LARGE FORMAT ACOUSTIC STRUCTURES IN THE CONCERT HALLS

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Abstract
Large surfaces of ceiling, walls and audiences of concert halls, as well as large reflecting surfaces hung over the stage, particularly influence the acoustics of the rooms interiors.
The paper presents the results of simulation and experimental research of that kind of structures in a few concert halls. We have examined halls on a horseshoe and fan plans equipped, among others, with large surfaces of Schroeder diffuser or consisting of displaced equilateral triangles. Taking advantage of obtained acoustic parameters on audience surface, interesting acoustic effects were revealed. Large format acoustic structures could positively impact on the acoustic field inside the room, but can also result in negative acoustic effects. It was indicated that a sound strength G parameter was particularly helpful in identification of the influence of analyzed surfaces on the acoustics.

Keywords: room acoustics, acoustic structures, interference

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1 Introduction

Without a doubt, audience, ceiling, side and rear walls are large surfaces, that have crucial impact in creating acoustic field in concert halls. If the surface area is significant, even small differences in acoustic parameters of that kind of structure makes a great difference in room acoustics [1]. However rarely noticed problem is connected with large surfaces with repetitive geometrical structures like sin-like waves, equilateral triangles or Schroeder diffusers. A good example is a single semi-cylinder, which reflects sound in all directions almost perfectly, while using several kinds of such structures in a row, is a reason of serious sound waves interferences resulting in sound level distribution irregularity [2], [3]. That kind of problem is significant because the most frequently used for room acoustic simulations ray tracing method ignores phenomenon of interferences.

The paper presents the influence of large surfaces acoustic treatment on the distribution of acoustic energetic parameters of the interior. Analysis is based on numerical calculations and acoustic measurements in two music rooms with specific shapes. In auditoria, very important is also a large surface of audience [4], [5] as well as overhead stage canopies [6], [7]. However, it is very complex theme, that should be dealt with as a separate paper. Conclusions from the study help to choose a proper shape and materials for large surfaces in auditoria.

2 Studies

2.1 Examined objects

In the analysis there were two objects included, that recently were renovated according to acoustic guidelines. In Figure 1, there is Artur Malawski Podkarpacka Philharmonic in Rzeszów. In the auditorium, there are characteristic large homogenious surfaces of ceiling, side walls and audience.
In the philharmony, there are mostly symphonic concerts, as well as small theater plays and conferences. It is a fan-shaped room with amphitheater audience, divided into six sectors. Difference in audience heigth is 5 m, area of the audience: 530 m^2. On the right side wall (looking at the stage) there are four boxes, that makes the room not symmetric. Stage area is equal to 270 m^2. The ceiling is made of 3 meters long tilted equilateral triangles, that improve the sound field diffusiveness.

Figure 1 - Podkarpacka Philharmonic interior.

The volume of the room is about 7050 m^3, and it is designed for 757 listeners (plus 43 in boxes). Interior is 35.5 m long, and 14 - 29.5 m wide. Height of the ceiling is between 4.7 and 11 m in the middle of the auditory.
Lviv National Theatre of Opera and Ballet of Solomiya Krushelnytska was built in 1900. The audience volume is about 5500 m^3 designed for 998 listeners. In 2008 there was a renovation of the floor and upholstery (Figure 2). Four years later, Schroeder diffuser was mounted on the under balcony part of the rear wall. Diffusing panels are mounted on the concave surface of 12.6 x 1.8 m (Figure 3).

Figure 2 – Lviv Opera interior

Figure 3 – Lviv Opera rear wall with sound diffuser

The main goal of diffuser installation was the correction of acoustic faults created by disadvantageous dimensions of the space under balcony on the ground floor, excessive sound absorption of upholstered walls and armchairs, as well as sound focusing effect due to rear wall concave shape.
That kind of faults decreased the quality of subjective impressions in listening to the music and speech in under balcony space, as well as in places near sound focus. Acoustic measurements before and after installation of the sound diffuser, let one assess its influence on overall room acoustics.

2.2 Research methodology

Acoustic measurements in Podkarpacka Philharmonic and in Lviv Opera were made according to ISO 3382-1 standard [8] using omnidirectional sound source and microphones. The number of receiver positions was much bigger than recommended in the standard in order to increase the precision of acoustic parameter distribution measurements. Sound source was placed on the stage.
Meausrements results were used to calibrate numerical models. Finite elements method was used to analyze the distribution of sound pressure levels in the audience area for different shapes of large homogenous surfaces. In Podkarpacka Philharmonic, there were four different variants of side walls (Figure 5) as well as four different shapes of ceilings (Figure 8). In Lviv opera, two different acoustic treatments of rear concave wall were analyzed (Figure 3).

3 Results

3.1 Podkarpacka Philharmonic

In Figure 4, there is a frequency characteristics of reverberation time T30 presented for empty and occupied room. Both characteristics fit the +/-20% tolerance for almost all frequencies.

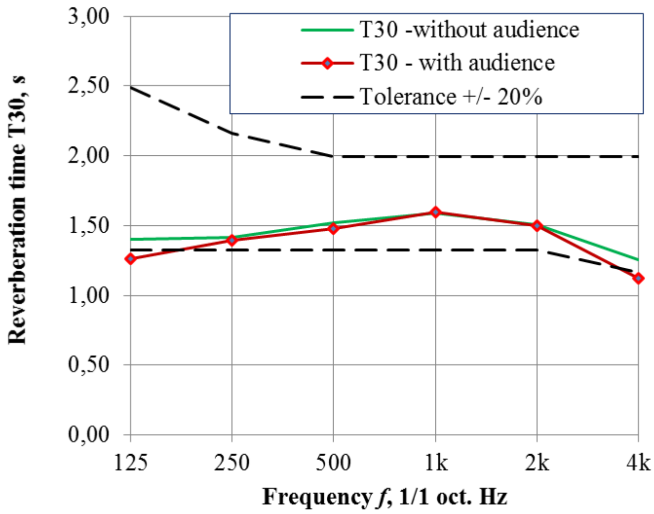

Figure 4 - Frequency characteristics of reverberation time T30 measured in Podkarpacka Philharmonic for empty and occupied room.

Four different types of side walls (Figure 5) as well as four different ceiling variants were analyzed (Figure 8). Calculations were made using finite element method, in 2D domain for cross section of the room. For all materials, there was applied absorption coefficient equal to 0.1 for all analyzed frequencies.

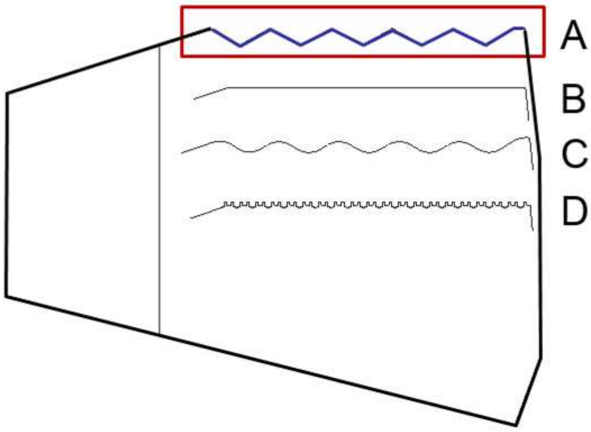

Figure 5 – Podkarpacka Philharmonic plan with four different shapes of the side wall. A - existing wall, B - flat wall, C - waves shaped wall, D - wall with Schroeder diffuser.

In Figures 6 (a, b) sound pressure levels depending on the distance from the stage for different shapes of side walls are presented, respectively for 800 and 1250 Hz.

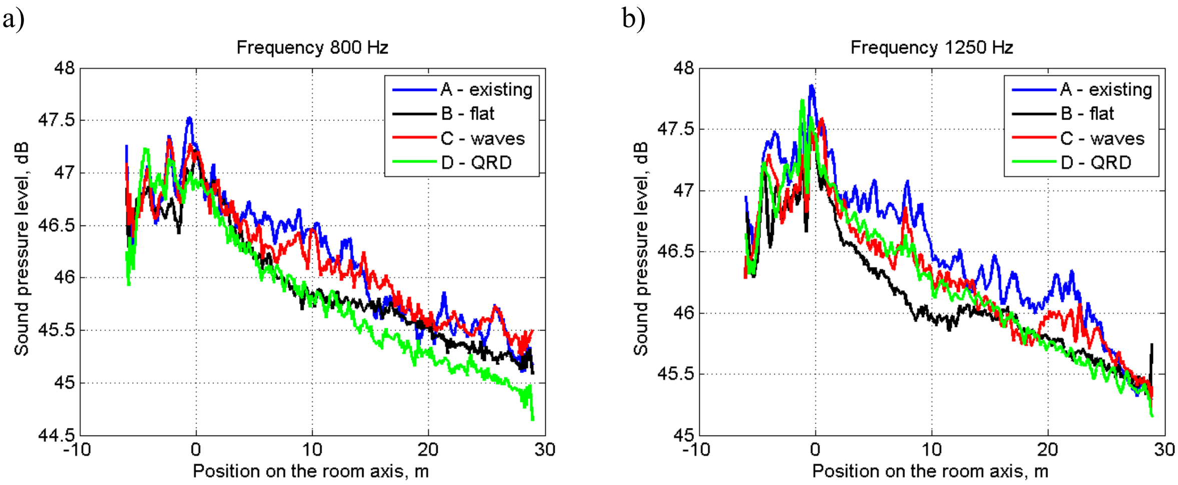

Figure 6 – Sound pressure level for frequency a) 800 Hz and b) 1250 Hz versus distance on the axis of the room from the sound source for four different shapes of the side walls.

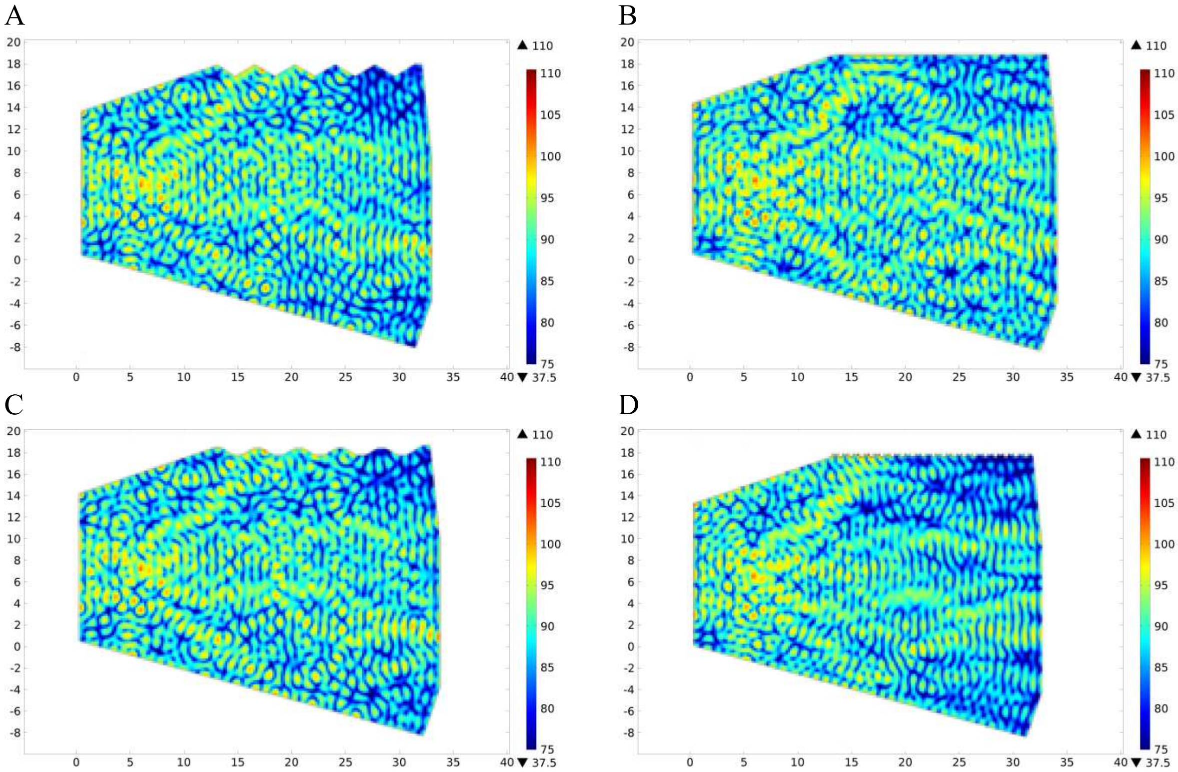

Figure 7 – Sound pressure level at 200 Hz distribution in Podkarpacka Philharmonic plan for four different side wall shapes. A - existing wall, B - flat wall, C - waves shaped wall, D - wall with Schroeder diffuser

As it could be seen in Figure 6, existing side wall's shape (A), as well as waves shaped wall (C) provide the highest sound pressure levels in the audience area. However, for these profiles, linearity of decrease of the sound pressure level over distance from the stage is the most uneven. A complicated shape of the side wall is a source of many sound reflections directed in different directions (Figure 7). As a result, there are areas on the audience of higher and lower sound pressure level. Flat side wall (B) gives locally linear decrease of the sound level over the distance from the stage, but with lower values. What is more, because of the concentration of reflections in the middle of the room (Figure 7), there is characteristic inflection of the decay curve in that area (Figure 6). Wall with Schroeder diffuser (D) gives the best uniformity of the sound decay over distance from the stage, but at the same time causes low sound pressure level.

In the next stage, the influence of the ceiling's shape on the uniformity of sound pressure level in the audience area was analyzed. Four different variants of ceilings were analyzed (Figure 8).

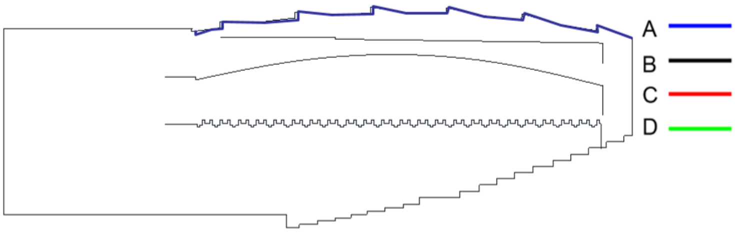

Figure 8 – Cross section of Podkarpacka Philharmonic with four different ceiling shapes. A - existing ceiling, B - flat ceiling, C - concave ceiling, D - ceiling with Schroeder diffuser.

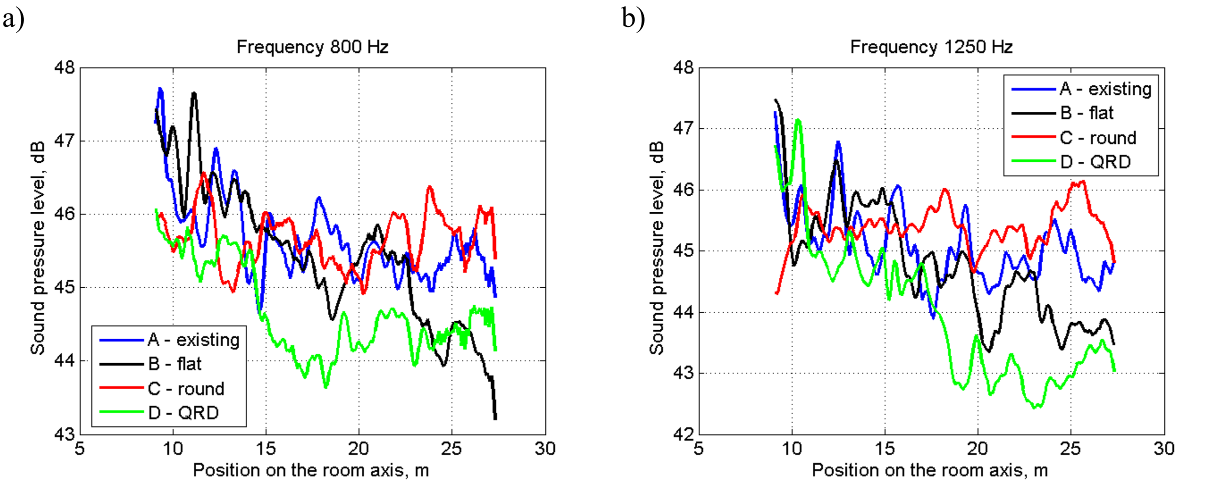

Figure 9 – Sound pressure level for frequency a) 800 Hz and b) 1250 Hz versus distance on the axis of the room from the sound source for four different shapes of the ceiling.

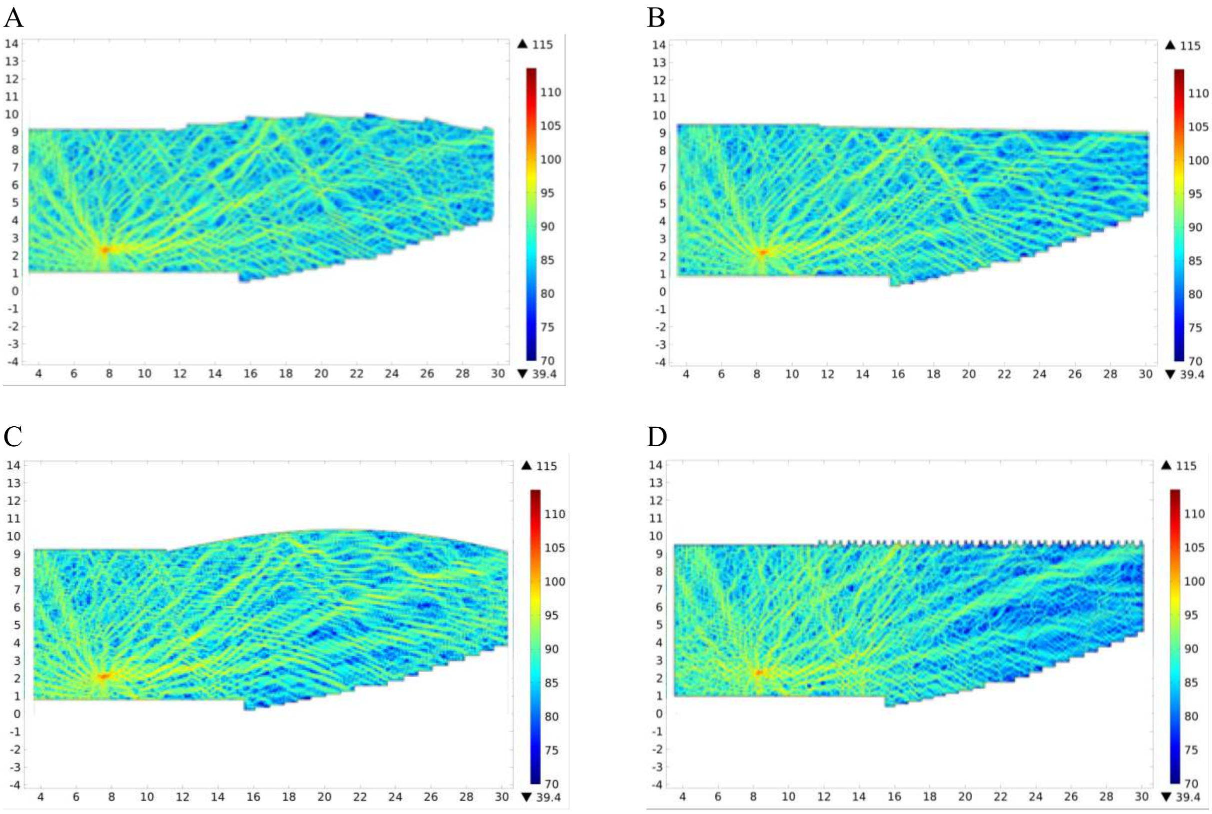

Figure 10 – Distribution of sound pressure level at 1000 Hz for four different shapes of the ceiling. A - existing ceiling, B - flat ceiling, C - concave ceiling, D - ceiling with Schroeder diffuser.

In Figure 10 (A-D) distribution of sound pressure level for four different shapes of the ceiling in Podkarpacka Philharmonic is shown. Figure 8 shows the cross section of the existing ceiling (shape A), that is made from 3 m long equilateral triangles. Plates are tilted to diffuse the sound field inside the room (figure 1).
Curves of sound pressure level versus distance from the stage for different ceiling shapes (Figure 9) reveal that for profile A and C there are highest values for most distances. What is more, for the concave ceiling, some area with local maximum and minimum could be observed. For the flat ceiling (B), like for the flat side wall, there are some irregularities in sound pressure level with significant reduction of sound energy in the rear part of the room (Figure 9). Putting Schroeder diffuser on the ceiling (D), increases the uniformity of the sound field in the audience area, but decreases the sound pressure level.

3.2 Lviv Opera acoustic parameters' measurements

In Figure 11 sound strength G_{4kHz} distribution in Lviv Opera is presented. Figure 11a and 11b are results of G_{4kHz} measurement before (a) and after (b) acoustic treatment. Figure 11c depicts the impact of acoustic treatment of the rear wall on analyzed parameter. Sound strength G_{4kHz} distribution was selected as being the most sensitive on rear wall modification. Changing thick textile upholstery to Schroeder diffuser gives audible results especially for under balcony area. Sound diffusers on the rear wall improve uniformity of the sound field in the audience area and reduce the focusing effect in the middle of the auditorium [9].

a) b) c)

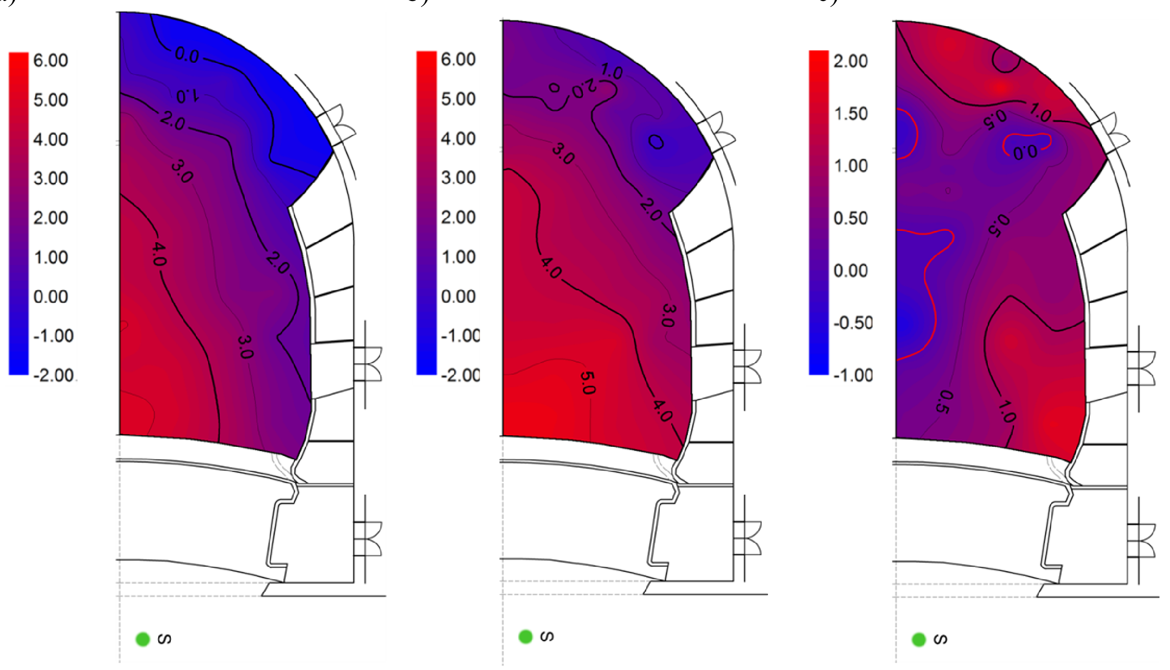

Figure 11 – Distribution of sound strength G4kHz in Lviv Opera measured for different wall acoustic treatment. a) sound absorbing upholstery, b) Schroeder diffuser, c) difference

Similar results were obtained using finite element methods. In Figure 12 there are distributions of sound pressure levels calculated for acoustic treatments described above. Again Schroeder diffuser on concave rear wall increased uniformity of the sound pressure level distribution under balconies and in the middle of the room. Higher levels of sound pressure are a result of lower sound absorption coefficients of Schroeder diffuser.

a) b)

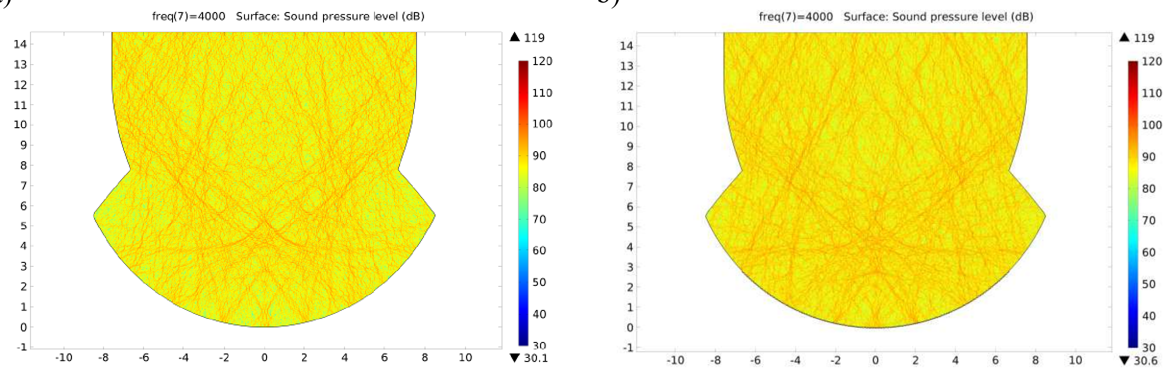

Figure 12 a) Distribution of sound presure level before modernization
b) Distribution of sound presure level after modernization

4 Conclusions

Large format surfaces in audience rooms with sound diffusers increase the uniformity of sound pressure level distribution but also could decrease the sound level in the room.
Using finite elements method, sound pressure levels in the audience area were analyzed for different variants of large surfaces. For Podkarpacka Philharmonic, four different side walls as well as ceiling shapes were analyzed. For Lviv Opera, the impact of acoustic treatment of concave rear wall on distribution of acoustic energy in the room was studied.
Large surfaces of Schroeder diffusers increased the uniformity of the sound pressure level inside the room, but could decrease the acoustic energy in the room. Flat or concave surfaces are sources of irregularity of distribution of sound pressure level, but give higher amplitudes of reflections.

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