relevant octave frequency bands. An exaggerated detailing in the sense of the above mentioned necessary resolution is meaningless and dupes only a not existing accuracy in the calculation of ray paths.

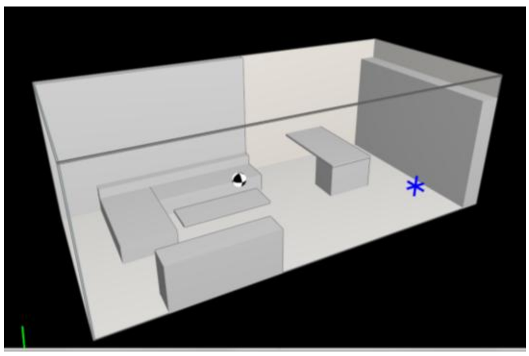

Figure 3: A simple model of an office with communication area

Due to this modelling requirements it makes sense to apply acoustically oriented software based filter techniques if computer models generated for purposes of visualization and layout planning shall be applied for acoustic calculations. Such filters must extract the relevant structures, add the acoustic parameter values and suppress the acoustically irrelevant details..

Taking into account the increasing importance of these acoustic simulation techniques it is necessary to include them in the framework of standardization. This encompasses many aspects like the acoustical description of construction components, the definition of quality scores and the formulation of requirements.

A typical example is the definition of the absorption index for ceiling banners in the new guideline VDI 3755 /2/. Such "ceiling banners" are absorbing plates suspended from the ceiling with gaps between them - they "float" in the sound field and due to the gaps even their backside contribute to the total absorption of the system.

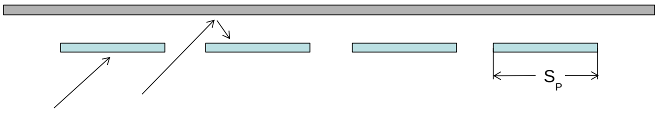

Figure 4: Ceiling banners contribute with their backside to the total absorption - if the equivalent absorption area determined in the reverberation chamber is related to the area of a plates Sp the absorption indices determined exceed 1.

According to the mentioned guideline the equivalent absorption area A determined for an arrangement of n ceiling banners in a reverberation chamber is divided by n to get the absorption area specific for one plate and further divided by the one-sided area Sp of a plate to get α_{Segel} (= α_{banner}). The values > 1 shall be declared and applied without replacing them with 1 - as it is done with all other absorption coefficients.

If these elements are included in an acoustic simulation, these values > 1 cannot be taken into account because the particles hitting the surface of the plate can only be absorbed completely. But the particles crossing the gaps may be absorbed at the backside - therefore it makes no sense to increase the absorption coefficient of the front side to include the absorption backside.

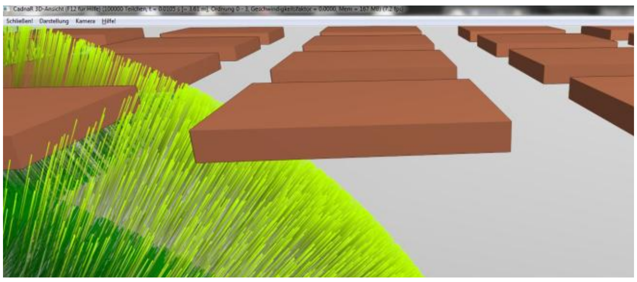

Figure 5: Particles crossing an arrangement of ceiling banners

There are only two correct ways to describe such arrangements correctly. The first method - with increasing importance due to the increasing application of simulation techniques - is to describe the single plate correctly with absorption coefficient and scattering index for both sides separately and with the transmission coefficient. This allows to include arrangements with different distances, gaps and absorption of the ceiling surface behind, as long as the simulation method can be applied. The different acoustic behaviour of different arrangements is calculated and it is not necessary to undertake a measurement for each arrangement separately.

The second method is to relate the equivalent absorption area determined for one element with a certain arrangement to the prorated projection area S_B of the arrangement for one element as shown in figure 6. This absorption coefficient is a description of this special arrangement and not a property of the single plate.

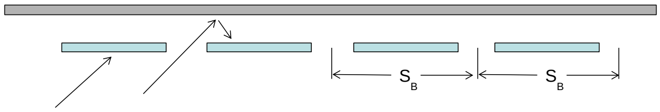

Abbildung 6: Bei Bezug der pro Element festgestellten Absorptionsfläche auf die dargestellte Bezugsfläche S_B eignet sich auch der so ermittelte Absorptionsgrad zur Berechnung

In an acoustic simulation the complete arrangement can be replaced by a single extended plate with that absorption coefficient.

The same is true for baffle systems with vertical panels or plates - in [3] the relation between the acoustic parameters related to the single element and those related to the complete arrangement are described. The method of VDI 3755 with an α_{banner} where the total absorption area detected in the reverberation chamber is related to the projection area of the element seen from room side would produce absorption coefficients up to 100!!

Acoustic requirements for offices according to standards and their application in plannings

A more general standard formulating requirements not only related to offices is DIN 18041 [4] – it distinguishes classes A and B to qualify rooms, where offices are a subgroup B4 of group B. To ensure the recommended or even required acoustic quality limiting values for the quotient of equivalent absorption area and volume A/V are proposed and for further requirements the guideline VDI 2569 [5] is recommended.

This guideline VDI 2569 related to acoustic planning of offices sets requirements on

- maximal acceptable reverberation times
- maximal acceptable sound pressure levels caused by the building (e.g. installations, but not persons)
- limiting values of characteristic parameters, that can be derived from measured sound pressure levels along measuring paths according to ISO 3382-3 [6] (Level decrease per doubling of distance $D_{2,S}$ and A-weighted sound pressure level $L_{p,A,S,4\,m}$ of speech in a distance of 4 m)

Further the distraction distance r_D is mentioned – this is the distance from a "reference"-speaker, where the speech transmission index STI according to IEC 60268-16 [7] has dropped to or below 0,5.

In the planning phase the values of these characteristic parameters must be determined by simulation techniques or estimated on the basis of former experience.

With the reverberation time this is no problem. Simulation techniques as the above mentioned particle model allow the determination of the room response even for different locations and for non diffuse sound fields whithout the limitations given by Sabine's theorie according to DIN EN 12354-6 [8] and for any complexity of the room. On the basis of the energy-related echograms and even with defined background noise the STI can be calculated.

Nevertheless it shall be mentioned that the application of these simulation techniques requires some experience about the assumptions for scattering indices, minimal absorption of very small-sized fittings and other not well known parameter values. But these techniques are a powerful support of the experts own know-how.

The pre-determination of the characteristic values derived from receiver-paths is more complicated. These paths defined in ISO 3382-3 stretch across workplaces that may be separated by partition walls and other screening objects and therefore the prediction of levels from diffracted sound may be important.

To cope with these problems the direct sound from the source to all receivers is calculated taking into account all possible ray paths and barrier attenuation according to ISO 9613-2 [9]. The reflected sound is simulated with the particle model up to any reflection order or propagation time. This strategy allows to calculate these parameters derived from receiver paths even for extended open plan offices with layouts of any complexity.

An example is the simplified model of an extended open-plan office shown in figure 7. A smaller area left is acoustically separated by a fencing partition wall to serve as "communication-center" where talks can be kept confidential.

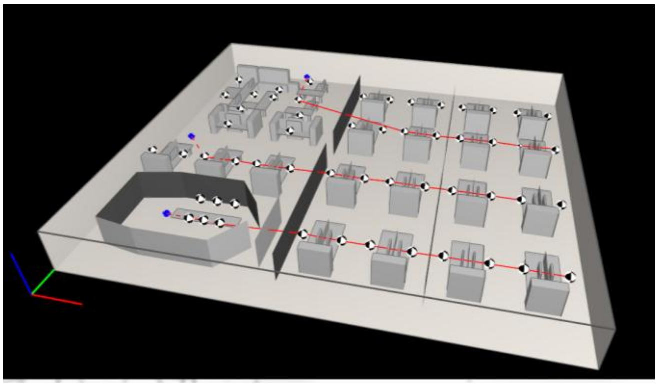

Figure 7: Open-plan office with partition walls with 3 receiver-chains (red) to predict the parameters and to qualify this environment according to VDI 2569

The receiver-paths shown red in figure 7 are produced in the "virtual" office-model as chains of work-places and for each chain a source position is defined. The sound-power spectrum related to speech is attached to each source and the calculation is performed in an automated sequence chain after chain.

With the assumption of an absorbing suspended ceiling the diagrams shown in figures 8, 9 and 10 are the result for the first path starting in the communication-area.

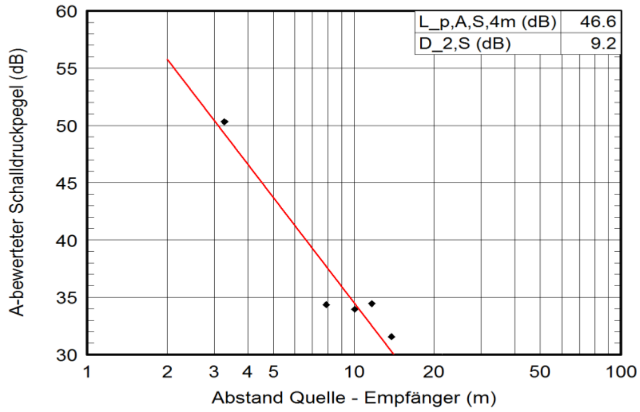

Figure 8: Sound levels along path 1 with $D_{2,S}$ and $L_{p,A,S,4m}$

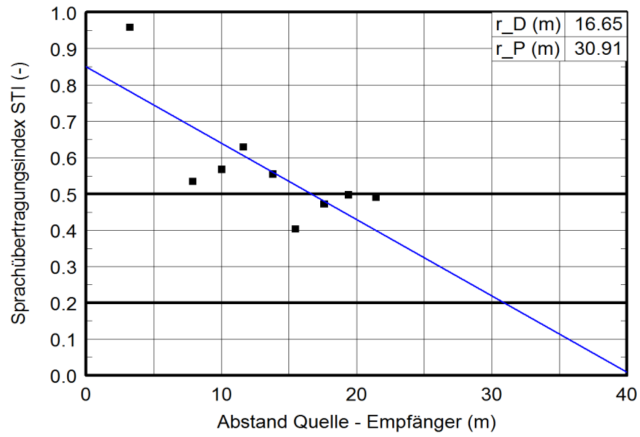

Figure 9: Dependency of STI from distance calculated from points along path - distraction distance is 16.65 m.

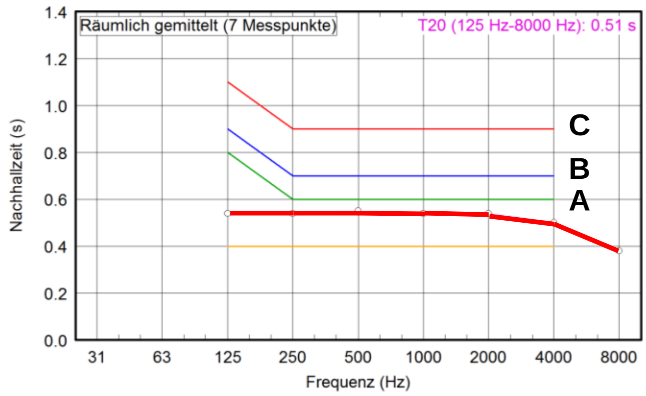

Figure 10: Reverberation time (red) averaged over all points of the path with the limits for roomacoustic classes A, B and C

The application of the STI

According to VDI 2569 the STI and based on it the distraction distance does not take into account the background noise even if is well known to be typical for a certain type of open-plan office. The STI quantifies in a certain way the smearing of the modulation of speech related sound by lingering sound due to reverberation and by other sound signals not correlated with the signal. These uncorrelated sounds or background noises are the main reason why the understandability of speech decreases if the intensity of the signal is decreased. The STI incorporates both effects - influence of reverberation and of background noise. Figure 11 show the dependency of the STI from reverberation time (in the diagram: "Nachhallzeit") and from SNR - the difference speech sound level and background noise level (in the diagram: "Pegeldifferenz Sprachschall - Hintergrund"). The calculation of this STI-surface in figure 11 is based on a diffuse sound-field or on a linear level decay after a sound source stops radiating.

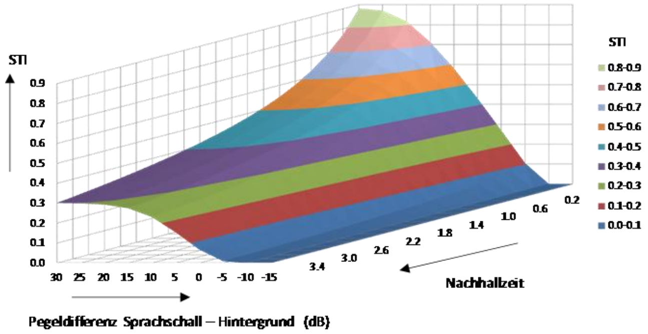

Figure 11: The STI as a function of reverberation time and of the difference of signal level (level of the speech related sound) and the level of background noise.

If background noise is not considered then the STI with a given source position does not depend on the signal level, only a decrease of the modulation would have an influence. Therefore screens and other attenuating devices have only little influence on the STI, because they reduce low levels and high levels by the same amount and don't therefore influence the modulation depth. In reality screens are helpful to reduce the understandability of speech, because they reduce its level and the difference signal - background gets smaller.

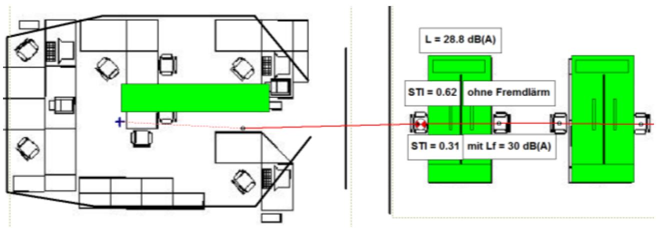

Figure 12: The assessment of the understandability of speech from the communication corner left side at the work-place behind the screens right side.

An example is shown in figure 12, where the STI at the workplace right side is calculated with the speech-source inside the communication corner left side. The room has a height of 3m and the ceiling is absorbing. The workplaces are separated by a screen 2m high. Takink no background noise into account, the workplace right is inside the distraction distance. One would conclude from this result that no confidence is given and speech from inside the communication corner will be understood outside. But if we take into account a background noise level of 30 dB(A) - a nearly unrealistic low level for such offices - the STI would only be 0.3.

This is in agreement with experience - absorbing and screening devices help to reduce the signal level and this will immerge in the sea of other sounds.

VDI 2569 may be helpful as a general qualification system for offices, but nevertheless it is recommended to take into account the individual needs for speech transmission between the different working areas if such offices are planned.

The STI should be taken as the most important parameter to qualify environments like offices, classrooms and other rooms where speech communication is important - positive or negative. In open-plan offices there are working groups with the need of a relaxed speech communication, and there are neighbored groups were the understandability of speech decreases concentration and disturbs.

Taking into account these aspects it would make sense to classify the level of the unavoidable background noises for typical working areas - determined as percentiles L_{90} or L_{95} - and to take these as input parameters in simulations if STI based decisions shall be made.

Literatur

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[3] Wolfgang Probst: „Die Schallabsorption von Kulissendecken“,Lärmbekämpfung Bd.3 (2008) Nr.2
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[4] E DIN 18041:2015-02 “Hörsamkeit in Räumen – Vorgaben und Hinweise für die Planung”, Beuth Verlag GmbH, 10772 Berlin
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[5] VDI-Richtlinie 2569 E: “Schallschutz und akustische Gestaltung im Büro”,”, Beuth Verlag GmbH, 10772 Berlin

[6] DIN EN ISO 3382-3 Akustik; Messung von Parametern der Raumakustik; Teil 3: Großraumbüros

[7] IEC 60268-16: Sound system equipment; Part 16: Objective rating of speech intelligibility by speech transmission index, ISBN 978-2-88912-522-7

[8] DIN EN 12354-6: Bauakustik – Berechnung der akustischen Eigenschaften von Gebäuden aus den Bauteileigenschaften; Teil 6: Schallabsorption in Räumen