ACOUSTIC MODELLING AND OPTIMIZATION OF A ROOM

Norbert TOMA, Marina TOPA, Irina MURESAN, Botond KIREI, Marius NEAG, Albert FAZAKAS
Faculty of Electronics, Telecommunications and Information Technology, Technical University of Cluj-Napoca
Str. G. Bariţiu nr. 26-28,400020 Cluj-Napoca, Romania, Tel: +40264401243; Fax: +40264591340
Marina.Topa@bel.utcluj.ro

Abstract: The paper presents the analysis and improvement of a room's acoustics using both software and hardware tools. First a model of the room is proposed taking into account the comparison of simulation and experimental results. Next improvements in the architecture are suggested and then the optimal placement of loudspeakers and listeners is provided. The performance is measured in terms of acoustic parameters.

Keywords: *room acoustics, modelling, reverberation time, sound pressure, acoustic parameters.*

I. Introduction

Rooms acoustics describe how the sound behaves in an enclosed space. Due to the rooms finite dimensions, reflections of the sound wave occur, giving birth to the echo room reverberation phenomenon. Depending on the rooms use, more or less reverberation is necessary; the acoustic modelling of the room is very important for concert and conference halls, classrooms and industrial spaces to get insight into the sound propagation [1], [2], [3].

The paper focuses on the acoustic modelling and optimization of a room, taking into account the treatment achieved by changing some of the materials in the room or adding objects and finally the optimal placement of loudspeakers and listeners [4], [5]. For this analysis both software and hardware tools were used.

The software tool is CARA (Computer Aided Room Acoustics), which designs a room and the objects in it, computes the acoustic parameters and optimizes the placement of sound sources [6], [7]. The used hardware consisted of a digital sonometer HD2010, acquisition boards.

The paper is organized as follows: section II proposes and validates an exact model of the acoustic room; section III presents the improved and simplified model of the room by changing the structure, materials in the room and then simplifying it; section IV deals with the optimization of the placement of loudspeakers and listeners and finally in section V conclusions are presented.

II. The exact model of the acoustic room

The objective of the paper was to provide a solution to improve the acoustics of a classroom (Figure 1) and suggestions for the placement of a Surround 5.2 system [6]. The CARA software enables the architectural design of a room (shape, objects) and provides the values of the reverberation time (RT) according to the Sabine (1), Eyring (2) and Kuttruff (3), based on the room's volume, the absorption of the surfaces and air in the room [7].

The Sabine equation is used when absorption coefficient of room $\alpha \le 0.2$:

$$RT = \frac{0.164 \cdot V}{\alpha \cdot S}, \tag{1}$$

where V is the room volume and S is the surface area.

For low frequencies RT is computed according to Eyring:

$$RT = \frac{0.071 \cdot V}{-S \cdot \lg(1-\alpha)}. \tag{2}$$

If there are different absorption coefficients in the room and the sound attenuation in the air is taken into account, then Kutruff computes RT as follows:

$$RT = \frac{0.16 \cdot V}{S \cdot [-\ln(1-\alpha)] + \Delta + 4mV}, \tag{3}$$

where Δ is the average reflection coefficient of surface area S_n and m is the absorption sound energy in the air of room [6].

The acoustic of a room is strongly influenced not only by the shape and dimensions, but also by the materials in the walls, ceiling, floor and the additional objects existing in the rooms (carpets, paintings, windows, etc.).

The software has a 3D tool that enables the modelling of the whole room. Each object in the room may be considered using the models and absorption coefficients provided by CARA, Ramsete or studiotips [7], [8], [9]. Two models of the room were created considering:

- only CARA's library;
- the libraries of CARA, Ramsette, studiotips.

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The observed parameter in the simulations of the sound propagation in the room using the two models was RT.

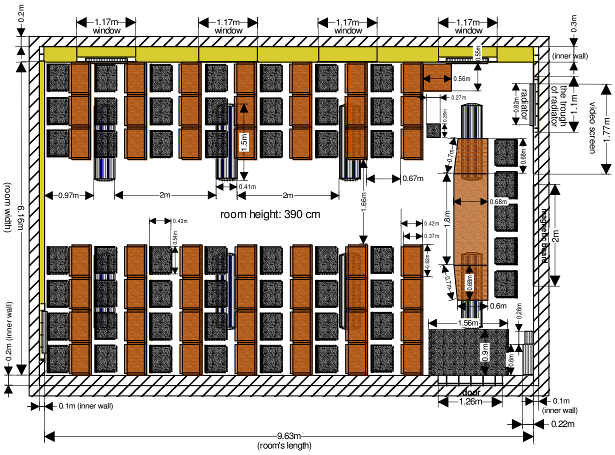


Figure 1.. The plan of the modelled room

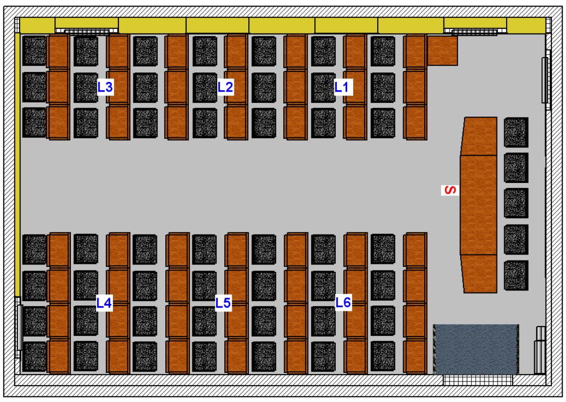
At the same time measurements with specific equipment were carried out in order to prove the accuracy of the model.

RT was measured using the sonometer HD 2010 and as excitation sources – balloons. The time was measured in different locations in the room with respect to different positions of the source and listeners (Table 1). In the first case there are a source S and 6 listeners: L1, L2, L3, L4, L5, L6; in the second case the source is placed in S1, then moved to S2, S3, S4, S5, S6, but the listener is always in L. From the measured results the mean value was extracted.

Figure 2 depicts the measured results compared with the ones delivered by CARACAD. One can easily see that the simulations using the second model are quite close to the experimental results, so this model is better. There are differences between simulations and RT measurements, but these are mainly due to the lack of information concerning the absorption coefficients of the materials in the room.

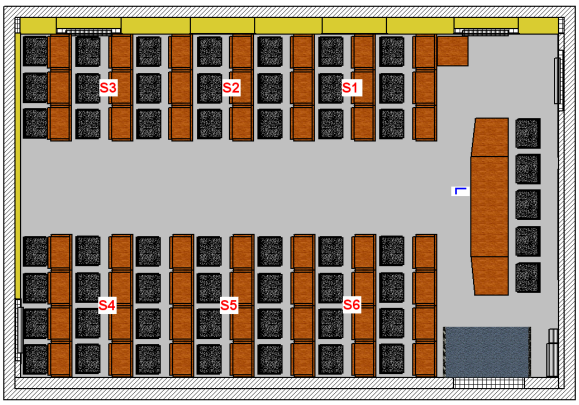
According to the analysis delivered by the CARA software, RT is above the nominal limits (for frequencies higher than 228Hz and lower than 3.6kHz); the low frequencies are too much absorbed and the middle and high frequencies too little absorbed (Fig. 3a).

First case



Frequency (Hz)	125	250	500	1000	2000	4000	8000
RT for L1	0.85	1.1	1.14	1.01	1.06	0.96	0.79
RT for L6	1.02	1.14	1.12	0.98	1.08	0.95	0.76
RT for L2	0.91	1.19	1.19	1.05	1.12	0.99	0.81
RT for L5	0.86	1.22	1.16	1.05	1.12	0.99	0.82
RT for L3	0.97	1.19	1.26	1.02	1.08	0.96	0.79
RT for L4	0.88	1.25	1.31	1	1.07	0.99	0.8
Mean values	0.92	1.18	1.20	1.02	1.09	0.97	0.80

Second case



Frequency (Hz)	125	250	500	1000	2000	4000	8000
RT for S1	0.83	1.08	1.3	1.03	1.14	0.95	0.77
RT for S6	0.92	1.25	1.24	1.04	1.09	0.93	0.74
RT for S2	1.05	1.21	1.19	1.05	1.09	0.97	0.78
RT for S5	0.94	1.18	1.19	1.03	1.13	0.96	0.77
RT for S4	0.97	1.19	1.22	0.99	1.12	1	0.79
RT for S3	0.97	1.19	1.26	1.02	1.08	0.96	0.79
Mean values	0.95	1.18	1.23	1.03	1.11	0.96	0.77

Table 1 RT measurements with HD 2010 sonometer

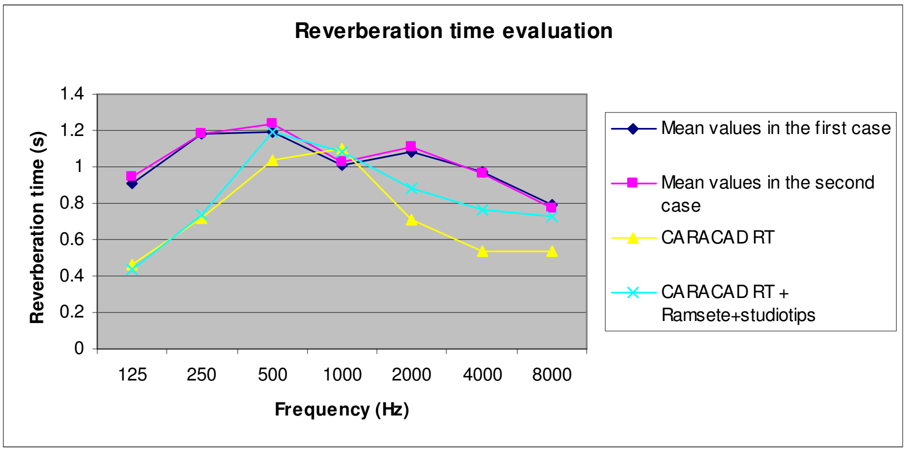
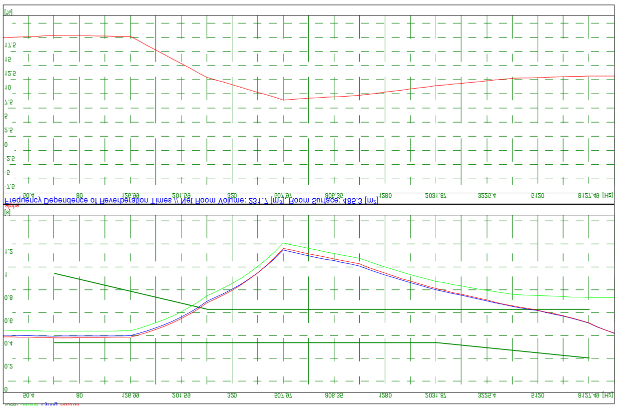


Figure 2. RT values provided by experiments and simulations



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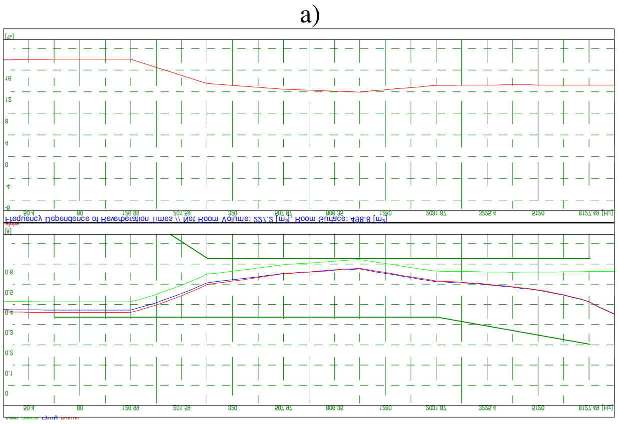

b)

Figure 3. Frequency dependence of average sound absorption coefficient and reverberation time of the: a) modelled room; b) improved room

III. The improved and simplified room model

The acoustic improvement consists in the introduction of shelves, wooden upholsteries up to 1.5m on the walls, change of carpet and curtains. After that RT is within the prescribed limits (Fig. 3b).

The improved model is very close to the practical configuration, but unfortunately the simulation time is prohibitive, the room having 5669 polygons. So the model was simplified, hereafter being called the improved and simplified model. The geometry of the furniture was largely changed, many objects as lamps, radiators, screen, whiteboard, curtains were considered plane objects (Fig. 4 a). To correct this rude simplification a wooden shelf was placed on the back wall. In this case the number of polygons was decreased to 2669.

The main loudspeakers were placed on the front wall, between them being the subwoofer and on it the central loudspeaker. On the back wall two effect loudspeakers were placed at 1.1 m above the floor. It is presumed that the hall is full and the front desk, the chairs were eliminated from the room.

Using the CARA software the acoustic field was studied. The maximum order of considered reflections is 3 and the optimization lasted for about 12.5 hours (Fig. 4 b). The software tool computes the sound pressure frequency response for the total sound and the first (direct) wave, the location and reverberation time with respect to the frequency.

Next the following acoustic parameters may be computed (computation time about 2 hours) and plotted with respect to the position in the room:

- The location – describes the quality of the position of a virtual sound source. It is calculated from the location diagram of the first wave front. The value +1 characterizes the correct position of the sound source; -1 means that a listener gets the impression of the sound source being situated in the opposite direction; the value 0 corresponds to a deviation of 90 degrees.
- The coloration – describes the influence of the room on the quality of the sound; it measures the timbre of the sound.
- The clarity is measured by the signal-to-noise ratio (SNR), where the useful signal is the direct sound and the early reflections and the detrimental sound consists of the late reflections.

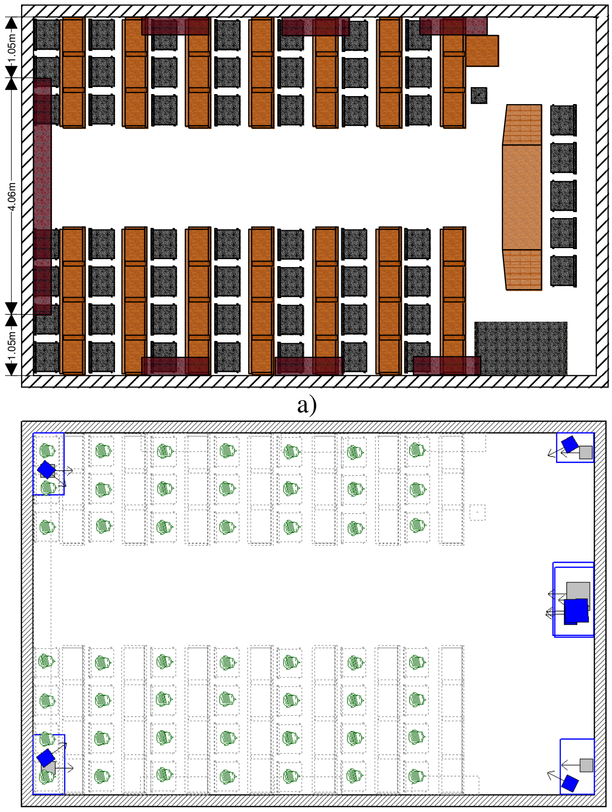

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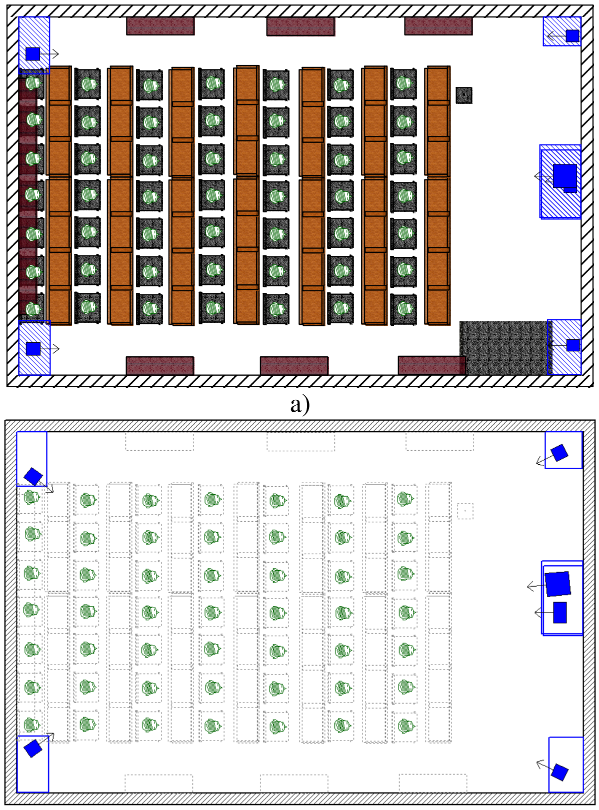
Figure 4. Improved and simplified room a) plan of the room; b) optimized placement of loudspeakers



a)

b)

Figure 5. Rearranged room a) plan of the room; b) optimized placement of loudspeakers

For the improved room a detailed analysis of the sound propagation was performed taking into account as sound sources the main, central, effect loudspeakers, in turn. The following not satisfactory conclusions were provided: the main and effect loudspeakers have a good coloration, clarity, but bad location, the central loudspeaker good location, clarity, bad coloration. On the other hand a large part of the sound energy is located in the central part of the improved room, where there are no listeners. The solution to improve the acoustic properties is to place the listeners in the middle and optimize again the loudspeakers placement.

IV The rearranged model and the optimization of the loudspeakers placement

The rearranged room is depicted in Figure 5a. An optimization procedure for the placement of loudspeakers was then performed. 5 acoustic parameters were taken into account; they describe the accuracy of the calculations of the sound pressure, the early decay time, the lateral sound level, the signal-to-noise ratio (SNR) and the location reference number. These numbers always refer to the sound field produced at a listening place (Figure 5b).

Table 2 presents the loudspeakers coordinates before and after optimization as well as the horizontal rotation angles from initial positions.

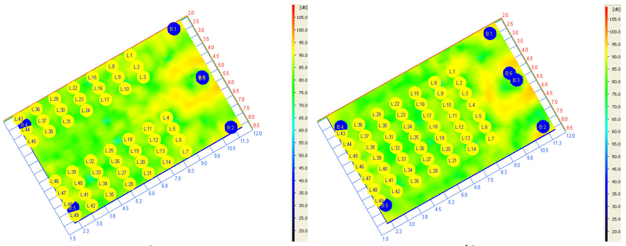
Speaker type	Unoptimized Position (X, Y, Z) [m]	Optimized Position (X, Y, Z) [m]	Horizontal rotation angle [degrees]
Main-left	2.33, 11.37, 0	2.40, 11.12, 0	25^o to right
Main-right	7.65, 11.38, 0	7.76, 11.12, 0	5^o to left
Centre	4.84, 11.33, 0.9	5.08, 11.12, 0.9	0^o
Subwoofer	4.74, 11.15, 0	4.61, 10.99, 0	5^o to right
Effect-left	7.71, 2.37, 1.1	7.33, 2.37, 1.1	36^o to right
Effect-right	2.64, 2.36, 1.1	2.83, 2.37, 1.1	38^o to left

Table 2 The speakers positional optimization results

Using this table, it is possible, in practice, to modify the position and the angles of speakers in order to optimize the room sound field.

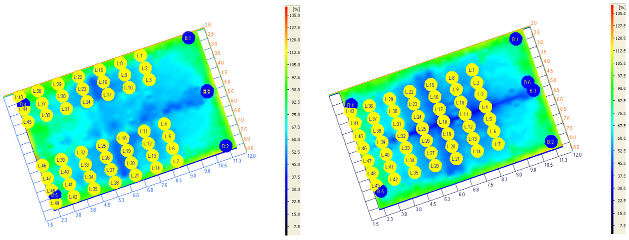
Next simulations were performed to test the acoustic performance of the unoptimized and optimized room. The level of the sound pressure for several frequencies (for example 201.6Hz sound level in Fig.6 was plotted.

There are large variations of sound pressure at low frequencies, in the vicinity of loudspeakers, constructive (orange peaks) and destructive interference (green peaks). The optimised version achieves a flatness of the sound pressure, especially at low frequencies. In the front part of the room there are large sound pressure variations, but they are not annoying because there are no listeners.



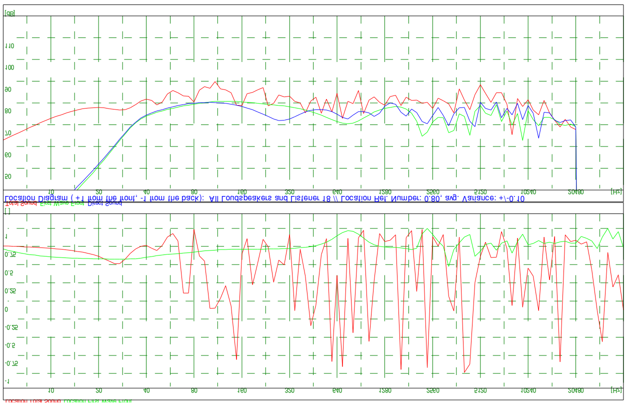
a) b)

Figure 6. Sound pressure level for 201.6 Hz: a) unoptimized version; b) optimized version.



a) b)

Figure 7. The location maps of: a) modelled, optimized version; b) rearranged, optimized version.



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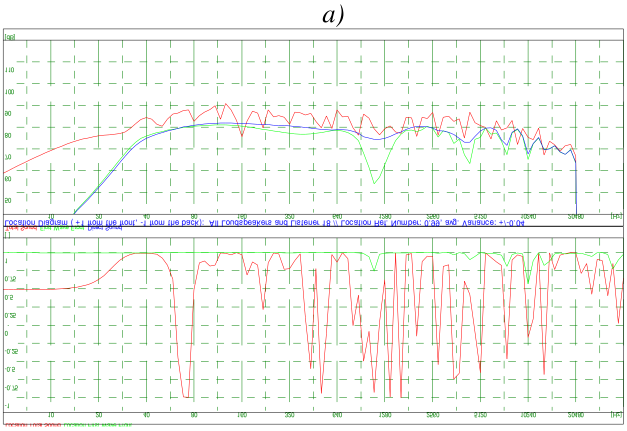
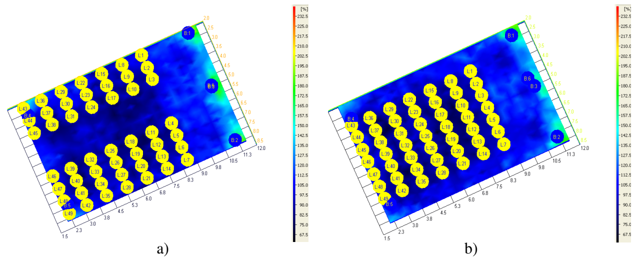


b)

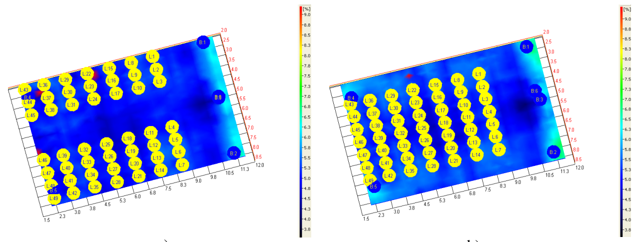
Figure 8. Sound pressure level and location number for the listener 18: a) modelled, optimized version; b) rearranged and optimized version.

The maps of the location are depicted in Fig. 7 and the characteristics of sound pressure and location reference



a) b)

Figure 9. The coloration maps of: a) modelled, optimized version; b) rearranged, optimized version.



a) b)

Figure 10. The clarity maps of: a) modelled, optimized version; b) rearranged, optimized version.

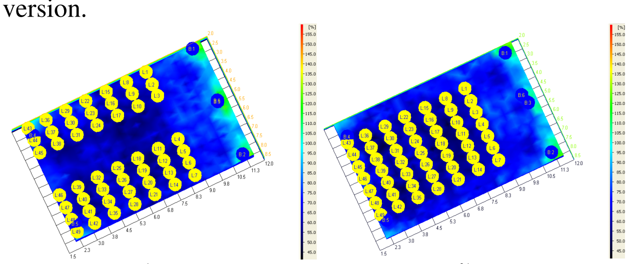
number for the listener 18 for both modelled, optimized and rearranged, optimized versions in Fig. 8.

The results show that the optimization leads to a better location in the room. But even optimized, the location is not good near the walls and very good in the central part; this observation strengthens the necessity of making the rearrangement in the room.

The maps of coloration (Fig. 9) show that the optimization leads to a decrease of the coloration, especially in the back front and in the vicinity of the effect loudspeakers.

In the maps of clearness (Fig. 10) an important improvement of the clarity at the back front after optimization may be seen. If before the rearrangement of listeners, two listeners (22 and 49) had serious problems of clarity, after the rearrangements these problems disappeared.

An overall parameter may be computed as the weighted sum of the above mentioned acoustic parameters. The maps of this parameter show the serious improvement of acoustics for the rearranged, optimized room in comparison with the initially modelled, optimized version.



a) b)

Figure 11. The global evaluation of the sound wave for: a) modelled, optimized version; b) rearranged, optimized version.

V. CONCLUSIONS

The paper analysis the acoustics in a room and suggests treatments to enhance its acoustic properties. The considered room is a classroom of medium size. The model adopted for the room was validated by comparing software results with experimental data. The proposed model was then used for the improvement of acoustic properties. The treatment consisted in adding objects and changing the materials of some existing objects, as well as the optimal placement of loudspeakers and listeners. A Surround system 5.1 was considered as sound source. All the steps of the treatment were validated by processing the simulations of sound waves propagation and computation of acoustic parameters.

Further improvements can be obtained by enhancing the facilities offered by the digital equipment. Future work will be devoted to the design of artificial reverberators for concert halls and echo cancelling for conference rooms.

VI. ACKNOWLEDGEMENT

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