Milica Jovanoska
Assistant
Ss. Cyril and Methodius University
Faculty of Civil Engineering - Skopje
24, Partizanski odredi blvd, 1000
m.jovanoska@gf.ukim.edu.mk

Todorka Samardzioska
PhD, Full Professor
Ss. Cyril and Methodius University
Faculty of Civil Engineering - Skopje
24, Partizanski odredi blvd, 1000
samardzioska@gf.ukim.edu.mk

CLASSROOM ACOUSTICS ASSESSMENT

The concept of “good acoustics” is a combination of subjective and objective acoustic parameters, [1]. The relevant parameters can be obtained using measurements or with numerical and analytical calculation. Real-time analysis allows the whole spectrum of a sound to be analyzed and to consider several parameters simultaneously.

To determine the sound fields and reverberation times in a selected classroom, in situ measurements were performed. Pink noise was generated from speakers and measurements were carried out using sound level meter. The sound source was located on the usual teacher’s position, centrally in relation to the width of the room and 11 measurement positions were used to register the sound.

To expand the information of the classroom acoustics, analytical and numerical analyses were carried out. Room modes were obtained using both analytical and numerical calculation, in order to see how they interact with the generated sound fields. For the low frequencies, FEM Pressure Acoustics Analysis in Frequency Domain Module was performed and for high frequencies, Geometric Acoustics - Ray Tracing method was used. Numerical analyses were conducted using the multi-physics software COMSOL.

The pronounced reflective nature of all constituent surfaces of the room is the main problem. This can be confirmed by the extremely large values of the reverberation time. To achieve satisfactory acoustics, sound absorbing materials is required.

Keywords: classroom acoustics, room modes, pressure acoustics, ray tracing

1. INTRODUCTION

Sound communication, which is the fundamental mechanism for perception, transmission and exchange of information, imposes the need for acoustic optimization of the rooms. Depending on the purpose of the room, various criteria for acoustic quality are set, starting from elementary comfort to precisely defined acoustic needs in rooms with specific purpose, such as concert halls, theatres, recording studios, etc. Low quality of classroom acoustics leads to poor speech perception, poor listening comprehension, sound-induced disturbance and vocal fatigue in teachers. This emphasizes the importance of classroom acoustic quality.

The main parameter for defining the acoustic quality of a room is reverberation time, T60 - time required for a steady sound pressure level to decay by 60 dB after turning off the sound source. With development of signal processing techniques and software, additional parameters have been developed such as Clarity (C50) and Speech Transfer Index (STI). These parameters can be calculated from the measured reverberation time with relations derived by Baron and Lee, [2], but also can be obtained from numerical analysis, from the Impulse Response and Energy Decay Curves, [3].

2. EXPERIMENTAL RESULTS

Adapting the basement space of the Faculty of Civil Engineering in Skopje, an auxiliary classroom was built, Figure 1. The classroom has a rectangular shape with plane dimensions of 6.73 m x 13.76 m and h=3.00 m up to the beam and h=3.30 m up to the slab. The walls are built of plastered concrete, the ceiling is uncovered ribbed concrete slab and the floor is covered with linoleum. Painted plywood panels are hanged on the walls. These panels are used during the student exhibitions. It is obvious that all of the interior surfaces of the considered classroom are hard and exclusively reflective. There is a lack of sound absorption surface and therefore, a long reverberation time (bad acoustics) in the classroom is expected.

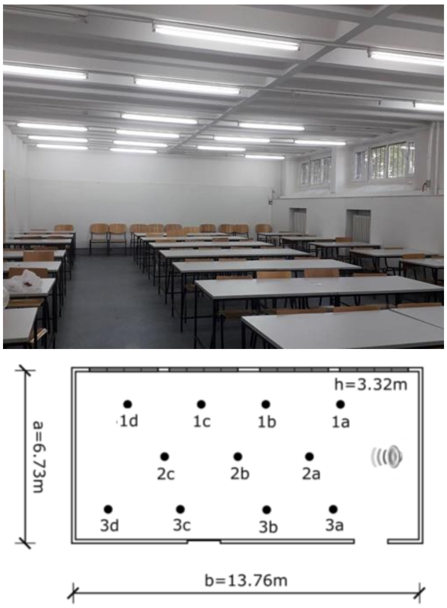

Figure 1. Interior and geometry of the classroom

In order to examine the acoustic quality of the classroom, several measurements were performed using the sound level meter Cirrus 171b (class 1 microphone, microphone pre-amplifier, 1:3 octave band filters). The sound source position and the pattern of the measurement positions are given in Figure 1. The sound level, L, is recorded in 11 positions in three levels (h_1 = 1.2 m, h_2 = 1.5 m, h_3 = 2 m). For each measuring position and for each level, 3 measurements were performed, and then averaged. Graphic representation of the sound field for f=250 Hz and f=500 Hz is shown in Figure 2.

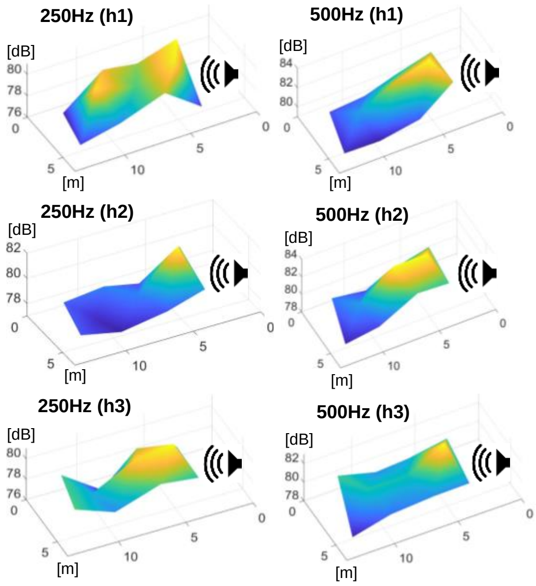

Figure 2. Sound field in the classroom for 250 Hz and 500 Hz

For each measuring position, the reverberation time is obtained as the mean value of 3 measurements. For low frequencies, T60 has values between 2.5 - 3.5 sec, for middle frequencies between 2.1 - 2.5 sec and for high frequencies between 1.6 - 2.1 sec, Figure 3. Recommended value of the mean reverberation time as a function of the room volume, for speech purpose is 0.5 - 0.7 sec, [6], which is not satisfied in this case.

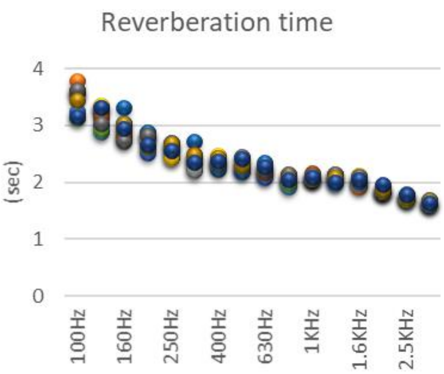

Figure 3. Reverberation time

3. ANALITICAL AND NUMERICAL RESULTS

3.1 ROOM MODES

The resonance frequencies in a room are called room modes or standing waves. The term regular room refers to a room that has three pairs of parallel walls. The room extends from x=0 to $x=L_x$ in the x-direction, and similarly from y=0 to $y=L_y$ and from z=0 to $z=L_z$. It is assumed that all walls are rigid, which means that normal components of the velocity of particles disappear at the surface of the walls. Starting from the Helmholtz equation and setting the appropriate boundary conditions, the room modes can be obtained from the relations, [5]:

$$f_{nx,ny,nz} = \frac{c}{2\pi} k_{nx,ny,nz} \quad (1)$$

$$k_{nx,ny,nz} = \pi[\sqrt{(\frac{n_x}{L_x})^2 + (\frac{n_y}{L_y})^2 + (\frac{n_z}{L_z})^2}\ ] \quad (2)$$

where n_x, n_y and n_z are positive integers that identify the room mode, c is the speed of sound in the air and k is the wave number.

Most of the sound energy is stored in the axial, then tangential modes, while the oblique modes are negligible. Above the Schroeder frequency (f_s), the room acts as a reverberant room, while bellow the Schroeder frequency the influences of discrete modes dominate (modal region).

For the room under consideration, the average reverberation time is T=2.5 sec, while the volume is equal to V= 13.76 x 6.73 x 3.15 = 291.7 m^3, hence:

$$f_s = 2000\sqrt{\frac{T}{V}} = 185\,\text{Hz} \quad (3)$$

If we adopt perfect regular form for the room, from the Equation 1 and Equation 2, the axial, tangential and spatial room modes can be calculated under the Schroeder frequency.

Table 1. Several room modes

12.46 Hz	1-0-0	ax	147.74 Hz	6-5-0	tan
24.93 Hz	2-0-0	ax	149.15 Hz	0-4-2	tan
25.48 Hz	0-1-0	ax	149.56 Hz	12-0-0	ax
28.37 Hz	1-1-0	tan	151.57 Hz	9-4-0	tan
35.65 Hz	2-1-0	tan	151.72 Hz	12-1-0	tan
37.39 Hz	3-0-0	ax	152.9 Hz	0-6-0	ax

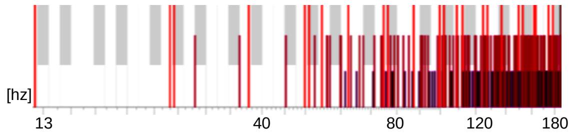

Figure 4. Distribution of the room modes under Schroeder frequency

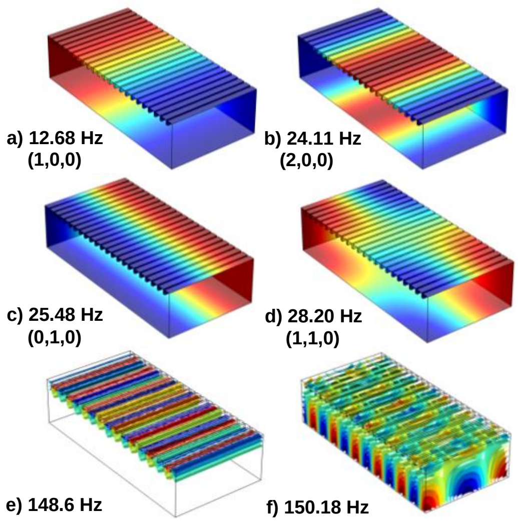

Figure 5. Room modes from COMSOL

This simulation in Pressure Acoustics interface in COMSOL predicts eigenmodes that for the low frequency strongly resemble with the analytical solution, Figure 5, a-d. The higher the frequency, the more the geometry details matters, in this case the concrete ribs interfere, Figure 5, e-f.

3.2 PRESSURE ACOUSTICS – FREQUENCY DOMAIN

The behaviour of rooms at low frequencies is analysed solving Helmholtz equation using the finite element method. In order to resolve the wave, the mesh size should be less than $\lambda/6$, where λ is wavelength. FEM method can be used optimally up to 2-3 kHz, after this region, the number of the degrees of freedom is too high and the computational effort is non-reasonable.

The model assumes that all boundaries are hard (rigid) boundaries. This can be easily changed and adapt to the real characteristics via absorption coefficients etc. The membranes of the speakers are modelled with normal acceleration boundary condition.

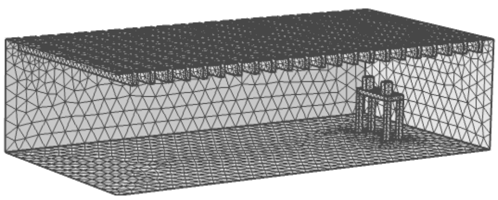

Figure 6. Model mesh

The distribution of the sound pressure level for f=250 Hz is presented in the Figure 7. The plots for h1, h2 and h3 levels are also given.

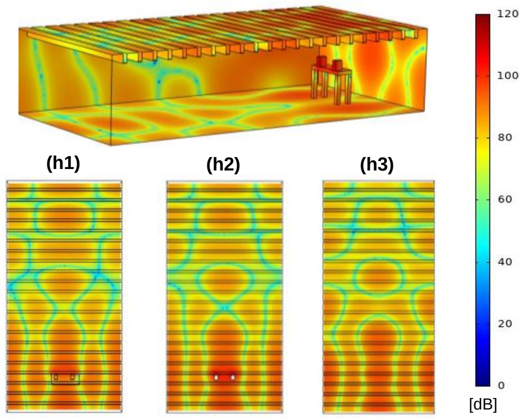

Figure 7. Sound pressure level, f=250 Hz

The measured sound level is more precise, but the numerically obtained sound level gives more detailed presentation and may have satisfactory accuracy.

3.3 RAY TRACING

For large geometries or/and high frequencies, the Geometry acoustics (Ray Tracing, Acoustic Diffusion) gives the more optimal results. The big advance for this method is that only coarse meshing of boundaries is needed. With Ray Tracing, the trajectories, phase, and intensity of acoustic rays can be computed, and also the impulse response.

The boundaries are modeled as concrete with recommended absorption coefficient with specular reflection and the source is modeled with spherical radiation. Specular reflection is a mirror-like reflection. The ray trajectories for different time sequences are given in Figure 8.

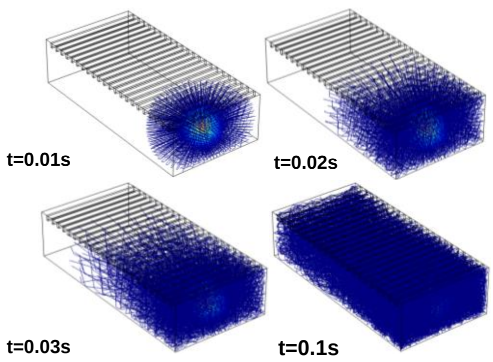

Figure 8. Ray trajectories

In order to obtain the impulse response, it is necessary to model the sound power and intensity through the rays. The propagation in the unmeshed domains is defined with the material properties of the fluid - air.

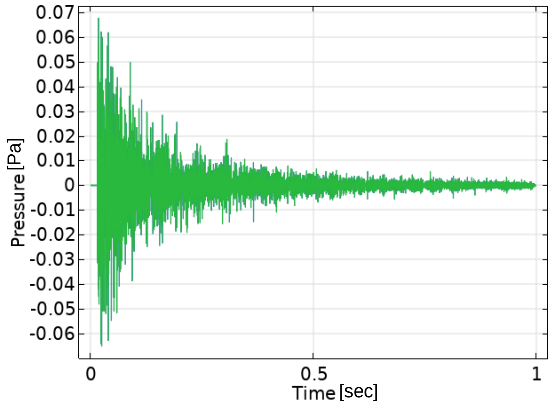

Figure 9. Impulse response for a defined receiver position

From the impulse response, with additional post-processing, relevant acoustic parameters can be obtained, such as C50, EDT, STI etc.

4. CONCLUSION

In classrooms and lecture halls, it is necessary to ensure clear perception of speech. The main problem in the analyzed classroom is the pronounced reflective nature of all surfaces. This is shown by the large values of the reverberation time. Regarding Sabine's equation, [5], to achieve an optimal reverberation time of 0.5 sec, an equivalent absorption area A=93.93 m^2 is required. According to the mean measured value T= 2.5 sec, A=18.79 m^2, which is five times less than the required absorption area. As the classroom falls into medium-volume rooms, by installing sufficient absorption surface, the Schroeder frequency will be shifted towards lower region, avoiding the modal region problem.

Numerical methods can simulate virtual measurements and/or expand all the necessary data, which is difficult to obtain with measurements regarding the fact that one microphone is one measuring point.

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