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Alternative Spaces for Learning: Reversible Acoustic Treatments for Transformation of Spaces into Classrooms During COVID Era

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Abstract
The design of acoustic comfort in classrooms is a challenging issue. It became a crucial aspect during the Covid-19 pandemic regarding class life organization, as for the latter large spaces for teaching were required in order to guarantee the minimum distance between the occupants to limit the spread of Covid-19, and it was important to ensure their acoustics functionality for the performance of lessons. To this aim, this investigation is to provide a guide (for school principals, administrators, safety managers, architects and engineers, acousticians) where easily implementable solutions for different types of school buildings are detailed in various case studies and they are an example in case of environments similar in shape and volume. In particular the focus is put on the transformation of school spaces created for different purposes than normal classrooms (e.g., corridors, atria, sports halls) into classrooms for teaching. Different layouts of the furniture and sound-absorbing materials have been applied and analysed by simulations (Odeon 15) comparing the results with the standardized optimal values and with those of the actual environments obtained through an extensive measurement campaign. Eight schools were taken into account as case studies, representing the Italian school heritage and including elementary schools, middle schools and high schools. A total of 26 different spaces with a volume varying in the range 135-2800 m^3 were analysed. For each of them, both general analyses at the overall environment level and more specific ones for single receivers located over the area occupied by the students were carried out. As a result, it should be highlighted that the proposed solutions could not be fully acoustically optimized for all of the spaces, as the analyses also took into consideration an affordable cost, the speed of realization and the reversibility of the intervention.

Keywords: classroom, Covid, reversible acoustics, simulation

1 Introduction

In Spring 2020, Politecnico di Torino as a leading organization brought together different working groups in order to address the challenges of the new working, learning and living conditions due to the Covid-19 pandemic [1]. The result of these working groups was a series of reports [2] that included guidelines for an optimized use of spaces and devices, as well as good behavioral practices that could limit the spread of the virus and allow the running of the activities, as close as possible, to a normal and inclusive framework. In particular, the work presented here reports the investigation regarding the transformation of school spaces created for different purposes (e.g., corridors, atria, sports halls) into classrooms where speech comprehension is fundamental, by evaluating their acoustic comfort conditions and by proposing possible desks arrangements and acoustic treatments. The goal was to guarantee functional acoustic conditions to properly conduct lessons, when there is the need of having additional and bigger spaces in order to put more distance between desks, as per the new rules originated by the Covid-19 situation.

The investigation of the state of the art on similar actions resulted quite limited within the acoustic field both in terms of case studies and design solutions that could be readily applied in practice. Several works can be found regarding reversible acoustic interventions in historical buildings [3, 4]. In Italy, it is well known the adaptive reuse of existing historical buildings into schools, however the acoustic result is often the outcome of thermal retrofitting actions [5].
The research on reference values of the acoustical parameters that have the greatest influence on student performance is ongoing research [6]. In this investigation, the acoustic results based on "minimal-reversible intervention" criteria were compared to the standardized optimal values [7] and to those of the actual environments obtained through an extensive measurement campaign, in order to obtain a useful guide for school principals, administrators, safety managers, architects and engineers, and acousticians.
Easily implementable solutions for different types of school buildings are detailed in this study and they constitute examples in case of similar rooms in shape and volume to be adapted. The proposed solutions show the resilience of extreme spaces (e.g., gyms) to host the demanding conditions required for teaching-learning performance. However, it should be highlighted that the solutions reported in this study are not fully optimized, as the analyses also took into consideration an affordable cost, the velocity in the setting-up and the reversibility of the treatment.

Table I: List of all the spaces with associated school level, floor area, volume and current function with the number of classes and students hosted in the new configuration. UNI 11532-2 optimal reverberation time value is indicated. The spaces that had already some acoustic treatment are signed with *.

Level of school	**Function**	**Area** [m^2]	**Volume** [m^3] (V_{class})	**Number of classes - Number of students**	**Optimal reverberation Time [s]**
primary	auditorium*	83	324	1 cl. 28 st.	0.6
	gym	84	435	1 cl. 28 st.	0.7
	canteen*	40	197	1 cl. 20 st.	0.6
	canteen*	42	204	1 cl. 20 st.	0.6
	canteen*	39	194	1 cl. 16 st.	0.6
primary	canteen*	44	135	1 cl. 16 st.	0.5
	canteen*	158	499	2 cl. 20+20 st.	0.7
	gym	84	1208	2 cl. 20+20 st.	0.8
primary	computer room*	93	257	2 cl. 16+16 st.	0.6
	reading room*	70	193	1 cl. 20 st.	0.6
	lobby*	98	269 (121)	1 cl. 14 st.	0.6
	lobby	98	293 (130)	1 cl. 14 st.	0.6
	lobby	75	225 (98)	1 cl. 14 st.	0.6
	gym*	298	2018	2 cl. 25+25 st.	0.9
	theatre*	297	990	3 cl. 24+24+24 st.	0.8
	canteen*	287	832	4 cl. 20+20+15+15 st.	0.8
middle	lobby	157	502	1 cl. 18 st.	0.7
	lobby	156	499	1 cl. 16 st.	0.7
middle	canteen	122	371	2 cl. 20+16 st.	0.7
	media room*	98	298	2 cl. 16+16 st.	0.6
	lobby	125	398 (142)	1 cl. 15 st.	0.7
	science room	97	311	1 cl. 18 st.	0.6
	mixed use room	97	310	1 cl. 28 st.	0.6
high	canteen*	194	776	2 cl. 16+24 st.	0.8

2 Methods

Eight schools were analysed in this study. The schools represent the Italian school heritage, which often does not meet up with the current acoustic standards and which is characterised by buildings of the nineteenth and early twentieth century, of the Sixties and Seventies and a small percentage of new buildings recently built up. The actual acoustic conditions of the five case studies were checked through a measurement campaign, later used to calibrate the models in the acoustic simulation phase.
A total of 26 different spaces with a volume varying in the range 135-2800 m^3 were analysed. For each of them, both general analyses at the overall environment level and more specific ones for single receivers located over the area occupied by the students, were carried out. It was not possible to perform acoustic measurements in two spaces, thus the data reported will focus only on 24 spaces.
The investigation was a methodical step by step analysis which started from an inspection of the case studies followed by an extensive in-field campaign in which the reverberation time and background noise levels was measured. A categorisation of each of the 24 spaces was performed by their function and dimensions (Table I). For each space a proper desk arrangement was proposed in line with the Covid-19 distance requirements, and the optimal reverberation time target values were identified for furnished and 80% occupied room. The minimum acoustic treatments were verified by a first analysis with the Sabine formula and later on, simulations were run with Odeon 15 software, after the calibration upon the measurement result was carried out. Noise conditions of each space was set through the NC curves, chosen appropriately with respect to the number of children in the space. After the speaker and the receivers were positioned over the seating area, STI (Speech Transmission Index) punctual specific STI and speech SPL (Sound Pressure Level) values were obtained.

2.1 Case study selection and description

Case studies included three elementary schools, two middle schools, two high schools and one school where all levels were present. They represent typical Italian school buildings, which span from old masonry vaulted buildings to concrete ones, to mixed concrete structure and masonry walls buildings. As mentioned above, since it was not possible to perform acoustic measurements in two spaces in one high school and the one where all levels were present, these were excluded from the data reported here.
Spaces with different volumes and shapes were chosen to include all the possible acoustic scenarios. In some cases, the acoustic treatment was already present, albeit with materials characterised by low-medium sound absorption. It must be highlighted that in case of a lobby, which is not a closed area, the volume and the floor area were an arbitrary chosen in order to have a valid model to run simulation.

2.2 Acoustic parameters

UNI 11532-2 has been used as reference standard for classroom acoustics [7]. It provides updated acoustic parameter and their reference values, which are in line with those applied internationally. In particular, the standard is aimed:

- to guarantee an effective speech comprehension for the students;
- to guarantee the minimum vocal fatigue and vocal effort for the teacher;
- to reduce chatting noise in case of the presence of simultaneous classes.

In the study, which has been carried out in order to be immediately put in practice in the case of emergency due to Covid-12 pandemic, it was decided to provide basic solutions that could be sufficient to obtain between fair and good acoustics in classroom.
Reverberation time (T), Speech Transmission Index (STI) and speech A-weighted Sound Pressure Level, SPL(A), were considered as the main acoustical parameters. Target values for T and STI are reported in the UNI 11532-2, where the school environments spaces are divided in 6 categories. Category A3 was chosen (Eq.1), that is aimed to lesson/communication, with teacher-student interaction.

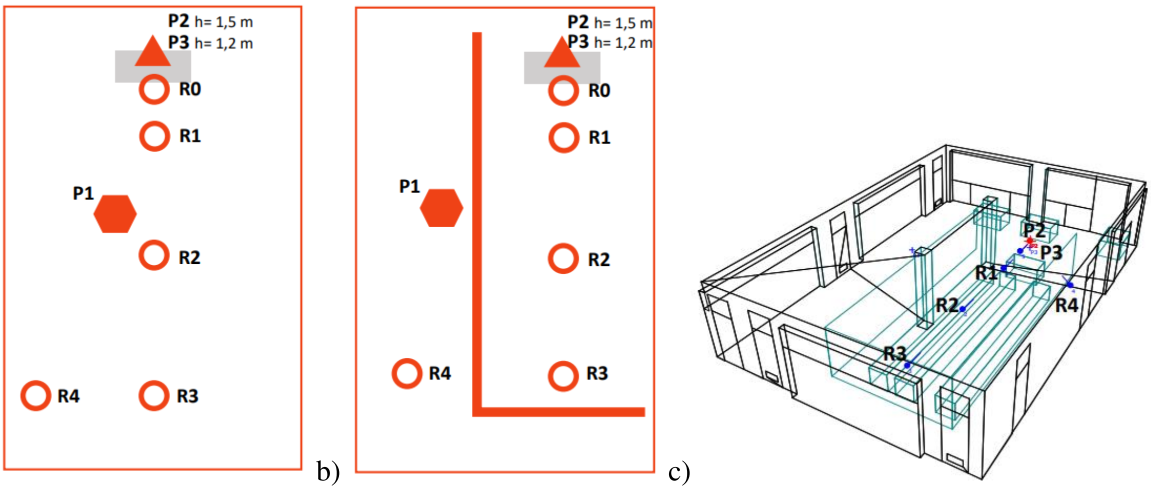
The optimal value for reverberation time is obtained with the following formula, which can be applied for a volume range 30 m^3 ≤ V < 5000 m^3:

$$T_{ott,A3} = 0.32logV - 0.17 \tag{1}$$

Table 1 reports the optimal reverberation time values for each volume. UNI 11532-2 indicates as the optimal values for STI, STI ≥ 0,55 for spaces with a volume V < 250 m^3 and STI ≥ 0,50 for spaces with a volume V ≥ 250 m^3 without sound amplification system. The standard was used a guideline for good practice. These target values were set to be reached as close as possible in order to allow a significant improvement in acoustic comfort compared to the starting condition.

a b c

Figure 1: Measurement campaign. Case studies a) auditorium, b) lobby, and c) gym.



a) c)

Figure 2: General scheme of the measurement (a) and simulation (c) layout with source P1-P3 (P1-omnidirectional and P2-P3 normal-speaker) and receivers R1-R4 (h=1.1 m in primary school and 1.2m in high school). Receiver R0 is at 1m distance from the source and at the same height h=1.5m. Scheme b) shows the distribution of the receivers when the separation between simultaneous classes occurs.

2.3 Measurement and simulation campaign

A reverberation time measurement campaign was run for 24 out of the 26 analysed spaces (Figure 1). Odeon 15 was used to simulate the different spaces at the different steps: (i) current configuration, which was calibrated based on in-situ measurement, (ii) new configuration without acoustic treatment, and (iii) new configuration with acoustic treatment. A transition order TO=2 and 4000-8000 rays have been used for all the configurations depending on the volume size. Two source and four receiver positions have been considered. One omnidirectional source (P1) and two sources (P2-P3) simulating the human voice directivity at normal speech level (namely TlkNorm in Odeon) at two different heights (sitting and standing up teacher) have been

tested. Only P2 has been used in the present work. STI was calculated assuming a female speech spectrum (Figure 2). Table II shows the NC curves applied for STI calculation both for the presence or the absence of the sound absorbing panels i.e. acoustic treatment and for the presence of one class or two/three/four classes in co-presence. Table I shows the spaces that were divided in more than one classroom.
Figure 3 shows the results of the measurement campaign, i.e., the mean reverberation time across the octave-band center frequencies 250, 500, 1000 and 2000 Hz vs rooms volumes.

Table II: NC curves used to simulate STI.

Number of classes simultaneously in the space	Acoustic treatment	
	yes	no
1	NC 30 – 39.7 dB(A)	NC 30 – 39.7 dB(A)
2	NC 35 – 44.2 dB(A)	NC 45 – 53.4 dB(A)
3	NC 40 – 49.0 dB(A)	NC 50 – 58.1 dB(A)
4	NC 40 – 49.0 dB(A)	NC 50 – 58.1 dB(A)

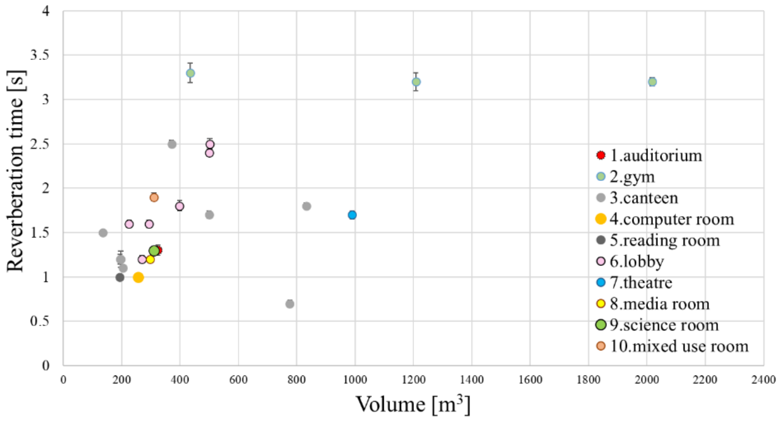


Figure 3: Relationship between the mean reverberation time (Tm) across the octave-band centre frequencies 250, 500, 1000 and 2000 Hz and the volume of each space.

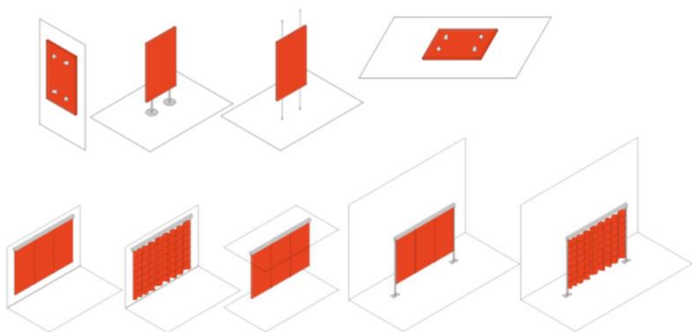


Figure 4: Basic acoustic treatment. These coloured schemes are used to indicate which solution was proposed for each space.

2.4 Selection of minimal acoustic treatments

As a first criteria for the selection of the acoustic treatment, only light and easy-to-handle acoustic materials and systems were chosen to transform different spaces into school environments suitable for teaching. The

main objective of this work was to arrange reversible treatments, fast-settled and well fitted into the existing context.
Only sound absorbing porous material with weighted sound absorption $\alpha_w \geq 0{,}8$ and sound insulating separation panels with $R_w \geq 18$ dB were considered. An acoustic reflective shell behind the teacher was added in larger spaces with high or vaulted ceilings or in case of absence of the wall behind or in case of lateral walls located at an excessive distance. The proposed solutions (Figure 4 and 5) are stand-alone panels to be hung like paintings on the walls or simply on the ceiling, free standing panels to be placed on the floor, or free standing baffles or acoustic curtains mounted on the ceiling or the walls.
Only in two cases, further acoustic treatment of the ceiling and lateral walls was proposed. These two cases represented an example of further treatment for all similar environments, which with the basic acoustic treatment cannot reach the optimal acoustic values.

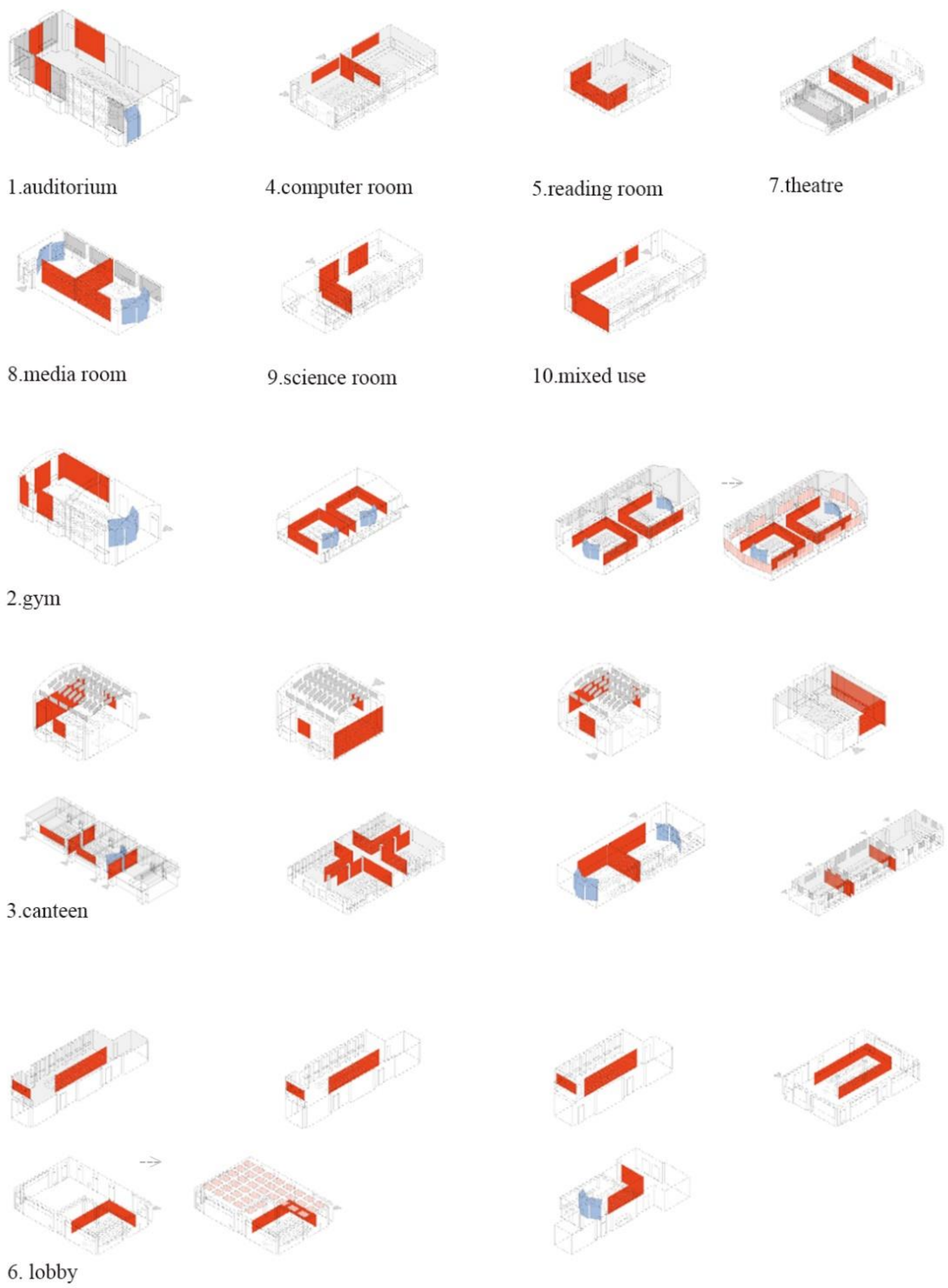


Figure 5: All spaces are divided upon their function with the indication of the extension and position of the acoustic treatment (orange red) and an acoustic reflective shell behind the teacher location in large spaces (light blue).

3 Results

Figure 6 shows the average, across frequencies, reverberation time T for each space with the basic acoustic treatment and the extra optimal treatment, in comparison with the measured reverberation time. Spaces are classified from 1 to 10 based on their function. It can be noticed that the basic treatment applied could reach the optimal values in most of the cases. However, given the unconventional volumes and space divisions it could not be fully achieved in all of them. Two of these cases have been further analysed with additional acoustic treatment (e.g. a 6.lobby and a 2.gym) applied as shown in Figure 5. This second application aimed at showing the significant effect on acoustic parameters (mainly T_m and STI) and the material extension needed to achieve a further improvement. It should be highlighted that this might have a considerable impact on the costs and speed of execution of the project. These two cases of optimal treatment, chosen on a sample basis, represent an example of further treatment in a second step for all similar environments, which with the basic acoustic treatment cannot reach the optimal acoustic values.

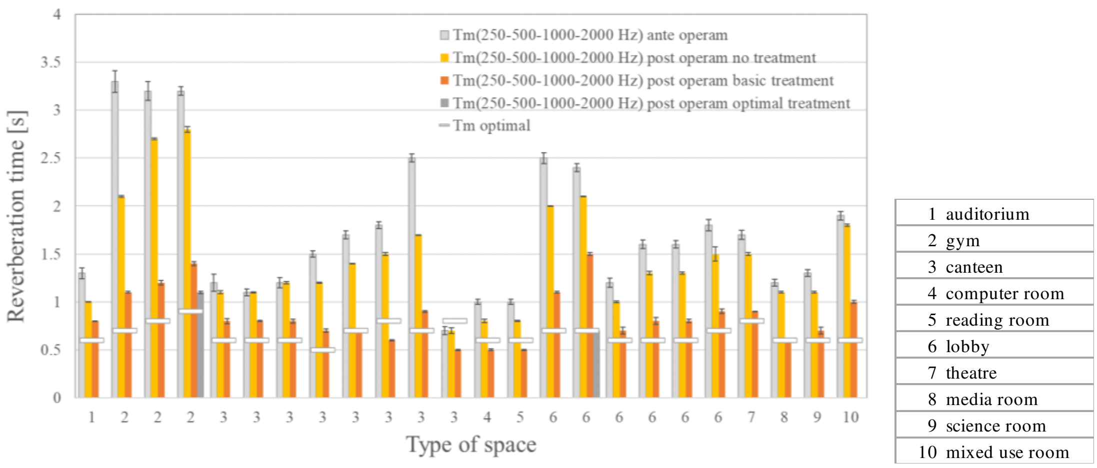


Figure 6: Actual reverberation time and *post operam* reverberation time (results for both the basic and the optimal acoustic treatments are shown for 2.gym and 6.lobby).

Figure 7 shows the average STI values across three or four receivers. The number of receivers was different for each space because in case of lobbies or large spaces with more than one class, a fourth receiver was placed outside the teaching area (Figure 2b), to check for reflections and speech level.

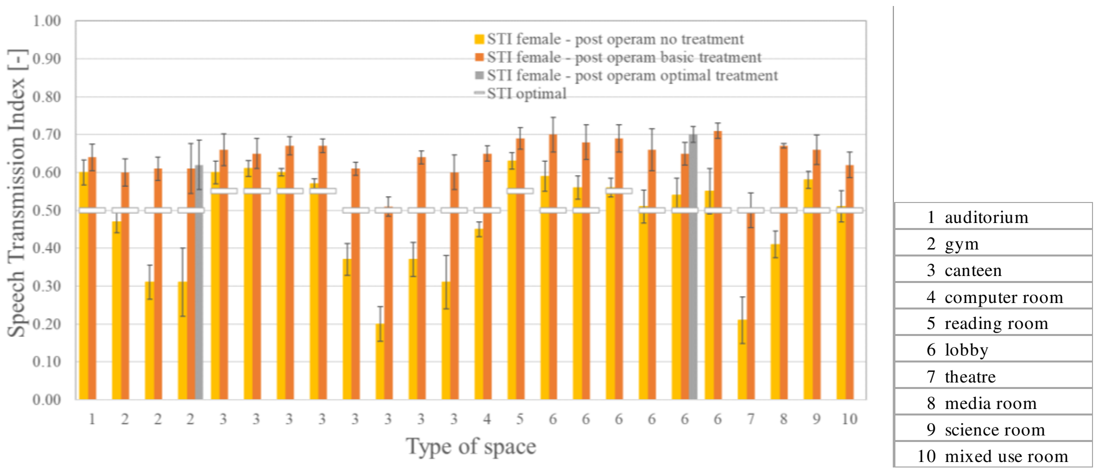


Figure 7: *Post operam* STI (results for both the basic and the optimal acoustic treatments are shown for 2.gym and 6.lobby).

Figure 8 shows the average speech SPL(A) values across three or four receivers simulated with Odeon software using a female speaker with a normal vocal effort.

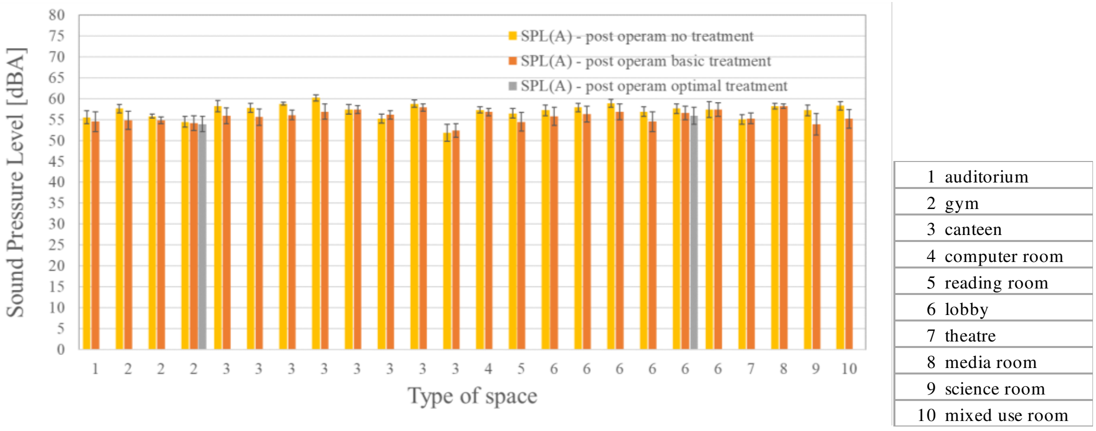


Figure 8: Average value of three of four receivers SPL (results for both the basic and the optimal acoustic treatments are shown for 2.gym and 6.lobby).

4 Discussion and conclusions

This study was carried out from the need of having additional teaching spaces with good acoustics, where it is possible to ensure the required distance between students to limit the contagion from Covid-19, on one side, and an effective teaching condition, on the other side.

The proposed acoustic treatments ensure the reversibility, the fast-settlement, and the good acoustics with respect to the requirements of one of the most updated Standards in the field of classroom acoustics. Some limitations in the achieved target values have been considered acceptable given the unconventional conditions of the treated spaces. However, two cases have been further implemented in order to achieve the standard optimal values. This helped to quantify the design effort and costs for extra acoustic treatment.

The investigation highlighted the absence of acoustic treatment or systems that can be used in emergency conditions as ready-to-use products. However, in conclusion, the proposed solutions can be adopted as guidelines to be used for similar construction types, shapes and volumes. They represent a compromise between good acoustics and reversible and costly affordable treatment. In case of more complex situations, deeper study must be carried out.

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