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Acoustic conditions in the atrium of Slovak philharmonic

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Abstract

Musical performances, conferences, receptions or other events when many people gather can take place in different types of rooms and large shopping centrums, atria or city courtyards are not an exception. Continental weather however, doesn't allow for keeping these semi-open spaces uncovered, in case of the whole year operation. Volume, shape and material choice of interior surfaces in atria are typically hard and thus sound reflective, which has very strong influence on acoustic comfort inside. This article analyses acoustic conditions in the atrium of Slovak philharmonic from room acoustic point of view and compares 5 different alternatives of a position of sound absorption in terms of its efficiency and adaptation of an atrium space for music performances, conferences or receptions.

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Keywords: acoustics; architectural acousitcs; room acoustics; atrium; musical performance

1. Introduction

When people speak about acoustic conditions in rooms, they typically refer to a so-called "good or bad acoustics". But what does a term "good acoustics" actually means? The answer of an acoustician should be: "The acoustic quality of a room depends on its function, and therefore we cannot speak about a "good or bad acoustics" of a room in general, without knowing what type of activity is performed inside [1].

Most of us have probably already experienced a musical performance in a concert hall, where symphonic orchestra sounded excellent, but once a string quartet started to play a disappointment came, due to lack of volume

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and envelopment by sound and even more problematic situation might have occurred once moderator of a concert started to speak from the stage without suitable microphone – loudspeaker system

It is well known, that understanding of speech needs shorter reverberation time in comparison with music and in case of large room with a volume above ca 1000m^3, it is almost impossible to reach all people in the audience without sound amplification system. But this is valid also vice versa, e.g. classrooms, auditoria or spoken theatres would be too “dry” for classical music presentation [2]. Different types of music also need different amount of sound absorption applied on interior surfaces, resulting in different reverberation times. While pipe organ sounds better in places with long reverberation, classical music needs a bit shorter sound reverberation [3]. Opera houses are somewhere in between, since opera music should sound well and in the same time certain amount of speech intelligibility of the singer must be kept [4].

Finally, in order to achieve a high quality of music perception in a hall, not only proper sound absorption, but also sound diffusion is extremely important [5].

Places such as restaurants or other gathering places need as much absorption as possible and in case that low sound levels are required also the amount of people per m^2 must be limited [6]. However, decreasing the number of people in a public room such as atrium is in most cases very difficult to control.

If we look back in the history, returning to the period in which electroacoustic equipment haven’t exist yet, we will see that antique open air theatres, used mainly for political gatherings and theatre plays, had typically very steep slope of the audience area, so that the distance between the speaking person and the audience would be as short as possible, allowing for sufficient sound intensity at receiver positions. If we look at the paintings of Napoleon, showing him speaking to large crowds of people, we cannot unnoticed, that he was sitting on a horse. This has allowed him to sit higher (for visual an acoustic reason), and also to move in the crowd of people in order to reach a broader public by being well understood. The development of electroacoustic amplification systems (microphone – loudspeaker) has brought completely different situation when giving a speech to large amounts of people in the same time. This, although very positive development in electroacoustic, gave also a powerful tool to dictators to manipulate large crowds easily.

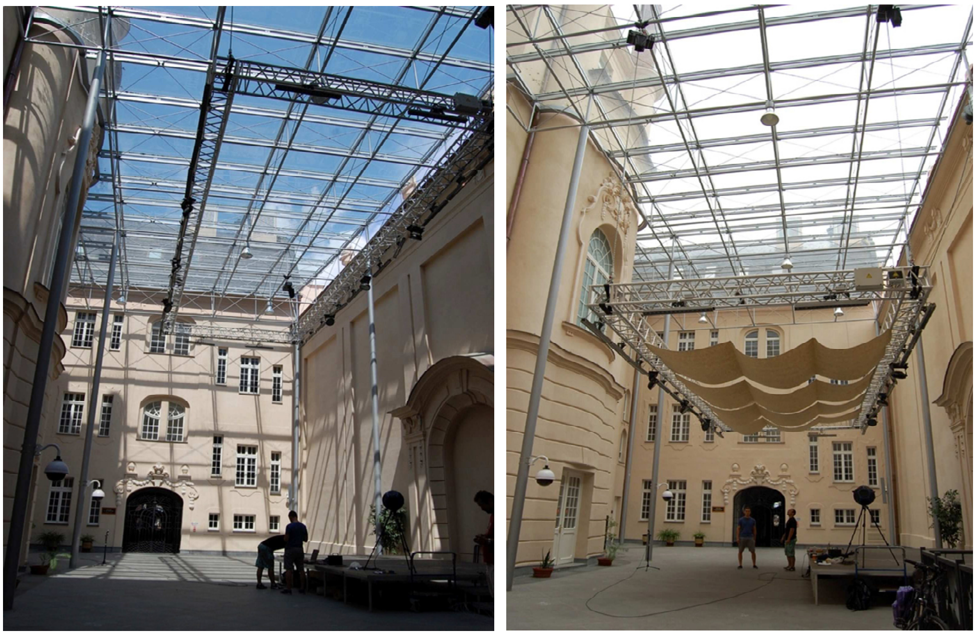

Fig. 1. Interior of the atrium of Slovak philharmonic in Bratislava with and without absorptive material placed over the stage

Nowadays trends show, that architects like to design multipurpose and flexible places. On one hand, flexibility gives to architectural design new dimension, but on the other hand, acoustic solutions for multipurpose halls belong to biggest challenges of any expert on acoustics. Atria often covered by structural skins belong to rooms with many different functions. Sometimes social events such as receptions or banquets take place, sometimes, musical concert or conference is arranged.

In large atria, covered by hard roof material, which are potentially used for conferences (where speech must be understandable), placing of a sound absorptive materials might act well in terms of reduction of reverberation time. On the other hand, as a consequence, too low sound levels of a signal (speaking person) might occur, due to too little sound reflections present in a hall. In comparison with ordinary lecture rooms situated in traditional buildings, the background noise levels in atria are typically much higher. This is also caused by natural ventilation systems, which due to roof openings make direct connections with outdoor noise [7,8].

In case, that an atrium is used for musical performances, we face a problem, that a room shape is typically not the most suitable one, walls don't have enough scattering and a stage is often places on a longer wall (in the ground floor scheme). It is well know that rooms for musical performance need to have an optimal reverberation time, sufficient distribution of sound pressure level, enough diffusion and sufficient lateral energy fractions, which help to increase the perception of spaciousness. Most of the old concert halls with high quality ratings are shoebox shaped with a presence of sufficient sound scattering elements and stage placed at the shorter side of the shoe box in order to supply enough lateral sound reflections [9]. In case of a multipurpose place, such as atrium covered by hard transparent structure, it is impossible to expect that the acoustical performance (of a hall) will be similar to a concert hall. Nevertheless, once an atrium is used for music performances often, special attention should be given to the amount and to the position of sound absorption, since the shape and volume is typically fixed by architecture itself. For sake of understanding the acoustic behavior of an atrium covered by glass, a didactic study has been performed on an existing case and results are shown in this paper. This article deals with an atrium in the building complex of Slovak philharmonic, which has been covered by transparent glass structure during the renovation process. The presence of the new roof on one hand allows for usage of the space during whole year season independent on weather conditions, but on the other hand it has an impact on its acoustic quality. In case study presented in this paper we compare 5 different alternatives of sound absorption distributions, with a focus on the assessment of room acoustic parameters, such as Clarity of sound C_{80} (dB), Speech intelligibility STI (%), lateral energy fractions *LEF* (%) and sound pressure level distribution by means of the parameter Strength *G* (dB). Reverberation time and average sound absorption α (-) was also calculated for each alternative (Table 1).

2. Description of the case study

The atrium chosen as a case study for this paper belongs to a historical building of Slovak philharmonic in Bratislava (Fig.1). The atrium was recently renovated and as a part of the renovation works it was covered by glassing system. The total volume of the atrium is around V = 4550 m^3 and the area of interior surfaces is around S = 1900 m^2. Walls and floor in the atrium are acoustically hard and thus very reflective. During the measurements, there was a small stage present, which is usually built along one of the long walls (Fig.1). Above the stage there is a height-adjustable supporting steel structure for technical equipment such as lighting or cameras, with a possibility to hang a sound reflector or similar element on it, such as a heavy curtain (Fig.1 – right). Atrium is used for many different activities and mainly music performances, conferences, receptions take place here.

3. Measurements

Impulse response measurements [10] for two positions of sound source (P1 and P2) and 31 microphone position (Fig.2) were performed in the atrium by means of omni-directional loudspeaker, omnidirectional and Dirac software. During the measurements, microphones were places in the height of 1,2 m and sound source at 1,4 m above the floor.

Measurements were done for two situation: without and with a presence of a heavy curtain of about 40 m^2 hanged above the stage in the height of ca 5 m, e.g. ca 4 m above the stage (Fig.1-right). The curtain was a fabric with density of 1.1 kg/m^2.

Results of the average Reverberation time T_{20} (s) for the two measured cases are shown in the Fig.2 - left. It can be seen that the additional sound absorptive material placed above the stage helps to reduce the reverberation time by 0,5 - 1 s, depending on a frequency. This is at the limit of the so called just noticeable difference (JND = 10% of T_{20}). According to the STN 73 0525 [11], optimal values of reverberation time for chamber music in a room with a volume 4500 m^3 are T_{opt} = 1,4 s. For orchestral music the values are T_{opt} = 1,45 - 1,7 s. This means, that the reverberation time measured is in the atrium is too high not only for speech but also for music performance.

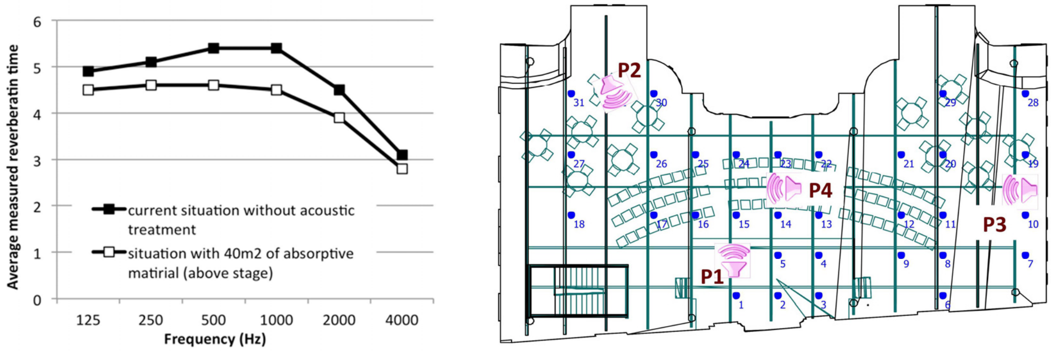

Fig. 2. Left: Average measured reverberation time T_{20} (s) in the atrium with and without absorptive material, Right: Sound source (P1 and P2) and 31 receiver positions as used during the measurements and sources (P1-P4) as used during the simulation.

4. Simulations

Simulations were performed by means of ray-based acoustical prediction software Odeon, which uses a hybrid calculation method and combines image source method with early-scattered rays for calculation of the first sound reflections, and special ray-tracing method for calculation of late reflections [12]. Spatial geometrical model was created in Sketch up and imported to Odeon software. Acoustic model was calibrated according to the measurements of T_{20}.

Five (5) different acoustical scenarios were simulated (Fig. 3) and compared with a current acoustic situation in the atrium. Alternatives 1, 2 and 3 have very similar amount of sound absorption, which is in each case differently distributed over the room (Fig. 3). Alt.1 has absorptive surface with total area of 205 m^2 placed on the wall behind the stage, in the Alt.2 a sound absorptive surface was placed on side walls 159 m^2 + 123 m^2 and on small parts of back wall: 47 m^2 + 42 m^2 and in the Alt.3 the only highly sound absorptive surface is a ceiling. The sound absorption coefficient α (-) of the highly absorptive material used for these simulation is between 125 – 4000 Hz: 0,87; 0,78; 0,83; 0,83; 0,90; 0,96.

The Alt.4 and Alt.5 are cases with 3D absorbers (Fig.4). In the Alt.4 absorbers are hanging just under the ceiling while in the Alt.5 they are hanging significantly lower. These two extra alternatives were simulated for sake of understanding of the influence of 3D absorbers in the room.

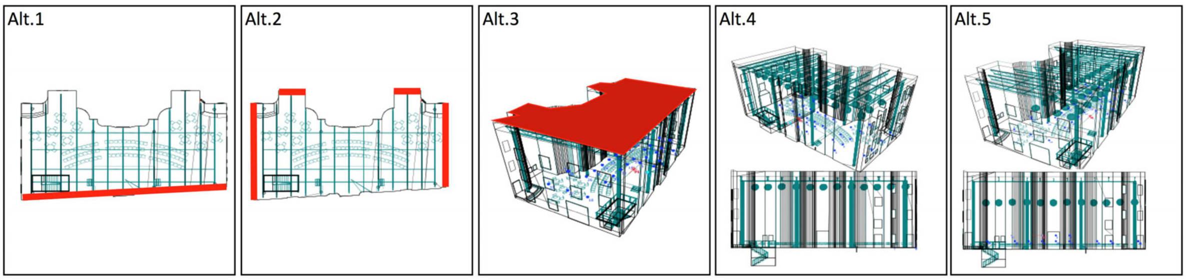

Fig. 3. Simulated alternatives

5. Results and analysis

The average reverberation time results of five (5) simulated alternatives are shown in the Fig.4 -left, where they are also compared with measurements of the current situation. We can see that a baffle structure (simulated in Alt.4 and 5) would has a strong influence on sound reverberation mainly in middle and high frequencies. The reverberations radius in the atrium is around 1.7 m for current situation and over 3m for the 3 simulated variants with additional absorption.

When comparing Alternatives 1, 2 and 3, with highly absorptive material placed in in the atrium in 3 different ways, we can see that the T_{20} drops to 2s in all octave bands (in all three cases). Differences in reverberation time between the Alt1.2 and 3 are not significant. The maximum difference of 0.5 s can be found between variant 2 and variant 3 at frequency of 125 Hz. For sake of better understanding and comparison with other studies in literature also the mean sound absorption coefficient was calculated (Fig.4 - right). Using the mean sound absorption coefficient instead of reverberation time is also much easier for architects.

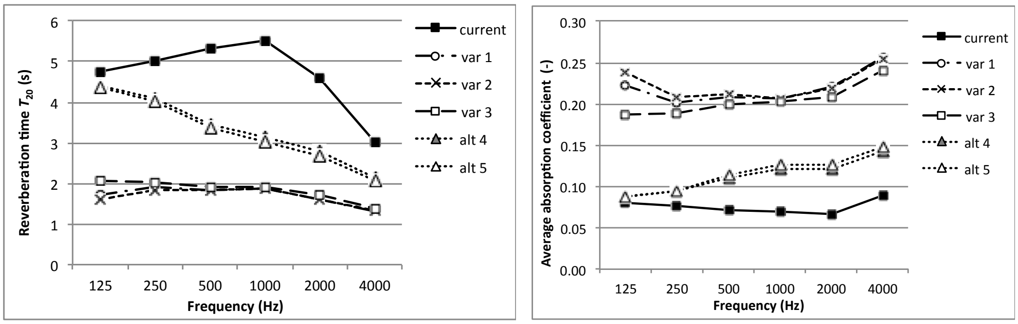

Fig. 4. Simulated values of reverberation time T_{20} (left) and average sound absorption (right)

For sake of simplicity, further in the text, only alternatives 1-3 will be analysed in terms of Strength *G* (dB), Clarity C_{80} (dB), Deutlichkeit *D* (-), Center time Ts (ms) and Lateral energy fractions LEF (-).

Sound pressure level distribution has been analysed through parameter Strength *G* (Fig. 5). Results of simulations are compared with Sabine's diffuse field theory and Barron's theory [13]. Figure 5 shows the data from measurements and 3 simulated alternatives. Differences between the Alt.1, 2 and 3 are not large, but the sound pressure level is in general lower for situation when the absorptive ceiling was placed on the wall behind the stage, e.g. Alt.1. This corresponds very well with theory and practice, which recommend to place a sound absorption close to the sound source in order to reduce noise in the room in most efficient way. The current situation (measured or simulated data) correlate very well with the Barron's theory, with only 0.5 dB differences (less then JND).

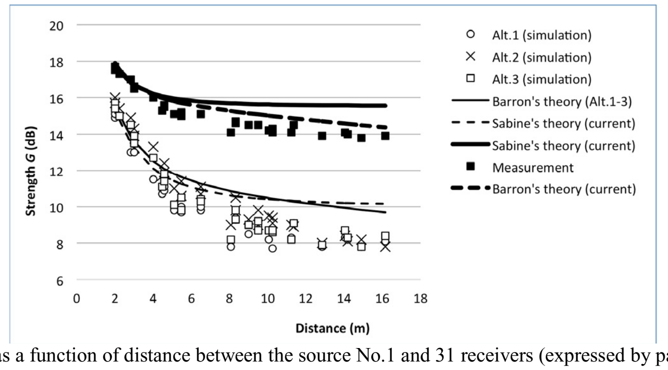

Fig. 5. Sound pressure level as a function of distance between the source No.1 and 31 receivers (expressed by parameter Strength *G* (dB)). Results are compared with calculation using Sabine's and Barron's theory.

Simulated results of the absorptive situations (Alt.1-3) are at distances > 8m from the sound source approximately 1-2 dB lower then theoretical calculation according to Barron theory. Differences between the alternatives are position dependent. According to the simulation, placement of the large amount of highly absorptive surface (> 300 m^2) in a room will help to reduce noise level in a diffuse field of the atrium with ca 8 dB. Theoretically calculated values would show the improvement of only 5 dB. It is because the theoretical calculation presumes equal distribution of sound absorption over all surfaces, and corresponds better in situations with low sound absorption in general.

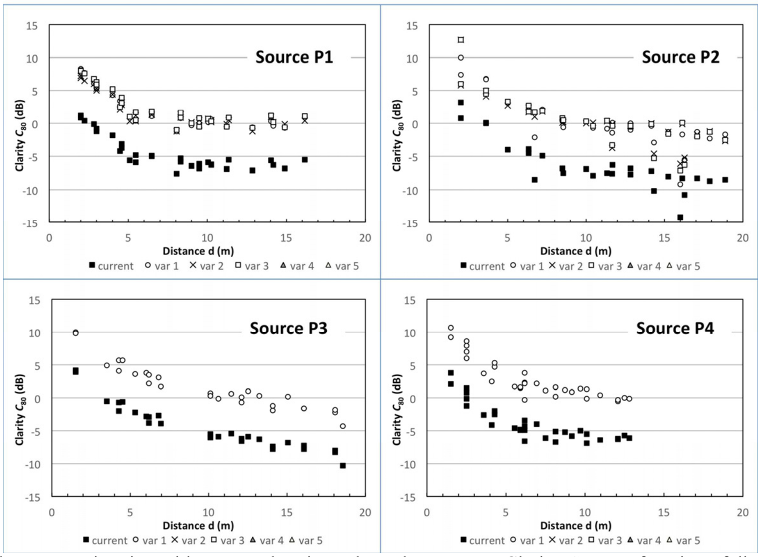

Fig. 6. Comparison of the current situation with proposed variants through parameter Clarity C_{80}, as a function of distance between sound source and receiver, based on simulation of 4 sound source positions.

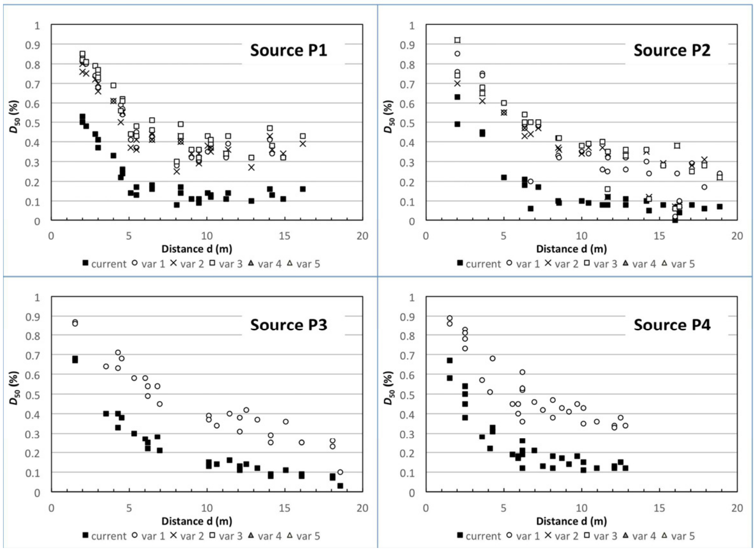

Fig. 7. Comparison of current situation with proposed variants through parameter Deutlichkeit D_{50} as a function of distance between the source an receivers (based on simulation)

In the analysis of the results of qualitative parameters Clarity C_{80} results (Fig. 6) it cannot be unnoticed that in simulations where the source was placed at the position P1 (Fig.2-right) there is a very different trend in decreasing of C_{80} values with a distance in the first 7m from the source in comparison with further distances. Decrease in clarity can be in the Figure 6 described in all alternatives (for P1) by two simple lines. The C_{80} values decrease with a distance from 2 to 7m almost linearly and above 7m they have a tendency to stay constant. It seems, like if there was a certain sharp distance (radius) splitting the spaces to a kind of "clarity free field" and "clarity diffuse field". In case of P4 we can see very similar trends (only slightly less pronounced). Sources P1 and P4 are places in the atrium in an area between two non paralel walls at a distance of about 10m, which is a distance that sound (c=340m/s) needs to travel in approximately 80 ms. This could be a possible hypothesis for explanation of the results, since clarity is defined as a logarithmic ration between the integral of sound pressure squared (of the impulse response) of sound reflection arriving in first 80 ms to the integral of the sound pressure squared of the late sound (> 80ms). Interestingly the mean free path in the given room is around 7.5m.

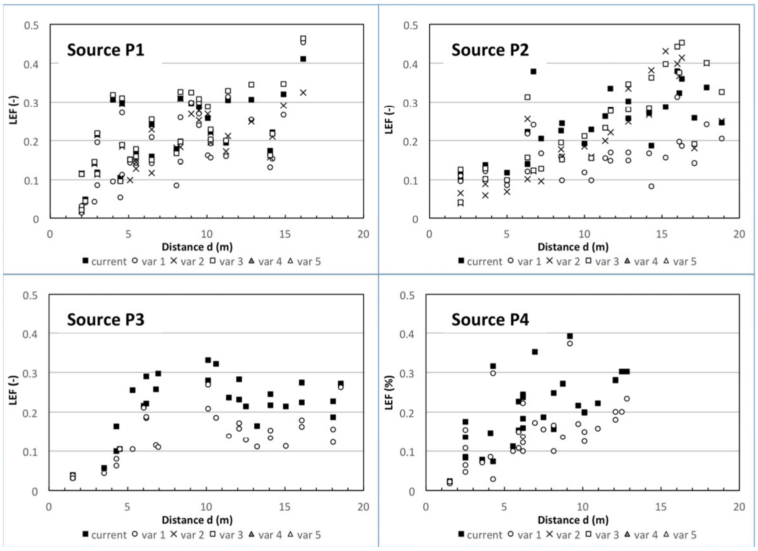

Fig. 8. Simulated values of LEF on 31 positions for simulated variants expressed as a function of distance, and compared with current situation.

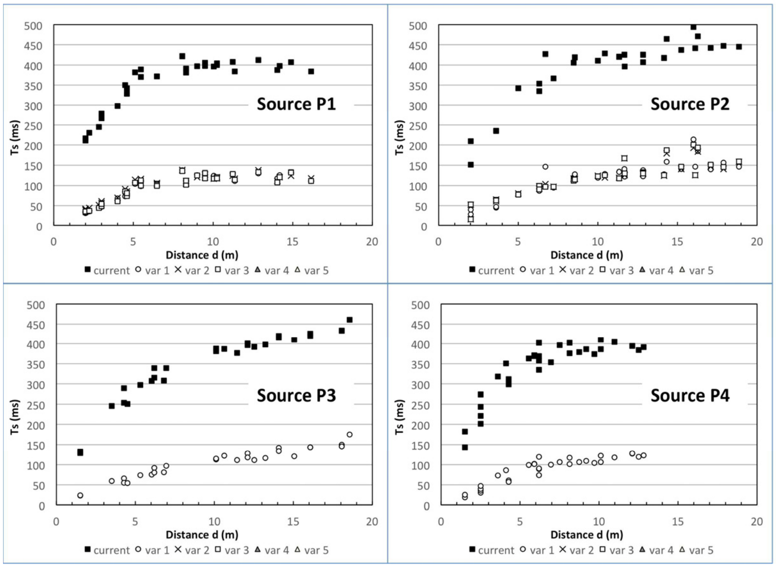

Fig. 9. Simulated values of Central Time (Ts) as a function of distance (Alt.1, 2and 3), compared with a current situation.

Simulated results of Deutlichkeit D_{50} (-) show similar trends like C_{80} (Fig.7). In the first 7-8 m, the speech intelligibility is dropping almost linearly, reaching values around 40%. At greater distances from the source the trend depends on the position of the sound source in the atrium

In rooms for music performances, spaciousness and lateral reflections of sound belong to important room acoustic parameters too. One of the possibilities to expres the mentioned features is to calculate so-called Lateral energy fractions LEF (-). Values of LEF are influenced by the shape of the room, such as its "narrowness" and the position of the sound source and receivers. In our case study, the trends for the four simulated sound source positions are very different (Fig.8). This is caused by the irregular shape of the room which tunes the ratio between the early lateral reflections of sound and the overall reverberation, depending on position of the sound source. This is an important observation in case music should be presented in the room. Suitable placing the stage at suitable position can help to reduce costs for other additional acoustic adjustments.

The last analysed parameter is so called Central time *T*s (ms). *T*s is the time of the centre of gravity of the squared impulse response and it typically correlates well with clarity of sound. High values are indicators of poorer clarity (Fig.9).

Conclusions

Results of the presented study have shown an interesting impact of the position of the additional sound absorption in the atrium place on its qualitative room acoustic parameters. While the same values of reverberation time have been observed in alternatives 1-3, differences of 1-2 dB on several receiver's positions were found depending on Alt1, 2 and 3, e.g. position of large sound absorbing surface. Probably the most interesting results are observed in case of Clarity and Deutlichkeit, where the decay of values with a position from the sound source is different from those expected by theory. This means that in large halls a shaping of the walls can have a significant impact on clarity of sound. When analysing the lateral energy fractions, as expected the position of the podium or stage is important once music performance should take place.

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References

[1] Ar-Ac Multibook for Architects, app
[2] Rychtarikova, M., Nijs, L., Saher, K., & van der Voorden, M. (2004). Architectural guidelines for living rooms, classrooms, offices, sports facilities and restaurants. In *33rd International Congress and Exposition on Noise Control Engineering, Prague, Czech Republic*.
[3] Ando, Y. (2012). *Concert hall acoustics* (Vol. 17). Springer Science & Business Media.
[4] Nijs, L., Saher, K., & den Ouden, D. (2008). Effect of room absorption on human vocal output in multitalker situations. *The Journal of the Acoustical Society of America*, *123*(2), 803-813.
[5] Jeon, J. Y., Lee, S. C., & Vorländer, M. (2004). Development of scattering surfaces for concert halls. *Applied acoustics*, *65*(4), 341-355.
[6] Nijs, L., & Vries, D. D. (2005). The young architect's guide to room acoustics. *Acoustical science and technology*, *26*(2), 229-232.
[7] Bielek, B. (2016). Strategy for cooling green buildings. *Applied Mechanics & Materials*, *820*.
[8] Hraska, J. (2015). Chronobiological aspects of green buildings daylighting. *Renewable Energy*, *73*, 109-114.
[9] Barron, M., & Marshall, A. H. (1981). Spatial impression due to early lateral reflections in concert halls: the derivation of a physical measure. *Journal of Sound and Vibration*, *77*(2), 211-232.
[10] ISO 3382 Measurement of room acoustic parameters.
[11] STN 73 0525: Design of room acoustics. General principles
[12] Odeon software, users manual, 2015
[13] Barron, M. (1996). Loudness in concert halls. In *Forum Acusticum* (pp. 21-29). University of Bath.
[14] Polmova, B., Vargova, A., Chemlik, V. & Urban, D. (2014) Multi–purpose Utilisation of Historic Building Glass Atrium. Case Study of the Slovak Philharmonic. In: Advanced Materials Research 899, 605-610