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Perception of acoustic comfort in large halls covered by transparent structural skins

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Large halls, such as shopping malls, atria or big entrance halls often suffer from various acoustic discomfort issues, which are not necessarily caused by extremely high noise levels. Due to the large size of halls and consequently the long trajectories that sound waves travel between the source, interior surfaces and the receiver, sound reflections arriving from surrounding surfaces are not as strong as they would be in smaller rooms. Reports in literature and comments by users of large halls concerning acoustic discomfort in large halls, refer mainly to continuous reverberation related noise. Therefore, quantification of the acoustic comfort by the reverberation time, which is related to the average absorption of interior surfaces and by the equivalent sound pressure level, which in a large space is dominated by direct sound, is not adequate to describe the global acoustic comfort or soundscape. Based on statistical noise analysis on auralized soudscapes, this article proposes a set of measurable monaural and binaural acoustic parameters that adequately describes the acoustic comfort in large halls. The study is focusing on rooms covered by traditional materials, such as glass, plexiglass, etc. , and ETFE (ethylene tetrafluoroethylene) foil structures.

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1. INTRODUCTION

Structural skins are known as a building design element with many positive effects in terms of thermal and visual comfort. Their contribution to the reduction of environmental impact[1,2], and even reduction of budgets cannot be denied. Nevertheless, architects usually chose more traditional materials such as glass when it comes to the design. Different kinds of foil structures, such as Ethylene-tetra-fluoro-ethylene (ETFE) foil are already known but their positive impact on acoustic comfort is not completely explored[3]. Most literature refer to the rain noise and similar matters, but only little information can be found in literature on the contribution of foil-based structures to the improvement of indoor comfort.[4]

Successfully realized projects with modern foil-based roof structures show the positive impact on acoustic comfort, which plays an important role for the decision of the design of large shopping malls, restaurants or shops by customers and in this way indirectly influences the economic success.

This paper compares acoustic conditions in an atrium covered by foil-based structures, with situations in which the roof is realized by other type of material, such as glass. Presented results are based on (1) impulse response measurements in situ, for determination of room acoustic parameters such as reverberation time, early decay time, clarity of sound and speech intelligibility and (2) sound pressure level measurements followed by statistical noise analysis to understand the direct impact of roof material on the background noise levels (L_{90}, L_{95}) and peaks in noise (L_5, L_{10}) in the rooms. Measured results are also compared with (3) room acoustic simulations of 9 different alternatives of interior sollution.

2. CASE STUDY

Thanks to a good reputation on acoustic comfort, the central atrium space at the secondary school in Oldenburg was chosen as a case study in this research (Figure 1-left). This space is covered by a transparent 3-layer Texlon® ETFE (ethylene-tetra-fluoro-ethylene) cushion system. The outer layer is printed for shading purposes. The two air chambers between the three ETFE foil layers of the Texlon® cushion system is stabilized by low inner air pressure of 200 Pa. The volume of space is approximately 8900 m^3 and the area of interior surfaces is approximately 4570 m^2.

Different materials are present in the interior of the atrium. The largest surfaces are made from ETFE cushions, glass, relatively absorptive walls and ceilings above balconies, and rigid walls with brick based linings. The atrium is mostly used as a central communication and gathering space for students during breaks. Space is air-conditioned and almost all parts of the school relate to the atrium.

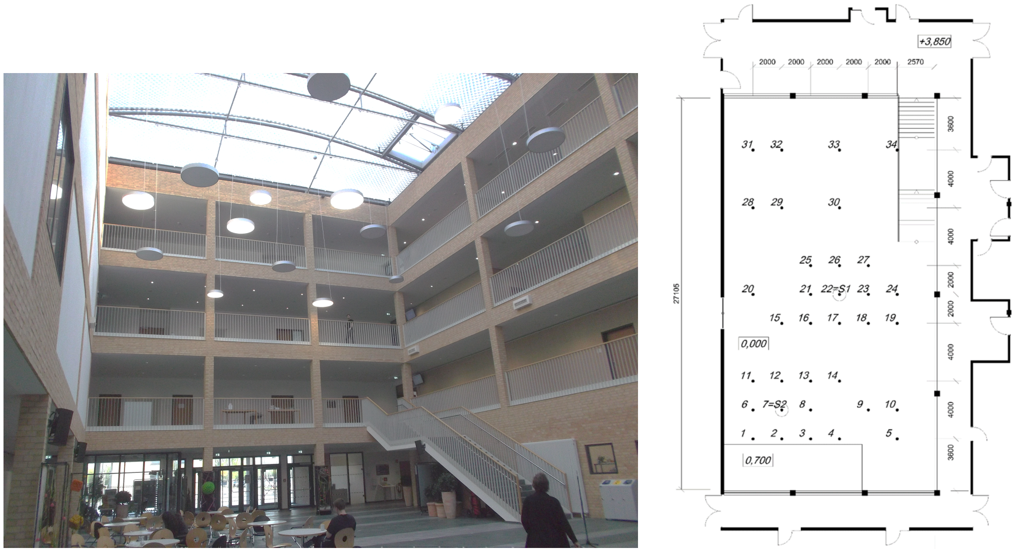

Figure 1. Positions of the sound source and microphones during the in-situ measurements (left), View of the atrium interior with Texlon® ETFE roofing system.

3. MEASUREMENTS AND SIMULATIONS

A. MEASUREMENTS

Background noise measurements and impulse response measurements were performed in the atrium in quiet period, before the students were present at school. The measured background noise in the hall before the lessons started and so in empty conditions L_{Aeq} = 42 dB. To determine the room acoustic properties of the space, impulse response measurements were performed according to ISO 3382[5] and ISO 18233[6] using sweep signals. Measurements were performed for 2 positions of omnidirectional loudspeaker and 34 microphone positions indicated in the Figure 1-left. The measured reverberation time was used for computer model calibration and it is therefore identical with the one of the simulation (Alt.1 in the Figure 2).

Beside the 2 operators of measurements, there were no people present in the atrium during the impulse response measurements, that could potentially increase the overall absorption in the room. Measurements in the atrium were performed as a part of the STSM stay in the framework of EU-COST action 1303[7].

B. SIMULATIONS

In oder to get insight in the influence of the roofing system on the acoustic comfort in an atrium, nine (9) different alternatives were simulated in Odeon software v10 (Figure 2). Alt.1-3 are expressing the current situation in the atrium in terms of walls and floor absorption, and they differ in terms of ceiling material and thus ceiling absorption. Alt.1 represents the atrium covered by ETFE foil cushions and as mentioned above, simulated data corresponds very well with measured data. Alt.2 is a virtual situation in which the ceiling is constructed by glass. Alt.3 was studied to investigate the impact of an extreem situation, i.e. highly reflective concrete ceiling, on the acoustic conditions in the room. Alt. 4-6 involve 3 different roof systems in a situation in which all other surfaces in the room (except for the ceiling) are made from concrete. Alt.7-9 show an extreme situation where all interior surfaces except for the ceiling are strongly absorptive, with an absorption coefficient α=50%.

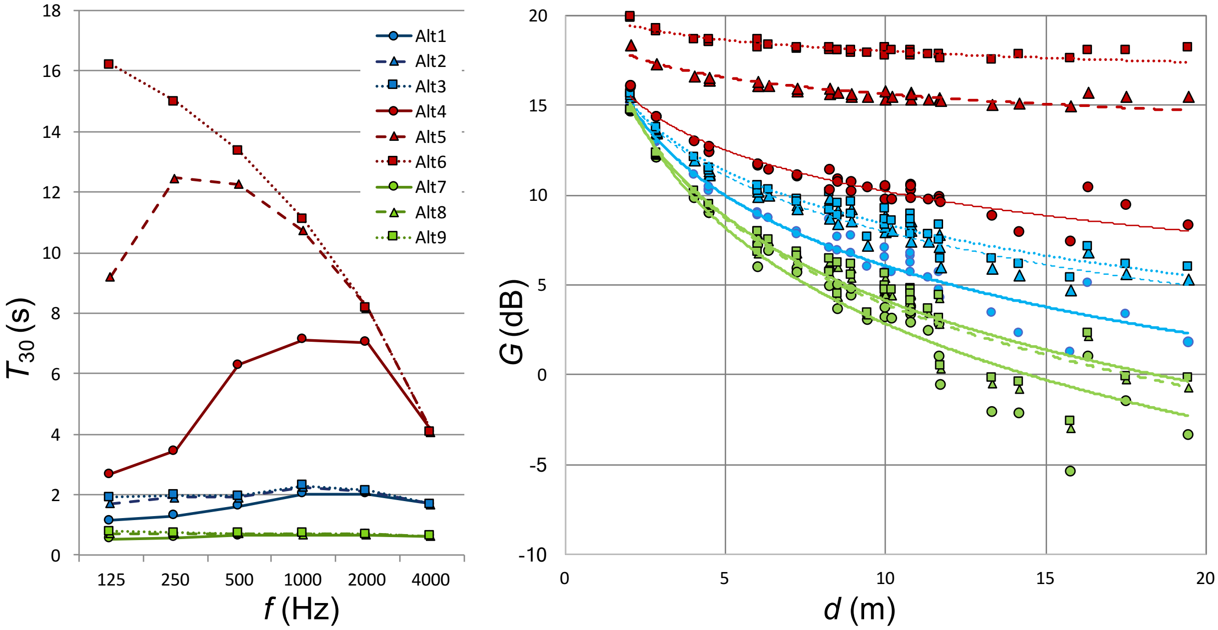

Figure 2. Nine simulated alternatives and their reverberation times (Alt.1 is current situation in the atrium) Left picture shows the reverberation time T30 (s) and Right picture shows the Strength G (dB) values for 125Hz. Green alternatives represent the absorptive walls-floor scenario, blue is the current situation of walls-floor materials and red is the situation with hard and highly reflective walls and floors.

To understand the acoustic comfort better and thus to estimate the background noise level in the hall caused by internal sources, a numerical simulation in Odeon software followed by auralisation was performed. In the simulations noise that is typically present in atria was emitted in the virtual atrium. Two kinds of noise signal were used: (1) restaurant sound that consisted of talking people, clinking cutlery, etc and (2) music sound with modulation and dynamics differing from the ones of the restaurant noise.

Like in urban noise assessment, statistical noise analysis was performed on auralized sounds in 9 alternatives. Statistical levels L_{90} and L_{95} were calculated and analysed in detail.

4. RESULTS AND DISCUSSION

The simulated reverberation times T_{30} (s) per octave band, for the different acoustic scenarios is shown in the Figure 2. The results show that differences between the alternatives are audible in the low and middle frequencies. (The so called just noticeable difference (JND) for the reverberation time is defined as 10%). In high frequencies, the sound absorption coefficient of the three different materials (foil, glass and concrete) is almost the same. Also, at high frequencies, sound absorption by air is rather high making the differences between alternatives smaller. Figure 2 also shows that that the impact of ceiling material on the sound pressure level is most significant in cases with hard concrete walls.

Significant differences in the decay of sound pressure level with distance are found between the different wall/floor-materials groups (Alt.1-3: current situation, Alt 4-6: highly reflecting walls/floor, Alt.7-9: absorbing walls/floor). At low frequencies, clear differences are present between the alternatives with foil ceiling (e.g. Alt.1, Alt.4 and Alt.7) and the other alternatives. In the most reverberant situation (with highly reflecting concrete walls and floor), the glass ceiling (Alt.5) performs better (ca 3-4 dB lower G-value) than the concrete celling (Alt.6). At larger distances from noise sources, application of a foil cushion system in very reverberant situations can help to reduce sound with 8-10 dB. In the middle frequencies, these improvements are less significant since the porosity of the foil cushions, and glass is as low as the one of concrete. Only in the most reverberant situation, a ceiling based on ETFE (Alt.4) slightly (2dB) helps more to reduce the sound pressure level, in comparison with class (Alt.5) or concrete (Alt.6) ceiling.

1.1 STATISTICAL NOISE ANALYSIS

Statistical noise analysis was performed for (1) restaurant sound and (2) sound of music binaurally auralized in 9 different scenarios. Figure 3 shows the results for the parameters L_{90} and L_{95}. For both types of sound, there are significant differences between the different wall treatment cases, i.e. between the groups "Alt.1-3" (current situation in the atrium), "Alt 4-6" (atrium with highly reflecting walls and floor) and "Alt.7-9" (atrium with absorbing walls and floor). This confirms our expectations, since the distance between the walls is smaller than the distance between the ceiling and the floor, and since the surface of the walls is larger than the one of the ceiling. The simulated receivers in auralized sounds were not simulated as omnidirectional microphones, but as human heads and thus binaurally. The sound arriving from horizontal directions have influenced the sound levels more significantly.

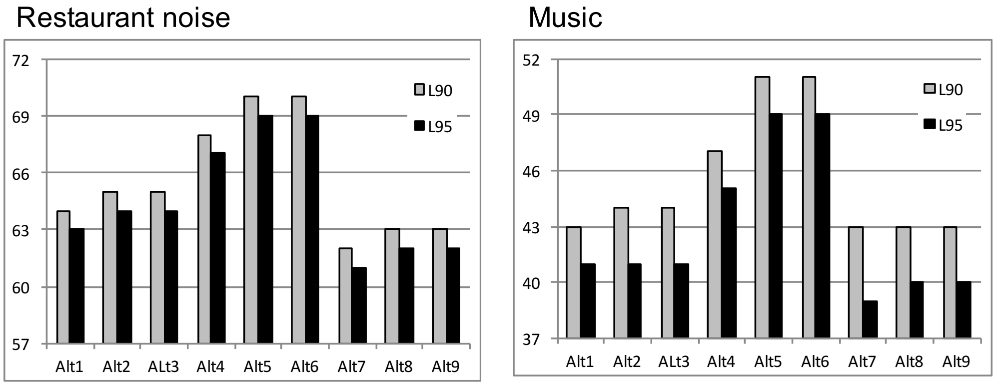

Figure 3. Statistical noise levels L_{90} and L_{95} (in dB) for auralized restaurant noise and music signal. Alt. 1,4,7 are scenarios with a foil ceiling, Alt. 2,5,8 with a glass ceiling and Alt. 3,6,9 with a concrete ceiling. Alt. 1,2,3 correspond with the current situation of the BBS atrium. Alt. 4,5,6 are scenarios with highly reflecting walls and floor, Alt. 7,8,9 are scenarios with absorbing walls and floor.

Except for the case of music with absorbing walls (Alt.7,8,9), there is an audible reduction in the (background) noise quantities for the scenarios with ceiling based on ETFE (Alt.1,3,5), compared to the other scenarios. These differences are expected to become prominent for background sound with more low frequency content. As expected, the effect of ETFE ceiling is most significant in the reverberant situation.

5. CONCLUSION

The reverberation time in an atrium with a volume of about 8900 m^3 with total area of interior surfaces of ca 4570 m^2 was significantly influenced by material used on the ceiling (roof). Thanks to a foil structure a significant reduction in reverberation time (in comparison with hard surface material) was achieved in middle and low frequencies. The difference in decay of G values with distance due to different ceiling material was significant mainly at low frequencies and in cases when walls and floors are highly reflective. It seem, that ETFE roof systems might offer a very convenient solution in renovation projects where historical walls are hard and cannot be changed due to monument protection reasons[8].

Thanks to a statistical noise analysis applied on auralized sounds differences between the three wall material conditions can be judged in terms of background noise in atrium due to internal noise sources. Noticeable differences in background noise described through L_{90} and L_{95} values are found between an atrium covered by foil and by the two other roof materials. Differences are subtle since the used noise did not contain strong low frequency components and since the fluctuations in chosen signals were rather high. Future research should therefore aim on prediction of background noise level in large halls caused by footsteps or other noises.

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