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Influence of the acoustic insulation position on the reverberation time and noise level in a large classroom

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Abstract. *Acoustic comfort is a requirement of major importance during the design of a classroom, conference room or cinema hall. This study is focused on the acoustic comfort parameters called reverberation time and sound pressure level. The aim of this study is to determine the placement influence of the sound absorption material upon the reverberation time for a classroom. In this study the reverberation time was determined using Sabine; Eyring, Arau Puchades and dedicated software of architecture modelling-Sketch-up and acoustic modelling- Odeon. Using these software, we have simulated various locations of the acoustic insulation and determined the most effective placement for sound absorption material to reduce the reverberation time and to maintain a good uniformity of sound pressure level inside the classroom.*

Key words: reverberation time, sound pressure level, acoustic modelling, sound isolation

1. Introduction

The most important acoustic parameters of a classroom that affect acoustic comfort are background noise and reverberation time. According to Zannin and Zwirtes [1], acoustical comfort in school classrooms, as well as university classrooms, has been the focus of more research from different countries [2-10]. Another study to highlight this has been published by Rasmussen B and Brunskog Jonas [11]. They have conducted studies witch showed that good acoustical comfort for learning demands low noise levels and little reverberation. The literature of room acoustic indicates several procedures to determine one the fundamental parameters that define acoustic comfort: reverberation time.

Sabine's formula [12], developed by Wallace Sabine in 1900, assumes that sound energy diffuses equally through a room. The formula for reverberation time, RT (s), calculation is given bellow:

$$RT = \frac{0.161 \cdot V}{A + 4mV} \quad ,$$

where V (m^3) is the volume of the room; A (m^2) is the absorption area and is calculated as $A=\Sigma(S\cdot\alpha)$, S (m^2) is the area of each material, and α (-) is the absorption coefficient of these materials; 4mV corresponds to sound absorption by air, where V is the volume of the classroom and m (m^{-1}) is the absorption coefficient of air.

Eyring's formula developed by Carl Eyring in 1930 [13] offer a revised theory and derives a formula of the reverberation time, RT (s), equation:

$$\mathrm{RT} = \frac{0.161 \cdot V}{-S \cdot \ln(1-\overline{\alpha}) + 4mV}$$

where $\overline{\alpha}$ (-) is the mean absorption coefficient of all the materials, being calculated as the surface weighted average of the absorption coefficients corresponding to the different materials inside the analyzed room $\alpha= \Sigma(S_i x \alpha_i)/\Sigma S_i$, α_i and Si are the absorption coefficient and the geometric surface of each material inside the room.

Another formula for calculating reverberation is that of Arau Puchades [14]. This formula is developed in 1988, should be used in rooms with asymmetric distribution of absorption and represents the product of three terms corresponding to the three axes of the space, each term being similar to an Eyring formula of the reverberation time.

$$\mathrm{RT} = \left[\frac{0.16V}{-S \cdot \ln(1-\alpha_x) + 4mV}\right]^{\frac{S_x}{S}} \cdot \left[\frac{0.16V}{-S. \ln(1-\alpha_y) + 4mV}\right]^{\frac{S_y}{S}} \cdot \left[\frac{0.16V}{-S \cdot \ln(1-\alpha_z) + 4mV}\right]^{\frac{S_z}{S}}$$

where the first term corresponds to the absorption of the materials located parallel to the x axis, the second term for the materials located parallel to the y axis, and the third term for the materials located parallel to the z axis, α_x, α_y, α_z are the arithmetic mean of the absorption coefficients of the surfaces parallel to the three space axes and S_x, S_y and S_z are the sums of the areas of these surfaces parallel to the axes x, y and z axes, respectively.

Romanian norms [15-17] offer a fast engineering approach for the reverberation time determination in case of rooms in accordance with their destination [18]. However, another study [19] shows that the reverberation time is variable inside an analyzed room and there is a considerable difference between the theoretically calculated reverberation time and the average measured value. Therefore despite their fast approach these theoretical formulas might not be applicable for any king of indoor geometry. To overcome this aspect, in this article we obtained the reverberation time using the simulation software ODEON Acoustics.

In the present work we want to understand if there either small or significant differences between the fast engineering formulas and the more precise approach using the ODEON Acoustics software. These differences between the simple calculation formula and the more precise approach are the same anywhere inside the room or depend on the position of the reception point. We would also like to understand the effect of the acoustic insulation position inside the room. Is the acoustic effect the same for the entire room or different from one location to another? What is the effect of the acoustic insulation materials inside the room and where is its maximum value?

Through these different positions of the acoustic tiles we will highlight whether there is a difference between the noise levels and the reverberation times obtained near the noise source or the other side of the room. The result is very useful when it comes to improving the acoustic comfort in a certain area of the room.

2. Acoustic simulations

For this study we used the geometry of a real classroom from Faculty Building Services and Equipment, Technical University of Civil Engineering of Bucharest. It is a large rectangular shaped classroom (dimensions 16.05m x 6.7m x 4.25m), with 6 large windows (1m x 2.5m each) for 72 students. A 3D virtual geometry model of this classroom (Fig.1) was sketched in Google Sketch up and further imported in Odeon Acoustics.

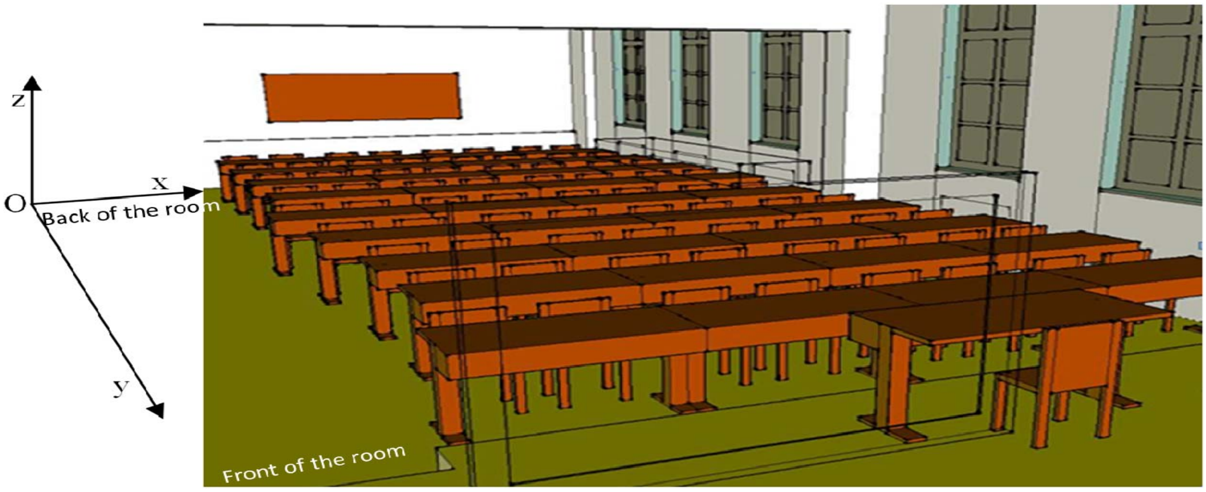

Fig.1. Analysed classroom, architectural of the virtual model classroom

The materials for each surface were noted by inspection and then absorption coefficients (Table 1) were assigned to the computer model's surfaces, based on the most appropriate data available in ODEON material library. No attempts were made to calibrate the ODEON virtual model to the real room (no comparison to experimental reverberation time value), since none of the predicted data are to be compared with measured data.

Table 1

Absorbance coefficients of materials by frequency

Frequency	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
α_{plaster}	0,02	0,02	0,02	0,02	0,02	0,02	0,02
α_{parquet}	0,25	0,15	0,10	0,09	0,08	0,07	0,07
α_{door}	0,14	0,10	0,06	0,08	0,10	0,10	0,10
α_{window}	0,05	0,03	0,03	0,03	0,02	0,02	0,02
α_{ceiling}	0,02	0,02	0,02	0,02	0,02	0,02	0,02
α_{chairs}	0,08	0,03	0,02	0,001	0,001	0,31	0,006
α_{table}	0,08	0,03	0,02	0,001	0,001	0,31	0,006
$\alpha_{\text{heating equipment}}$	0,01	0,01	0,01	0,01	0,02	0,02	0,02
α_{lamp}	0,01	0,01	0,01	0,01	0,02	0,02	0,02

The noise source chosen is an omnidirectional source characterized by a sound power level of 90 dB and is located, according to [18], in the middle of the room, with the following coordinates: 5 m on Ox axis; 16 m on Oy axis; 1.50 m on Oz axis. Therefore, since a single source position has been used in this study, a 10% nominal precision is expected [19]. Several receptors were also placed in order to obtain the acoustic comfort in specific points inside the room.

In this study we aim to determine how the location of the sound insulation influences the acoustic comfort inside the classroom.

For acoustic treatment we used tiles from one of the largest manufacturers on the market. Usually these tiles are used for acoustical ceiling throughout a space used for collaboration or focused work (offices, classrooms). This type of acoustic treatment can also be used for wall cladding, while maintaining a consistent visual.

To observe how efficient a solution can be with a minimal implication, we used only 10.25 m^2 of acoustic tiles with absorption coefficient present in Table 2.

Table 2

Absorbance coefficients of acoustic tiles by frequency

Frequency	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
α_{plaster}	0,02	0,02	0,02	0,02	0,02	0,02	0,02

The percentage of the acoustic treated surface -P_1 was calculated, in the formula below:

$P_1 = S_{\text{treated1}} / (S_{\text{wall}} + S_{\text{ceilling}} + S_{\text{floor}})$
$P_1 = 10.25/(193.37+97.29+107.54) = 10.25/398.2 = 2.574\%$
For P_1 the RT for Solution 1 is 2.87[s] at 1000Hz

We proposed eight different positions of the acoustic insulation, described in Table 3 and visually presented in Fig.2.

Table 3

Solutions of acoustic insulation positioning

Acoustic insulation location	Description
Solution 1	On the ceiling, towards the back of the classroom
Solution 2	On the ceiling, towards the front of the classroom
Solution 3	At the upper side of the front wall,
Solution 4	At the upper side of the back wall
Solution 5	On the external wall, towards the back of the classroom
Solution 6	On the external wall, towards the front of the classroom
Solution 7	On the internal wall, towards the back of the classroom
Solution 8	On the internal wall, towards the front of the classroom

A 3D architectural model as the two represented in Fig.2 was created for each solution, and then imported into the acoustic modelling software.

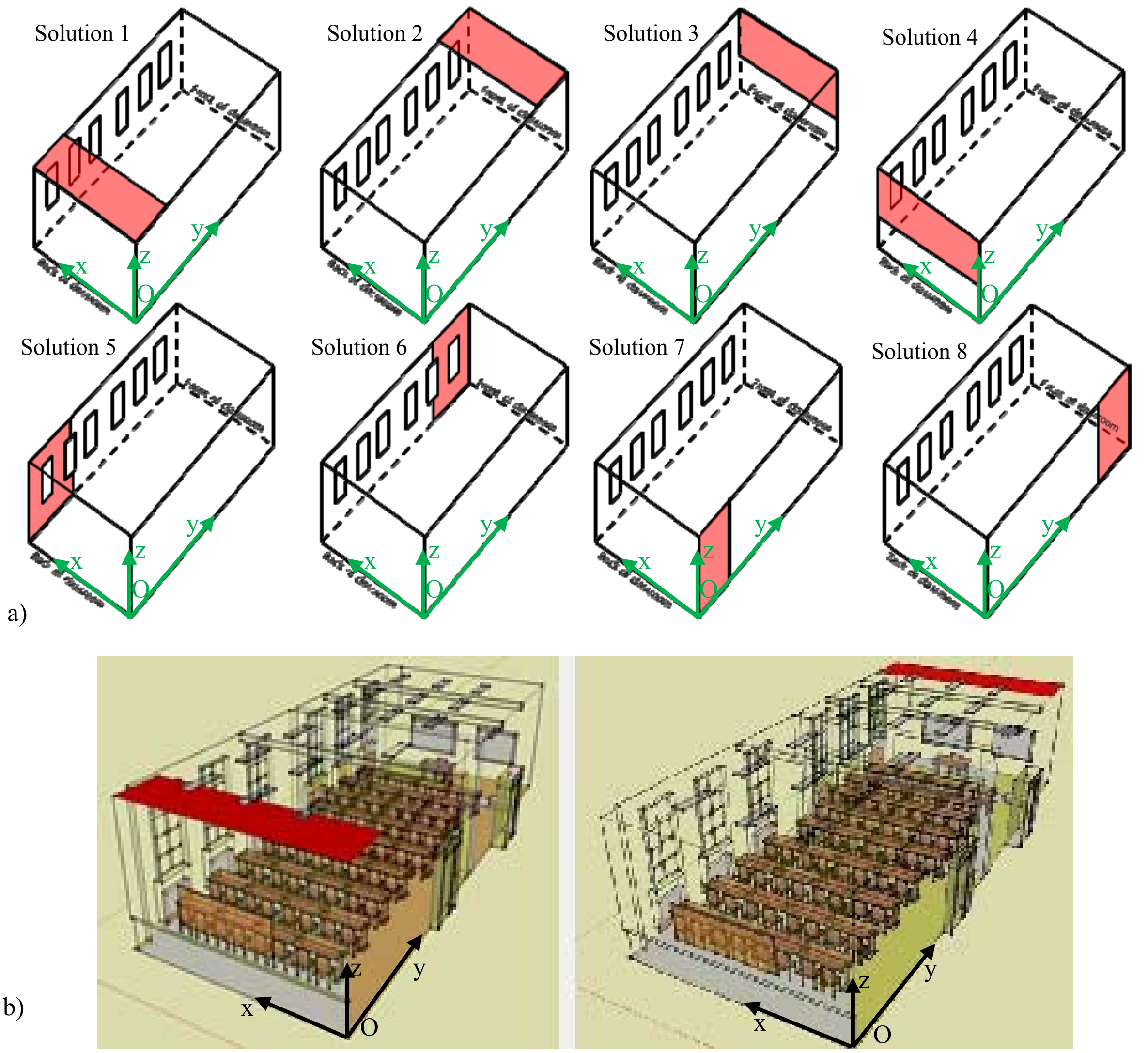

Fig.2. Noise protection solutions: a) Eight analysed solutions, b) 3D schemas for Solutions 1 and 2

3 Results

In this chapter, the results from the acoustical modelling outlined in Chapter 1 are presented. The effects of the acoustic insulation upon the acoustic parameters of the classroom and various design implications are discussed.

Since classical formulas only take into account the volume parameters and the absorption area, we will use the Odeon Acoustic software which uses a hybrid method that calculates each reflection of a sound, thus creating several diffused secondary sources, thus taking into account other factors such as room architecture and indoor objects.

The reverberation time was firstly calculated with Sabine, Eyring and Arau Puchaes formulas and its values were compared with the maximum value according to the Romanian norms. Next, the acoustic simulations for each 8 acoustic solutions in the Odeon Acoustic software were used in order to understand the importance of the o soundproofing materials location inside a room upon the acoustic comfort parameters (reverberation time and acoustic pressure level).

3.1 Results for room reverberation time (RT) without acoustic insulation

The Odeon simulated reverberation time is represented in the graph below. It was calculated for frequency between 125Hz - 8000Hz using literature formulas and was found to vary between 0.61-3.98 [s] depending on the frequency.

The maximum value of the reverberation time to assure indoor acoustic comfort, RTmax (s), according to the norms [17], for this classroom is 0.97 seconds.

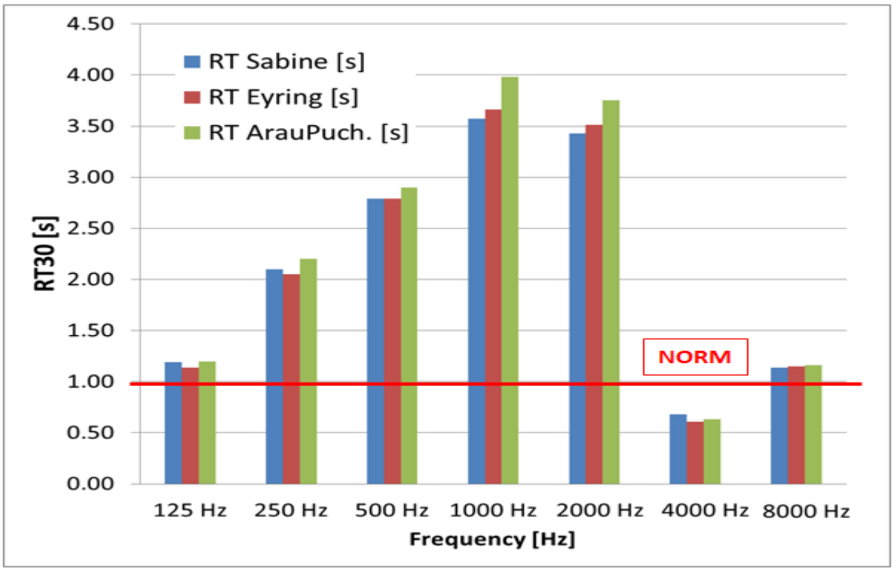

Fig.3. The comparative graph of RT, according to Sabine, Eyring, and Arau Puchades formulas, compared to RT according to C125: 2013 [17]

One could note that the reverberation time respects the norm only for the frequency 4000Hz. There is a similarity of the reverberation times obtained with the three prediction formulas. The Arau Puchades formula indicates slightly higher values compared to those obtained using Sabine or Eyring formulas.

3.2 Results for acoustic insulation treatment

Following the simulation of the soundwave propagation inside the classroom for each acoustic treatment solution, the average noise level for the classroom not refurbishment at frequency between 125Hz – 8000Hz was compared to the average values throughout the classroom with refurbished solutions (Table 4).

Table 4

The average sound pressure level of the classroom according to Odeon Acoustic

Sound pressure level	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
$L_{p\ \text{Room Not Refurbished}}$ [dB]	75,7	78,7	80,2	81,2	80,7	72,5	72,8
$L_{p\ \text{Refurbished Solution 1}}$[dB]	75,5	77,8	78,6	79,3	78,6	71,7	72,0
$L_{p\ \text{Refurbished Solution 2}}$[dB]	75,2	77,5	78,2	79,0	78,3	71,2	71,7
$L_{p\ \text{Refurbished Solution 3}}$[dB]	75,2	77,6	78,5	79,3	78,6	71,3	71,8
$L_{p\ \text{Refurbished Solution 4}}$[dB]	75,3	77,6	78,4	79,2	78,5	71,2	71,8
$L_{p\ \text{Refurbished Solution 5}}$[dB]	75,3	77,8	78,6	79,4	78,7	71,5	71,9
$L_{p\ \text{Refurbished Solution 6}}$[dB]	75,3	77,6	78,4	79,1	78,4	71,4	71,7
$L_{p\ \text{Refurbished Solution 7}}$[dB]	75,4	77,8	78,5	79,4	78,6	71,5	71,9
$L_{p\ \text{Refurbished Solution 8}}$[dB]	75,6	77,7	78,5	79,3	78,6	71,3	71,8

All the acoustic refurbishment solutions lead to a similar result: lower noise level in the classroom compared to the value before the refurbishment. It is noticed that the most effective solution to position the acoustic tiles to reduce the noise level is solution 2 (acoustic tiles placed on the ceiling in front of the room), while the least efficient would be to position the tiles according to the acoustic solution1 (acoustic tiles placed on the ceiling in back of the room). The differences between these two values are from 0.2dB (for 125Hz) to 0.5dB (for 4000Hz).

A similar comparison of the 8 refurbishment solutions was carried out with respect to the reverberation time criteria. Following the simulation in ODEON Acoustics the average value of reverberation time was determined for the entire room geometry and compared to the average values obtained for the room with refurbishment solutions (Table 5).

All the acoustic refurbishment solutions lead to a similar result: smaller reverberation time values compared to the values before the refurbishment. One could notice that the most effective solution for the location of the acoustic insulation to reduce the reverberation time is according to the solution 8 (acoustic insulation placed on the wall behind the room) while the less effective solution would be solution 2 (acoustic tiles placed on the ceiling in front of the room). The highest difference between the two solutions was 0.15(s) corresponding to frequency 2000Hz. We also note that the most important acoustic effect brought by solution 8 was obtained for frequency 2000Hz (0.92(s) lower reverberation time compared to the room not refurbished).

Table 5

The average reverberation time of the classroom according to Odeon Acoustic

Frequency	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**	**8000 Hz**
RT$_{\text{Room Not Refurbished}}$[s]	1,48	2,38	3,05	3,71	3,54	1,12	1,18
RT$_{\text{Refurbished Solution 1}}$[s]	1,47	2,16	2,49	2,87	2,68	0,98	1,06
RT$_{\text{Refurbished Solution 2}}$[s]	1,45	2,11	2,50	2,94	2,77	0,97	1,07
RT$_{\text{Refurbished Solution 3}}$[s]	1,42	2,12	2,49	2,93	2,74	1,04	1,08
RT$_{\text{Refurbished Solution 4}}$[s]	1,50	2,13	2,45	2,85	2,67	1,00	1,06
RT$_{\text{Refurbished Solution 5}}$[s]	1,45	2,14	2,50	2,94	2,73	1,00	1,07
RT$_{\text{Refurbished Solution 6}}$[s]	1,49	2,17	2,49	2,88	2,69	0,96	1,08
RT$_{\text{Refurbished Solution 7}}$[s]	1,46	2,11	2,39	2,81	2,60	1,02	1,06
RT$_{\text{Refurbished Solution 8}}$[s]	1,49	2,09	2,38	2,81	2,62	0,95	1,05

Overall we conclude that solution 8 presents a significant acoustic effect compared both to the room not refurbished and to all other analysed solutions. Given this acoustic effect was obtained with only a small acoustic surface, 10.25 m^2 of acoustic tiles (representing 2.57% of the room surface: walls, ceiling and floor, without furniture), we consider that the position of the acoustic insulation inside the room represents a very important aspect for any acoustic refurbishment.

In order to better understand the influence of the position of the acoustic tiles inside the room upon the acoustic comfort (noise level and reverberation time), mapping of these parameters are presented for the solution 1 (acoustic tiles on the ceiling in back of the room) and solution 2 (acoustic tiles on the ceiling in front of the room). The maps represent the acoustic parameter value on a horizontal plane at 1.2m height.

Fig.4 and Fig.5 present the noise level mapping for the frequency 1000Hz for solutions 1 and 2 respectively. In the back part of the classroom, solution 1 leads to noise level values of 78.6(dB), lower than those obtained for the solution 2 (79.1dB). In the front part of the classroom, solution 1 leads to noise level values of 83.6(dB), higher than those obtained for the solution 2 (81.6dB).

Thus, the acoustic tiles partially absorb noise energy near the place where they are located. The sound pressure level already has the lowest value towards the back of the classroom; therefore placing the tiles in this place (solution 1) would further amplify this drop, while solution 2 will decrease the noise level in the front part of the classroom.

To achieve a levelling of noise level in this room, a positioning of acoustic insulation is recommended in front of the room.

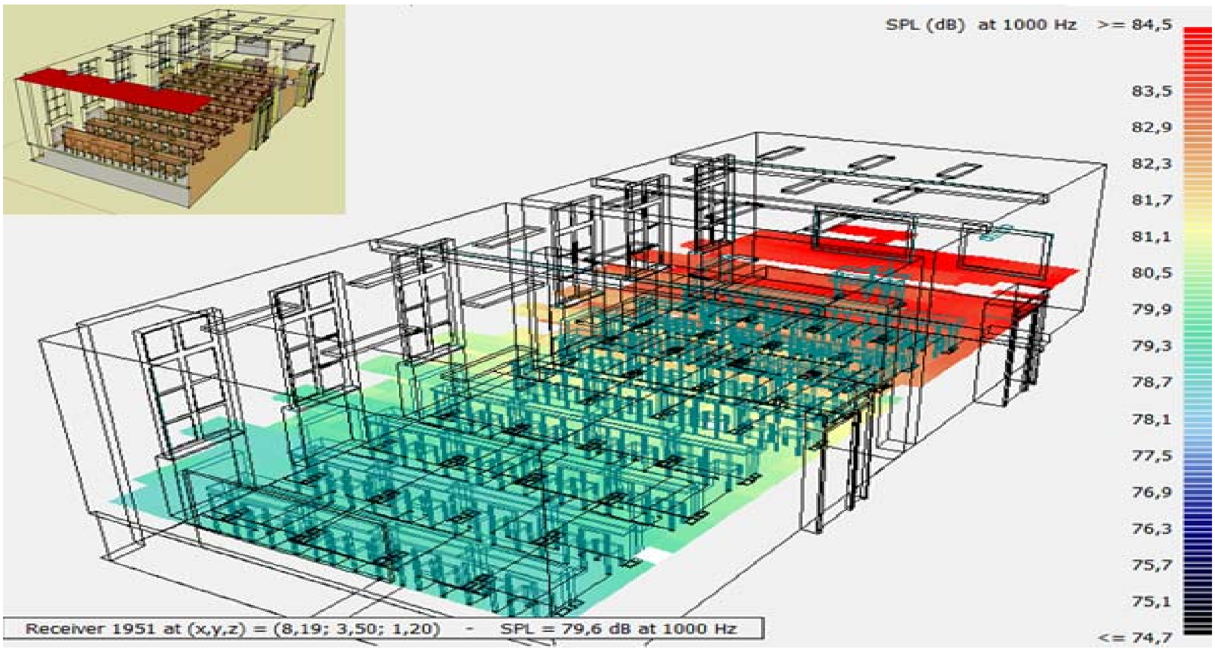

Fig.4. Map of Noise level at 1000Hz distribution for Solution 1

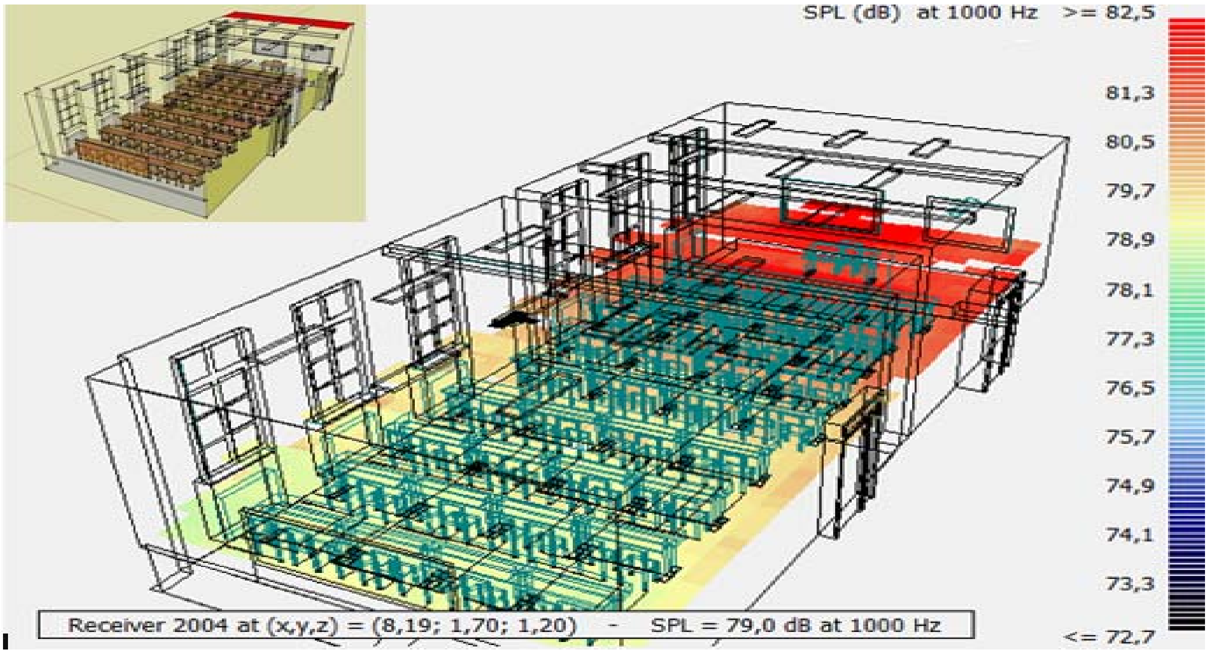

Fig.5. Map of Noise level at 1000Hz distribution for Solution 2

Fig.6 and Fig.7 present the reverberation time mapping for the frequency 1000Hz for solutions 1 and 2 respectively. Initially, the reverberation time was about 3.7 (s) uniformly distributed along the entire geometry pf the room. After the refurbishment solution implementation we find lower reverberation time values. In the back part of the classroom, solution 1 leads to a reverberation time of about 2.85 (s) similar to that obtained by means of solution 2.

In the front part of the classroom, solution 1 leads to a reverberation time of about 2.4(s) while for the solution 2 the reverberation time is just under 2(s).

After de refurbishment of the classroom the reverberation time is not uniformly distributed. It decreases more close to the location of the acoustic protection solution. In our case, the reverberation time decreases 1.5 (s) in the front part of the classroom. This means that the acoustic insulation should be placed close to the part of the room where the noise protection conditions are not met and also close to that zone of the room where the occupants are.

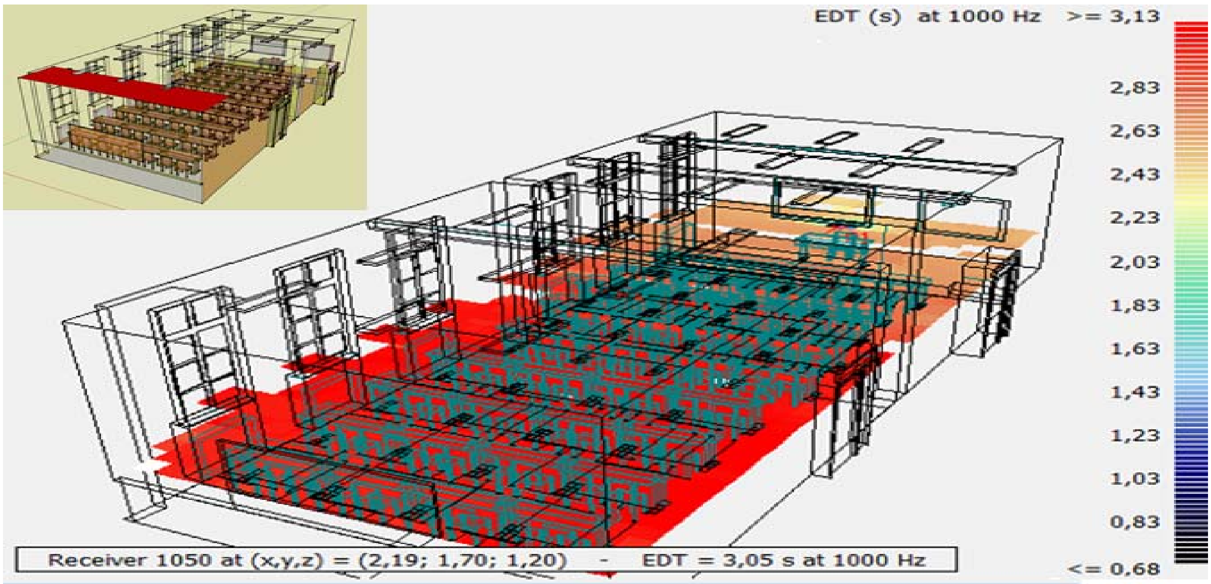

Fig.6. Map of Reverberation Time at 1000Hz distribution for Solution 1

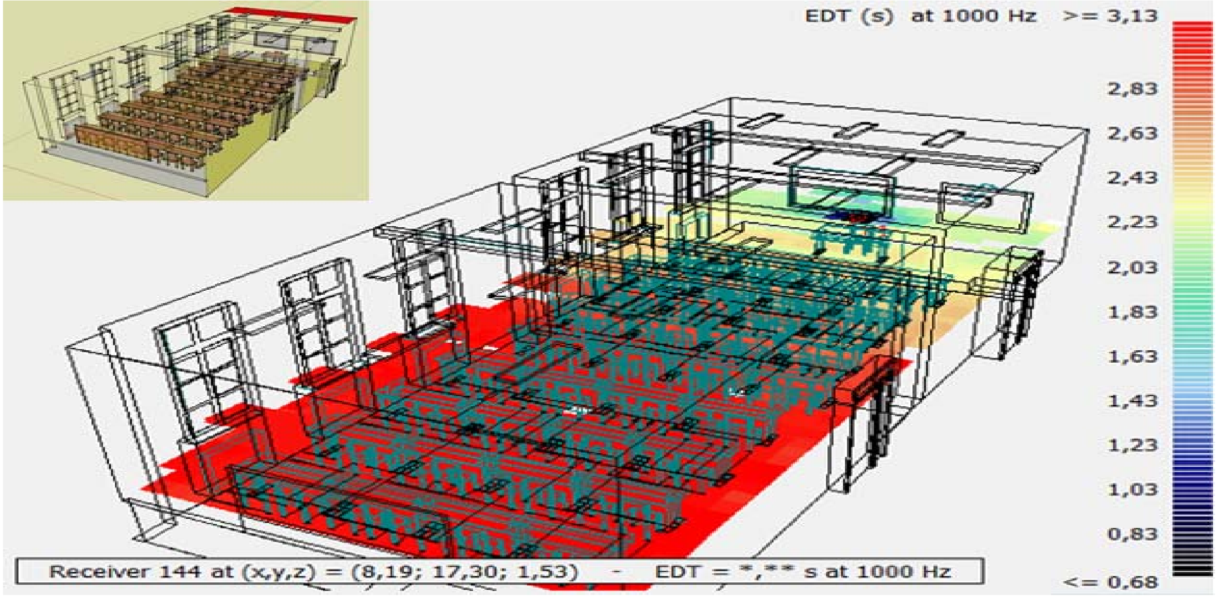

Fig.7. Map of Reverberation Time at 1000Hz distribution for Solution 2

In conclusion, the acoustic refurbishment has multiple effects upon the acoustic indoor environment. The sound energy is absorbed in the sound insulation materials and consequently the noise level, which represents the effect of the superposition of the direct and the reflected soundwaves, is smaller. The reduction of the soundwave reflection leads to a smaller reverberation time. Thus, both the noise level and the reverberation time values decrease. The change of these two parameters is greater close to the location of the acoustic insulation and less significant towards the opposite end of the room.

4. Conclusions

The analyses in this study show the most common fast estimations of the reverberation time using Sabine, Eyring or Arau Pouchade formulas might lead to uncertain estimation of acoustic comfort parameters if one for small sound absorption areas. They present only one value characteristic for the entire room while in reality the reverberation time as well as the noise level varies.

The findings from the current study show that the position of the acoustic insulation influences differently the reduction of the noise level and the reverberation time in diverse locations inside the room. In such situations, changing the location of the sound-absorbing material can be a simple and viable alternative to reduce noise. For example insulation placed in front of the room will led to a greater decease in noise, while for uniformity of reverberation time it will be recommended to place it behind the hall.

However, such a modelling approach might present an inconvenient concerning the choice of the materials inside the rooms with respect to their acoustic parameters. Therefore an experimental phase is necessary in order to identify the real acoustic parameters of existing materials so that the model would be calibrated to the real measurements before the simulation.

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