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Estimation of the background noise levels in large atria with known room acoustic properties and function

Richard ŠIMEK[1]; Vojtech CHMELÍK[1]; Jarmila HÚSENICOVÁ[1] Monika RYCHTÁRIKOVÁ[2]

[1] Slovak University of Technology in Bratislava, Faculty of Civil Engineering, Department of Architecture,
Radlinského 11, 81005, Bratislava, Slovakia

[2] KU Leuven, Faculty of Architecture, Hoogstraat 51, 9000 Gent/ Paleizenstraat 65, 1030 Brussel, Belgium

ABSTRACT

One of the major identified acoustic problems in large halls such as atria or shopping malls is continuous unpleasant background noise, based on typically long reverberation of sound. Levels of background noise caused by internal sound sources depend on activity performed in the place on one hand and on room acoustic conditions on the other hand. Present noise can be measured relatively easily, by means of sound level meters and evaluated through statistical noise analysis, expressed e.g. by histogram of noise levels. However, the prediction of statistical noise levels, such as L_{95}, L_{90} or even L_{eq}, in rooms is very difficult, as it doesn't depend only on the overall sound power spectrum of sound source (typical sound source definition in ray-based algorithms), but also on the time varying character of sound. Function and thus activity performed in an atrium plays therefore an important role in terms of acoustic comfort analysis and without the information on time variation in source signal, parameters such as L_{90} or L_5 cannot be successfully predicted. In this paper several typical signal sounds (such as human steps, speech, music, ventilation etc.) are synthesized and auralized in Odeon software and assessed in parametric study of an atrium, followed by statistical analysis of predicted auralized wave files. Correlation between the activity and room acoustic parameters is calculated and estimation of background noise levels L_{99} is shown together with equivalent sound pressure level $L_{A,eq.}$

Keywords: Room acoustics, background noise, statistical noise levels, large halls

1. INTRODUCTION

Acoustic comfort in large halls, where many people gather, is rather complex issue which depends on several objective and subjective factors. The challenge is to find correlation between the two in order to propose a suitable acoustic prediction parameter and to summarize the knowledge into guidelines that would help architects in their design. In spite of many already existing acoustic parameters, an adequate acoustic comfort descriptor does not exist yet. Many questions typically arrise in renovation projects of historical atria that belong to national or regional monuments (1,2).

Common practice in preparation of guidelines for room acoustics is stereotypically based on reverberation time measurement, calculation or simulation. The reverberation time is a good measure in the assessment of classrooms, auditoria or aulas, thanks to their high correlation with the Speech transmission index (STI) and the Clarity (C_{50}) of the space, which takes into account the ratio between early and late reflections of sound) and thus the speech intelligibility. Combined with the other parameters that can be found in ISO 3382, the value of the reverberation time, gives an adequate description of the acoustics, suitable for designing concert halls, operas or theatres (3). However, when it comes to functional places, often high or continous background noise levels are identified as a problem as these can be influenced not only by global reverberation time, but also by the shape of the room and the distribution of sound absorption over the interior surfaces.

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[1] richard.simek@stuba.sk; vojtech.chmelik@stuba.sk; jarmila.husenicova@stuba.sk;
[2] monika.rychtarikova@kuleuven.be;

Furthermore, unpleasant acoustic situations are not always associated with extremely high noise levels. Sound reflections in rooms with large volumes arrive from surrounding surfaces from relatively far distances are not strong enough to significantly increase the maximal noise levels directly. However, due to Lombard effect (4), reflections increase noise levels indirectly as shown in (5). As a matter of fact, typically reported problems are pointing at the presence of continuously present background sound (6,7).

This article is therefore based on a paramteric study that shows, how do the statistical noise levels such as L_{90}, L_{95} and L_{99} change with different activity, volume and sound absorbing properties of interior surfaces.

2. DESCRIPTION OF THE CASE STUDY

2.1 Description of the atrium

For this study the atrium of the manor house in the village of Halič has been taken as a starting point. Given atrium has been built in a Baroque style. It has been originally an opened exterior space, with grassy vegetation and stone walkways on the ground. In 2016, the purpose of the space was changed and atrium was covered by glassed roof and the grass on the ground was replaced by marble stones. Doing so, an interior space was created, suitable for hotel dining room and transition space.

Figure 1. Left picture (Variant A): original atrium before renovation; middle picture (Variant B): renovated atrium covered by ETFE foils; right picture (Variant C): atrium after renovation covered by glass.

First, the impact of renovation (glass roof and hard floor) is investigated, on the known acoustic parameters (such as reverberation time, sound pressure level distrubution and clarity of sound) predicted by means of simulation model in Odeon software. Later, third alternative was created in which ETFE is used as roof material instead of glass and porous plaster is placed on the walls, and was compared with the first two cases (Figure 1). However, the main scope of this paper concerns the acoustic comfort issues under different boundary conditions such as volume and sound absorption properties of interior surfaces.

2.2 Description of the parametric study

In order to investigate the acoustic comfort issues in large rooms vs small rooms, a parametric study was performed that consisted of 3 different volumes and 3 different sound absorbing properties of interior surfaces, and thus 9 different alternatives. The volume 1, corresponds to the original atrium, the second volume is modeled with doubled dimensions in comparison with the original atrium and so 8x larger volume and 4x larger area of interior surfaces. The volume 3 is modeled with half of the dimensions of the original volume, e.g. 8x smaller volume and 4x smaller area of interior surfaces. All simulated cases are sumamrized in the Table 1.

Table 1 – Summary of simulated variants

Volume (m^3)	Variant A (original)	Variant B (ETFE)	Variant C (glass)
8767	Alt.1A	Alt.1B	Alt.1C
70100	Alt.2A	Alt.2B	Alt.2C
1097	Alt.3A	Alt.3B	Alt.3C

The three variants (A, B and C) have different sound absorbing properties of interior surfaces. Variant A represents the situation before renovation, it is without roof and contains grass on the ground and stone walkways. Variant B contains roof made out of ETFE foil roof system, slightly porous plaster on the wall surfaces and marble floor. In the variant C, glass roof, marble floor and painted plaster is presumed.

3. DESCRIPTION OF EXPERIMENTS

The two main experiments (based on Odeon simulations) were performed for the 9 given cases (alternatives). The 3D simulation model is shown in the Figure 3.
Experiment 1, was performed for one sound source and 20 recivers on a grid with dimensions 3x3m, across the atrium part. It was done to have a detailed information about the sound presure level distribution *G*(dB) in each alternative. Position of sound source and receivers in three different volumes is shown in the Figure 4.

In the experiment 2, one receiver position was chosen together with a set of sound sources simulating walking person, through the middle part of atrium in two different speeds. Sound sources simulated positions of impact sound sources (discrete steps of person, later synthethised into continous walking sound). Distribution position between the receiver and sources was the same in all variants. (Figure 5)

3.1 Simulation models

Simulation model for this experiment was prepared in Google Sketchup software and simplified for the needs of the Odeon acoustic model to include only surfaces coming into contact with acoustic waves represented by rays in simulation software. Software used to simulate room acoustics is based on a hybrid calculation method. This method combines the use of image source method for early sound reflections, and a special raytracing method with advanced scattering algorithm for simulations of higher order reflections (8).

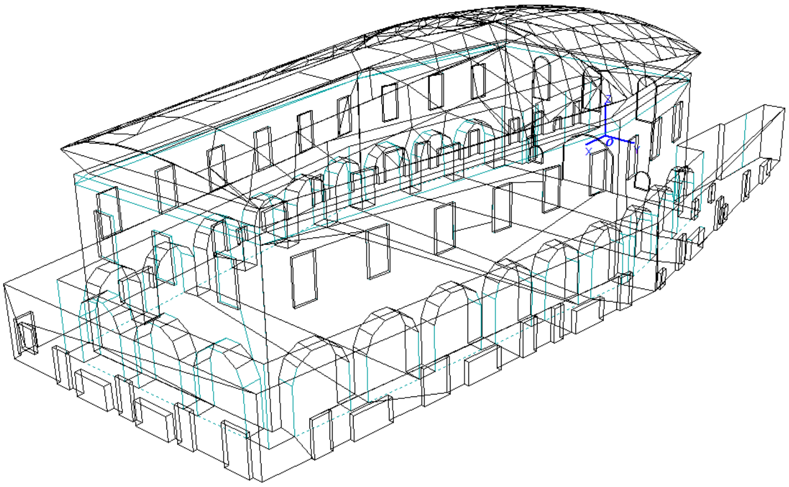

Figure 3. Simulation model 3D perspecive view

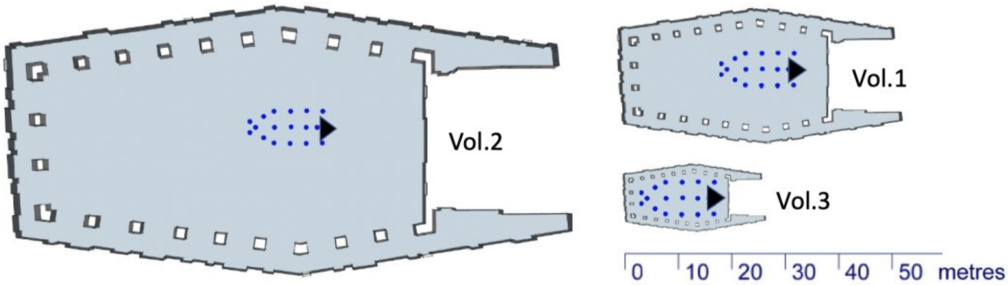

Figure 4. Topview of the 3 atria (Vol.1,2 and 3) with indication of the position of the omnidirectional point sound source (black triangle) and distribution of receivers (blue dots), in Experiment 1.

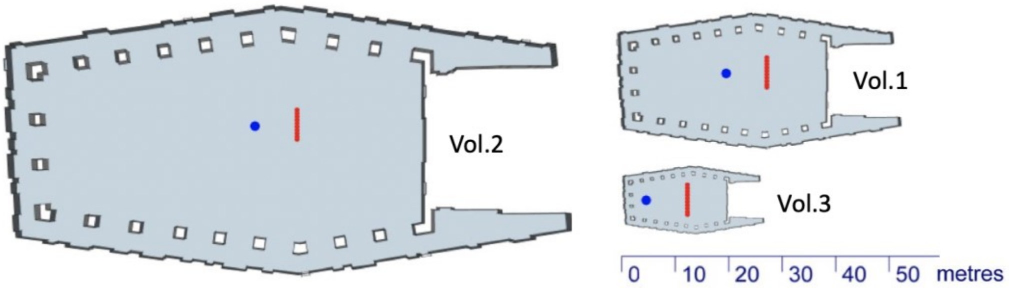

Figure 5. Topview of the 3 atria (Vol.1, 2 and 3) with indication of the position of the receiver (blue dot) and sound sources (steps), indicated on red line, in Experiment 2

4. RESULTS AND ANALYSIS

4.1 Experiment 1

Results of the reverberation time and mean sound absorption coefficient α (-) is shown in the Figure 6. Figure 6 – left shows large differences between different alternatives caused by differnces in volume and absorption. In the Figure 6-right we can see the mean absorption alpha, calculated as weighted average. In theory, the mean alpha should be the same for each variant (A, B or C) because it is independent on volume, except of high frequencies where the air sound absorption contributes to reverberation time. These trends can be observed.

Reverberation time is clearly longest in large room with least absorption and the shortest reverberation time is observed logically in the small volume (Vol.3) in situation without roof. It can be also observed that within one volume the reverberation time at 4000 Hz is almost the same, e.g. at high frequencies the influence of volume was larger than actual mean α (-) of interior surfaces.

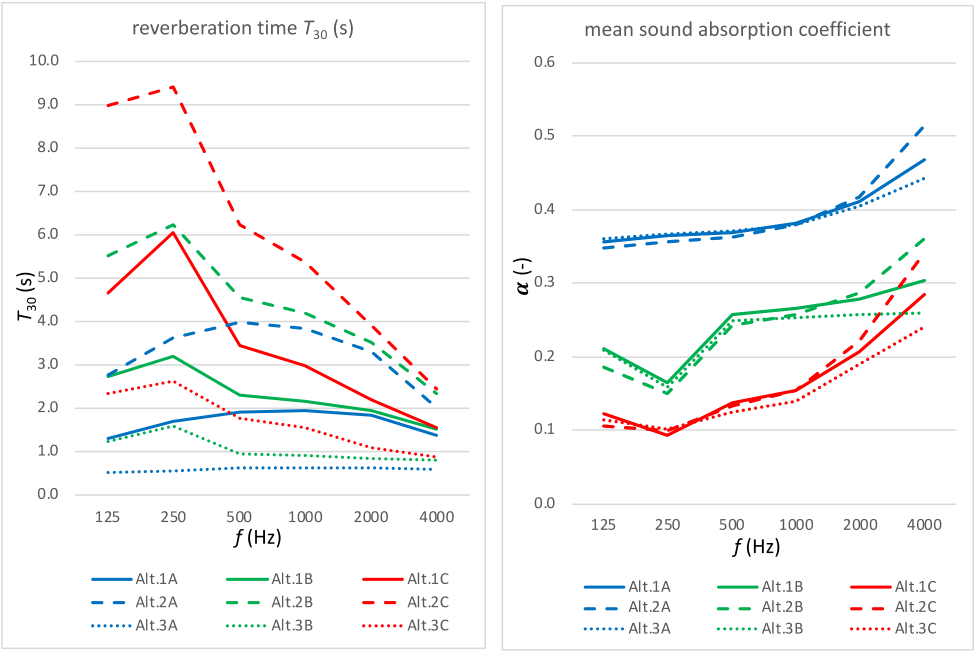

Figure 6 Sumary of average T_{30} over the all simulated impulse responses and mean sound absorption coefficient α (-) of interior surfaces for all of simulated variants. NOTE 1* The colours represent the absorptive properties of surfaces. Blue is used to show the orginal situations before renovation, without roof; in green are alternatives with ETFE foils and porous plaster; and the red colour represents variants with glassed roof and painted plaster. Volume 1 (current room volume) is shown in full line; dashed line represents cases with Volume 2 (big volume); and the dotted line is showning results for small volume 3.

Another important parameter in general room acoustics is the sound pressure level distribution over the room case. In this paper we show the results through a parameter sound strength G (dB) for two octave bands, 125 Hz and 1000 Hz (Figure 7). The most noisy rooms according to the predicted sound level should be small room (Vol.3) with roof, where the glazing + painted plaster is ca 5 dB louder in comparison with ETFE situation and porous plaster. The density of reflection plays here a strong role. Interestingly, sound levels in small room without roof (at the distance of 14m from the sound source) are less "noisy" than Sound levels in Volume 1 (original volume) when roof is present. The lowest sound pressure level is observed in large volume (Vol.2), where in Alt.2A (situation without roof) is almost following the free field theory. The large dimensions of the atrium don't bring significant contribution to the sound strength G increase at further distances.

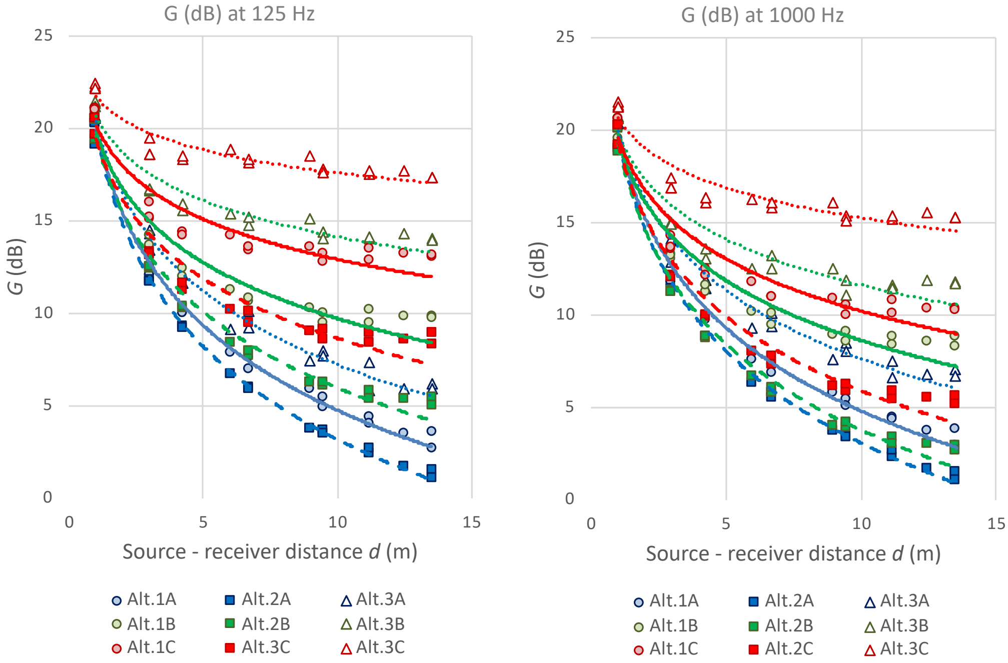

Figure 7. Graphical representation of the decrease of sound pressure level, expressed through the parameter sound strength G (dB) with increasing distance between omnidirectional sound source and receivers. Data are described as following: circles are showing data for Volume 1 (original volume), squares are used to show results of Volume 2 (big) and triangles represent the samal volume (Volume 3). The same logic of colours and line representation is used for trendlines as in the Figure 6 (see NOTE 1).

4.2 Experiment 2

Experiment 2 was conducted for sake of better understanding the acoustic comfort issues. Here we focuse on the research question: "How does the human steps in an atrium influence the overall equivalent sound pressure level ($L_{\mathrm{A,eq}}$) on one hand, and the quasi continous background noise caused by long reverberation defined (in our experiment) by statistical noise level parameter L_{99} on the other hand."

Simulations of person walking at the distance of ca 10m from the receiver was performed for 9 alternatives (3 volume cases), shown in the Figure 5. Discrete steps were simulated and auralized at two different speeds as (quick and slow). The statistical noise analysis was performed on auralized samples. Results given in the Figure 8 are averaged values between the left and right ear.

On a first sight some inconsistencies could be observed when comparing $L_{\mathrm{A,eq}}$ with reverberation time and sound pressure level distribution, however this can be explained easily. Parameters $L_{\mathrm{A,eq}}$ and $L_{\mathrm{A,99}}$ were calculated based on binaural auralized sound, whereas the T_{30} and G values were calculated from omnidirectional receiver. The binaural simulation in which the sound reflections are arriving from walls are for real listening person stronger than those from ground or ceiling, due to shadowing effects of head (defined by HRTF – Head related transfer function). Therefore, they might influence the final auralized results especially if the wall properties and distance of receiver differ from alternative to alternative.

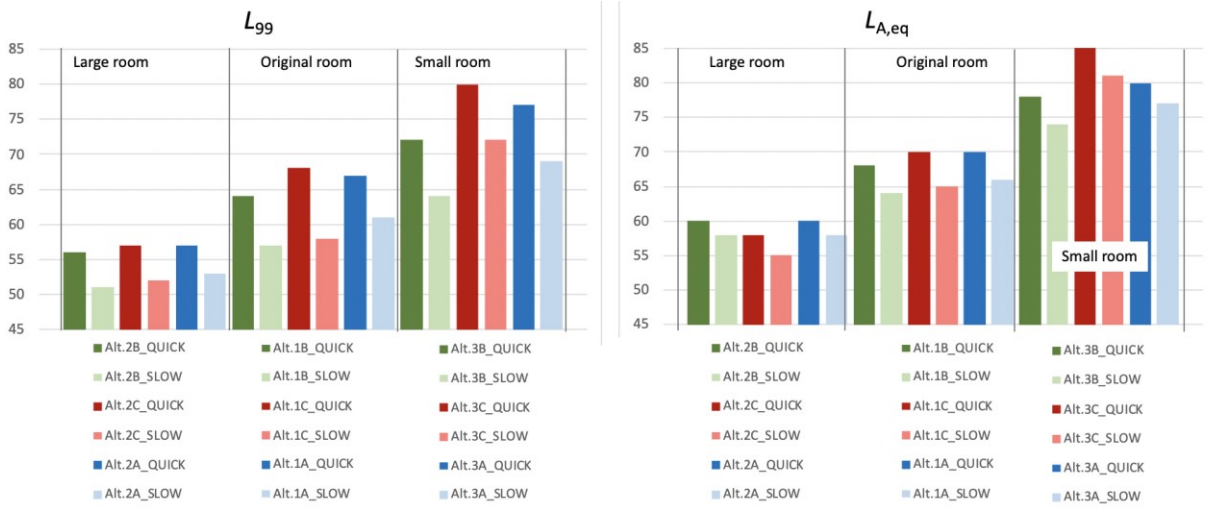

Figure 8. Results $L_{A,eq}$ and L_{99} as calculated from auralized samples.

5. CONCLUSIONS

Based on the performed experiment 1 and 2 it can be concluded, that there might be difference between the objective assessment (according to the ISO 3382) using omnidirectional speaker and omnidirectional receiver, in comparison with finally binauraly simulated sounds. HRTF might have influence on accuracy of results once the comfort issues in rooms are adressed as they represent the listening person better.

Sometimes the same backgroun noise levels are produced in rooms with different sizes and interior surfaces. The question arrises, wheter these would be judged by people as similar (in relation to nosie annoyance).

In the proposal/development of a suitable paramter or criterion for acoustic comfort in atria, that whould express the comfort issues related to quasi continous background noise caused by internal sources (such as walking people), therefore requires suitable listening test.

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REFERENCES

1. Gregorová J, Kiabová E, Vargic L, Kvasnicová M. The importance of the pre-project setup and documentation for the restoration of the monuments. In proc. of ATF 2018. Leuven 2018, p.46-55.
2. Vojteková E. Presklené Átriá. (Atria covered by glass). Publisher STU, Bratislava 2016.
3. ISO 3382: Acoustics - Measurement of room acoustic parameters - Part 1.
4. Lombard É. (1911) Le signe de l'élévation de la voix, Annales des Maladies de L’Oreille et du Larynx 37,101-119.
5. Zelem, L. Analysis of the noise impats on verbal comunication and its modulations. In *Advances in Architectural, Civil and Environmental Engineering.* Bratislava 2016, p. 545-552.
6. Yang W, Kang J. Acoustic comfort evaluation in urban open public spaces 66, 2005, p.211-229.
7. Rychtáriková M, Chmelík V, Urbán D, Vargová A. (2016) Acoustic conditions in the atrium of Slovak philharmonic. Procedia Engineering 155, 2016, p. 464-471
8. Rindel J.H. The Use of Computer Modeling in Room Acoustics. Journal of Vibro Engineering 3(4) p.41-*72* Paper of the International Conference BALTIC-ACOUSTIC.