ACOUSTIC TREATMENTS AIMING TO ACHIEVE THE ITALIAN MINIMUM ENVIRONMENTAL CRITERIA (CAM) STANDARDS IN LARGE REVERBERANT CLASSROOMS

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Résumé

Une législation italienne récente a établi les critères environnementaux minimaux (CAM) pour tout environnement de travail. En ce qui concerne les écoles, des objectifs de confort acoustique adéquat sont requis en termes de contrôle du bruit et de qualité acoustique. Les écoles doivent se conformer à la norme UNI 11532 pour la durée de réverbération (T), la clarté (C50) et l'intelligibilité de la parole (STI). Dans les salles de classe, les valeurs suivantes sont requises : T <0,7 s, C50> 0 dB et STI> 0,6. Dans les installations sportives telles que les gymnases ou les piscines, les exigences CAM sont T <1,5 s, C50> -2 dB et STI> 0,5. Pour atteindre ces objectifs, l'insertion de traitements acoustiques est souvent inévitable. Les acousticiens utilisent couramment la théorie du champ parfaitement diffus pour calculer la quantité de matériau absorbant nécessaire pour se conformer à la législation en vigueur. Le but de ce travail est d'évaluer l'emplacement optimal d'une quantité minimum de traitement absorbant permettant d'atteindre les CAM dans certaines classes de l'université. Ces salles de classe ont un sol en marbre et des murs en plâtre et, à 1,0 kHz, ont des valeurs T comprises entre 2,5 s et 4,5 s, C50 entre 3 dB et -0,5 dB et ST entre 0,34 et 0,47. À l'aide d'un logiciel acoustique, il a été possible d'estimer la quantité minimale et de placer de manière optimale les panneaux absorbants afin d'atteindre les CAM des salles de classe sélectionnées.

Mots clefs : salles de classe, clarté, temps de réverbération, intelligibilité de la parole, critères environnementaux minimaux italiens.

Abstract

A recent Italian legislation has established the Minimum Environmental Criteria (CAM) for any working environment. In regards to schools, adequate acoustic comfort targets are required in terms of noise control and acoustic quality. Schools must comply with the Italian technical standard UNI 11532 for their reverberation time (T), clarity (C50) and speech intelligibility (STI). In classrooms, the following values are required: T<0.7s, C50>0dB, and STI>0.6. In sports facilities such as gyms, the CAM requirements are T<1.5 s, C50> -2 dB, and STI> 0.5. To achieve these objectives, the insertion of acoustic treatments is often unavoidable. The new requests for classrooms are leading acousticians to propose sound correcting interventions in many educational buildings. Acousticians typically use the perfectly diffused theory to calculate the minimum amount of needed sound-absorbing material to comply with current legislation. The purpose of this work is to evaluate the optimal position in which to place the minimum amount of sound-absorbing treatments to reach the CAM in some university classrooms. These classrooms have a marble floor and plastered walls and, at 1.0 kHz, have T values between 2.5 s and 4.5 s, C50 between 3 dB and -0.5 dB, and STI between 0.34 and 0.47. Using an acoustic software, it was possible to estimate the minimum quantity and the optimal placement of the sound-absorbing panels to insert in each classroom to reach the CAM.

Keywords: classrooms, clarity, reverberation time, speech intelligibility, Italian Minimum Environmental Criteria.

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1 Introduction

In classrooms, non-optimal acoustic conditions negatively influence speech understanding and students' performance. Students who sit in the front rows, close to the teacher, better understand listen to the class than those students who are sitting in far back rows. It is common that in the back rows of large classrooms, the teacher's voice gets weaker and the excessive reverberation makes hard to listen clearly to it. The reverberation of a classroom has a negative effect on speech understanding, and this effect increases as the distance between source and receiver increases.

Many studies on excess reverberation in classrooms have been reported [1-6]. Some authors in Brazil have verified the acoustic quality of new schools by measuring different acoustic parameters. The effects of the distribution of spaces on acoustic comfort were also analyzed [1].

Other authors have studied the acoustics of the classrooms through the use of software, and have proved that the sound field in classrooms can be far from being perfectly diffused. Therefore, the Sabine diffused field

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theory should not be applied in classrooms without critical analysis of the specific conditions [2].

Analyzing audio recordings acquired in some classrooms, both occupied and empty, it has been shown that the reverberation time is not the only acoustic parameter that influences the acoustic comfort of classrooms, but clarity, speech transmission index and ambient noise due to the simultaneous presence of other students in adjacent classrooms should be analyzed too [3].

In another study, the acoustic parameters calculated within high school classrooms in northern Italy were compared both with software and with the classical formulas of the perfectly diffused field in order to obtain an accurate prediction of reverberation time [4]. In this case, the absence of a diffused field has been indicated as an important element for a detailed design. Other authors report the acoustic measurements performed inside classrooms after the renovation, and evaluated the effectiveness of the intervention [5, 6].

In architectural acoustics, small deficiencies, such as insufficient reverberation, can be tolerated, but other deficiencies like a barely perceptible echo, often result highly annoying and disturbing perceptions

The echo is a sensation in which the listener distinctly perceives a replica of the direct sound. In large classrooms the presence of large parallel reflecting walls generates a reflected sound that if the direct time and the delay of the reflected sound is less than 50 ms, improves the understanding of the speech. However, when the distance between the parallel flat walls is larger than 10 meters, undesirable flutter echo phenomena may occur due to the interference between the direct and the reflected sound from the walls. This common condition in many classrooms significantly degrades the speech understanding. Furthermore, the presence of large vaulted ceilings produces acoustic focusing effects by concentrating sound energy at defined points, and contributes to a non-uniform distribution of the sound [7-10].

A recent Italian legislation has established the Minimum Environmental Criteria (CAM) for working environments. With regard to schools, acoustic comfort targets are required in terms of noise control and acoustic quality. Schools must comply with the UNI 11532 [11] for their reverberation (T), clarity (C50) and speech intelligibility (STI). In classrooms, the following CAM values are required: T<0.7 s, C50>0 dB, and STI>0.6. Moreover, in educational sports facilities such as gyms, the requirements are T<1.5 s, C50>-2 dB, and STI>0.5. To achieve these objectives, the insertion of acoustic treatments is often unavoidable.

Acousticians commonly use the perfectly diffused theory to calculate the amount of needed sound-absorbing material to comply with current legislation. However, to prove the efficacy of sound absorbing treatments, the perfectly diffused theory cannot always be assumed. The purpose of this work is to evaluate the optimal position in which to place the minimum amount of sound-absorbing treatments to reach the CAM in some university classrooms.

2 Case study

Using an acoustic software, it was possible to estimate the minimum quantity and the optimal placement of the sound-absorbing panels to reach the CAM of five classrooms located in the Department of Architecture and Industrial Design of the Università degli Studi della Campania [12].
The classrooms are located in an ancient building in Aversa near the city of Caserta. The building, called "San Lorenzo ad Septimum", was built in the X century as Benedictine monastery. In the XV century the building was expanded. Then, in 1807, the monastery was closed and a school for young boys was set up. Since 1990 the Department of Architecture and Industrial Design is located in this historical building, with 13 classrooms and administrative offices.

Figure 1 shows the Department of Architecture and Industrial Design aerial view, while Fig. 2 shows the cloister on two levels with arches and columns.

The building is located in a suburban area of the city, away from traffic lines. In addition, the classrooms are located at the rear of the building in relation to the access road and therefore the ambient noise is very low and is such that it does not affect the acoustic comfort. During the acoustic measurements, the background noise expressed as equivalent sound level (LeqA) was always below 40 dBA.

Figure 1: Department of Architecture and Industrial Design aerial view.

Figure 2: Department of Architecture and Industrial Design showing the cloister on two levels with arches and columns, behind which there are classrooms.

The classrooms located in this historic building, have irregular shapes, a marble floor, vaulted ceilings, and plastered smooth walls.

Five university classrooms were analysed; the dimensions are reported in Table 1. Figure 3 shows some of the classrooms investigated in the present study.

Figure 3: Photos of the classrooms: P3 (top), S2(center), T5 (bottom left), and T4 (bottom right).

Table 1: Average dimensions of the five selected classrooms.

classroom	Volume, m^3	Average height, m	Base area, m^2
P3	416	5.4	77
S3	1,850	7.2	257
T5	2,517	12.1	208
S2	626	4.6	136
T4	275	5.5	50

3 Acoustic measurements

For each classroom, acoustic measurements were carried out using an omnidirectional sound source. Following this, the impulse responses were recorded, and the acoustic parameters were analyzed. The sound source was placed in each classroom at the height 1.6 m, and the measurements were done in different points in the classrooms at typical ear height of 1.2 m, to obtain an average value of the acoustic parameters for speech understanding.

The acoustic parameters were measured according to the ISO 3382 [13], with a microphone GRAS 40 AR endowed with the preamplifier 01 dB PRE 12 H through the interface 01 dB Symphonie. The omnidirectional sound source was fed by a MLS signals [14]. The acoustic parameters measured were the reverberation time (T), the Clarity (C50), and the Speech Transmission Index (STI) [15, 16]. The acoustic measurements were carried out without students, in empty condition. These classrooms at 1.0 kHz, have T30 values between 2.5s and 4.5s, C50 between 3 dB and -0.5 dB, and STI between 0.34 and 0.47, values far from those reported in the new Italian regulations about the CAM. The need for acoustic interventions was hence evident.

4 Simulations

To evaluate a possible solution to reduce the reverberation time and allow the achievement of an adequate acoustic comfort, the architectural acoustics software "Odeon" was used [17, 18]. The software was used because the perfectly diffuse field model was not applicable in the investigated rooms [19-23].

Odeon adopts a hybrid method using the ray tracing and image source methods for the acoustic simulations. The reverberation time was chosen as a reference parameter for the calibration, which was done by tuning the absorbent coefficient values of the walls so that the reverberation time measured coincided with the predicted one. The calibration was stopped when the difference between the time measured and the time calculated is inferior to 5% of all the octave bands calculated between 125 and 4000 Hz. Regarding the scattering coefficient, the desks and chairs were simulated as flat planes, with a scattering coefficient of 0.5 for the unoccupied condition [24, 25].

The best location to install the sound-absorbing panels to reduce the reverberation time and improve the acoustics characteristic, preserving aesthetics and following historic preservation instructions were searched. The results of the acoustic measurements for each classroom and the relative acoustic correction among several positions of the sound-absorbing panels are reported in Section 6.

5 Absorbent panel for the acoustic correction

To obtain the vales of the sound absorption coefficients used for the computer simulation of the acoustic correction, an impedance tube was used according to ISO 10534-2 [26]. In this way, it is possible to obtain the absorbent coefficient measurements at normal incidence using samples of diameter 10 cm. This geometry corresponds to an upper frequency limit measurement of 2000 Hz. Polyester absorbent panels, with thickness of 4 cm were chosen. Table 2 reports the octave band values of sound absorption coefficient measured for the selected material samples. The average value of the absorbent coefficient was obtained from measurements with four different specimens. The value at the frequency band of 4000 Hz was assumed equal to the value at 2000 Hz, as porous materials typically have growing absorption at higher frequency and the recorded value at 2000 Hz was 0.9.

6 Results

This study aimed to know the effects of the insertion of absorbent materials in the classrooms on speech understanding. According to the UNI 11532, the acoustic parameters T, C50, and STI were analysed.

For each classroom, different surface areas of absorbent material that correspond to the walls behind the teacher's position were considered. For each classroom the measured values of T30, C50, and STI are shown and then the same parameters calculated by Odeon software after the acoustic correction are discussed. The sound-absorbing material are inserted in the virtual model of classroom on the vertical wall behind the teacher's position or on the ceiling. The equivalent area of sound-absorbing material changes for each classroom because the vertical wall is different for each classroom. Table 3 shows the STI values in numerical range from bad to excellent that were considered in order to assess the different scenarios.

6.1 Classroom P3 - hypothesis of correction

The classroom P3 has a volume of 416 m^3, an average height of 5.4 m and a base area of 77 m^2. The walls are plastered, the floor is marble, the ceiling is vaulted, with double glazed side windows, wooden benches and chairs.
Figure 4 shows the acoustic correcting panels simulated under ceiling or on the wall behind the teacher's desk. Tables 4 to 6 report the STI, T30, and C50 values respectively, for the following scenarios: A) empty room; B) 89 sqm located in front of the teacher in the lateral ceiling area, C) 89 sqm behind teacher in the lateral ceiling area; D) 89 sqm behind teacher in the central ceiling area.

6.2 Classroom S3 - hypothesis of correction

The classroom S3 has a volume of 1,850 m^3, an average height of 7.2 m and a base area of 257 m^2. The walls are plastered, the floor is marble, the ceiling is double-pitched wood, and there are wooden desks and chairs. Figure 4 shows the acoustic correcting panels simulated under ceiling or on the vertical wall behind teacher. Tables 7 to 9 report the STI, T30, and C50 values respectively, for the following scenarios: A) empty room; B) 364 sqm on the wall behind teacher; C) 422 sqm ceiling on the wall behind teacher; D) 412 sqm side walls; E) 437 sqm ceiling on the entrance wall.

6.3 Room T5 - hypothesis of correction

The classroom T5 has a volume of 2,517 m^3, an average height of 12.1 m and a base area of 208 m^2. The walls are plastered, the floor is in marble, the vaulted plaster ceiling, there are side windows with double glazing, there are wooden benches and chairs.

Figure 6 shows the acoustic correcting panels simulated under ceiling or on the vertical wall behind teacher. Tables 10 to 12 report the STI, T30, and C50 values respectively, for the following scenarios: A) empty room; B) 240 sqm on ceiling panels; C) 320 sqm on ceiling and entrance wall; D) 420 sqm on ceiling and on the walls at the entrance and behind the teacher; E) 440 sqm only on side walls, F) 550 sqm on the ceiling and the side walls.

Table 2: Sound absorption coefficients measured according to ISO 10534-2

	Frequency, Hz					
	125	250	500	1 k	2 k	4 k
Abs coefficient	0.2	0.4	0.6	0.8	0.9	0.9

Table 3: Judgment for different STI Value.

bad	Poor	fair	good	excellent
0 - 0.3	0.3 - 0.45	0.45 - 0.6	0.6 - 0.75	0.75 - 1

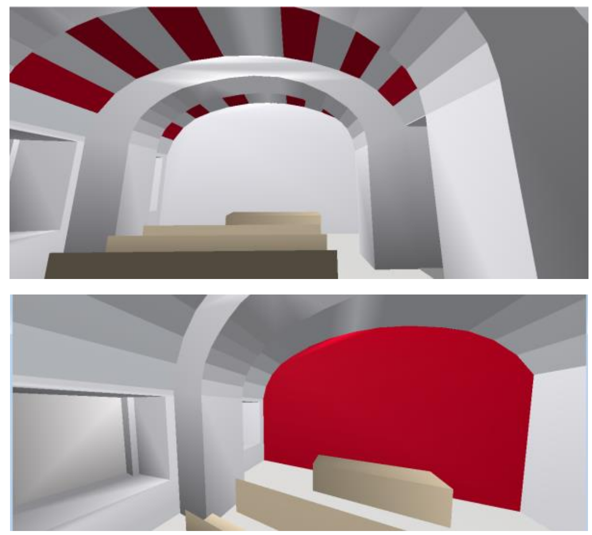

Figure 4: Panels under ceiling or on the wall behind teacher in the room P3

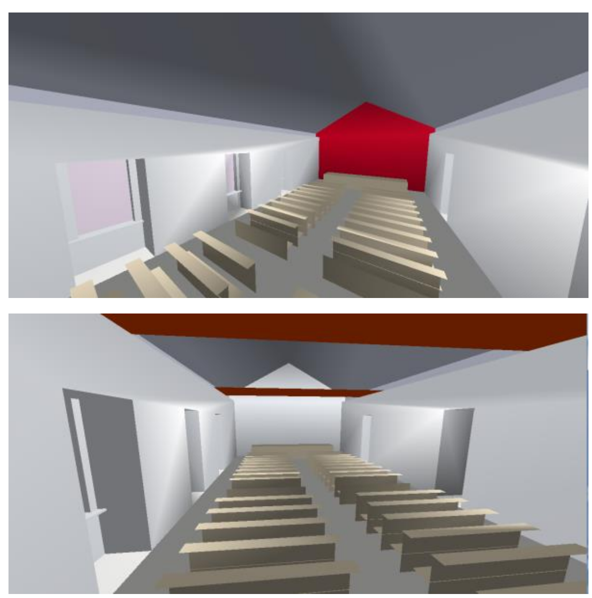

Figure 5: Panels on the wall behind teacher or under the ceiling in the room S3.

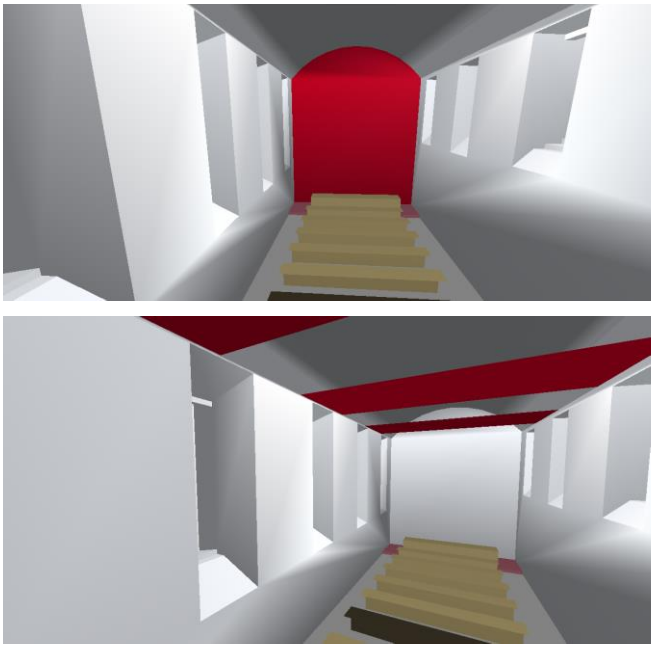

Figure 6: Panels on the wall behind teacher and under ceiling in the room T5.

Table 4: STI values assumed in room P3 for different scenarios.

	Scenarios	STI
A	empty room measured	0.43
B	89 sqm– lateral ceiling area	0.63
C	89 sqm behind teacher – lateral ceiling area	0.65
D	89 sqm behind teacher – central ceiling area	0.67

Table 5: T30 values assumed in room P3 for different scenarios

Scenario (as for table 4)	Frequency, Hz					
	125	250	500	1 k	2 k	4 k
A	2.8	2.7	2.2	2.2	1.8	1.6
B	2.1	1.0	0.8	0.7	0.7	0.6
C	2.1	1.0	0.8	0.7	0.7	0.6
D	2.0	0.9	0.7	0.6	0.6	0.6

Table 6: C50 values assumed in room P3 for different scenarios

Scenario (as for table 4)	Frequency, Hz					
	125	250	500	1 k	2 k	4 k
A	-6.0	-5.5	-4.8	-4.5	-3.3	-2.7
B	-4.8	-0.3	0.7	1.9	2.7	3.1
C	-4.5	0.3	1.6	3.1	3.9	4.1
D	-4.3	0.5	1.9	3.5	4.3	4.5

Table 7: STI values assumed in room S3 for different scenarios

	Scenarios	STI
A	empty room	0.43
B	364 sqm - wall behind teacher	0.63
C	422 sqm ceiling - wall behind teacher	0.65
D	412 sqm side walls	0.67
E	437 sqm ceiling - entrance wall	0.68

Table 8: T30 values assumed in room S3 for different scenarios

Scenario (as for table 7)	Frequency, Hz					
	125	250	500	1 k	2 k	4 k
A	3.1	2.8	2.8	2.7	2.3	2.0
B	2.9	1.2	0.9	0.7	0.5	0.4
C	2.8	1.1	0.9	0.6	0.4	0.4
D	2.8	1.1	0.9	0.6	0.4	0.4
E	2.8	1.2	1.0	0.9	1.0	0.9

Table 9: C50 values assumed in room S3 for different scenarios

Scenario (as for table 7)	Frequency, Hz					
	125	250	500	1 k	2 k	4 k
A	-5.8	-5.2	-5.2	-4.8	-4.1	-3.1
B	-5.8	-1.0	0.5	2.5	5.2	6.0
C	-5.5	-0.3	1.9	3.9	4.5	5.0
D	-5.8	-0.5	1.2	3.7	7.5	8.3
E	-5.5	0.0	2.7	5.5	6.6	6.9

Table 10: STI values assumed in room T5 for different scenarios

	Panels distribution	STI
A	empty room	0.36
B	240 sqm ceiling panels	0.53
C	320 sqm ceiling and entrance wall	0.59
D	440 sqm only side walls	0.59
E	420 sqm ceiling and wall entrance and teacher	0.60
F	550 sqm ceiling and side walls	0.70

Table 11: T30 values assumed in room T5 for different scenarios

Scenario (as for table 10)	Frequency, Hz					
	125	250	500	1 k	2 k	4 k
A	4.8	5.6	4.2	4.0	3.1	2.2
B	3.0	2.4	1.7	1.4	1.2	1.0
C	2.7	2.0	1.4	1.1	1.0	0.8
D	2.4	1.7	1.2	0.9	0.8	0.7
E	2.3	1.6	1.1	0.9	0.8	0.7
F	2.1	1.4	0.9	0.7	0.6	0.6

Table 12: C50 values assumed in room T5 for different scenarios

Scenario (as for table 10)	Frequency, Hz					
	125	250	500	1 k	2 k	4 k
A	-8.3	-8.7	-6.9	-6.6	-5.5	-3.7
B	-7.0	-2.9	-1.2	0.3	0.7	1.7
C	-6.7	-1.9	0.3	2.3	2.7	3.6
D	-6.3	-1.1	1.0	3.2	3.6	4.4
E	-6.3	-2.0	0.0	1.8	2.7	3.5
F	-5.8	0.3	2.5	4.8	5.5	6.3

6.4 Classroom S2 - hypothesis of correction

The classroom S2 has a volume of 626 m^3, an average height of 4.6 m and a base area of 136 m^2. The walls are plastered, the floor is marble, the ceiling is plaster floor, there are side windows with double glazing. There are wooden benches and chairs.

Figure 7 shows the acoustic correcting panels simulated on the vertical wall behind teacher or under ceiling. Tables 13 to 15 report the STI, T30, and C50 values respectively, for the following scenarios: A) empty room; B) 150 sqm side - front of the teacher; C) 150 sqm lateral - behind the teacher; D) 150 sqm ceiling - behind teacher.

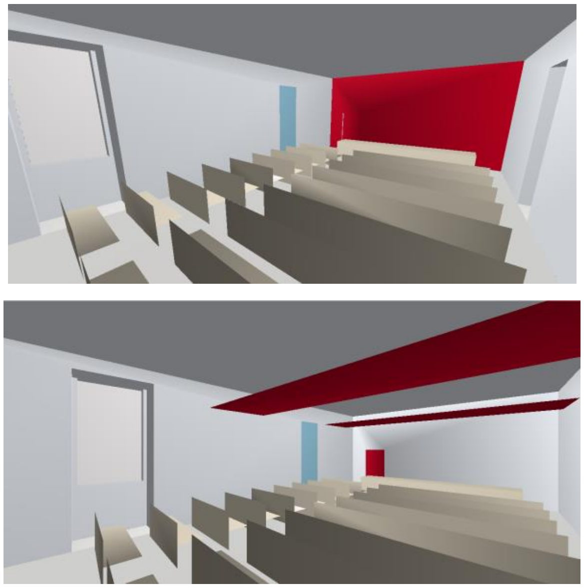

Figure 7: Panels on wall behind teacher and under the ceiling in the room S2.

Table 13: STI values assumed in room S2 for different scenarios

	Scenarios	STI
A	empty room	0.44
B	150 sqm lateral - front of the teacher	0.65
C	150 sqm lateral - behind the teacher	0.66
D	150 sqm ceiling - behind teacher	0.66

Table 14: T30 values assumed in room S2 for different scenarios

Scenario (as for table 13)	Frequency, Hz					
	125	250	500	1 k	2 k	4 k
A	2.8	2.8	2.7	2.6	2.3	1.7
B	2.0	1.1	1.0	0.9	0.9	0.8
C	2.1	1.0	0.9	0.8	0.7	0.7
D	2.0	1.0	0.9	0.7	0.7	0.7

Table 15: C50 values assumed in room S2 for different scenarios

Scenario (as for table 13)	Frequency, Hz					
	125	250	500	1 k	2 k	4 k
A	-5.0	-5.0	-4.8	-4.5	-3.7	-2.3
B	-3.3	0.9	2.1	3.5	3.9	4.8
C	-3.3	0.7	2.1	3.5	4.3	5.0
D	-3.1	1.0	2.5	3.9	4.1	4.8

6.5 Classroom T4 - hypothesis of correction

The classroom T4 has a volume of 275 m^3, an average height of 5.5 m and a base area of 50 m^2. The walls are plastered, the floor is in marble, the vaulted plaster ceiling, there are side windows with double glazing, there are wooden benches and chairs. Figure 8 shows the acoustic correcting panels simulated under ceiling or on the vertical wall behind teacher. Tables 16 to 18 report the STI, T30, and C50 values respectively, for the following scenarios: A) empty room; B) 50 sqm panels on the wall opposite to the teacher's wall; C) 50 sqm panels on the wall at the side of the teacher's desk; D) 50 sqm panels under the vault.

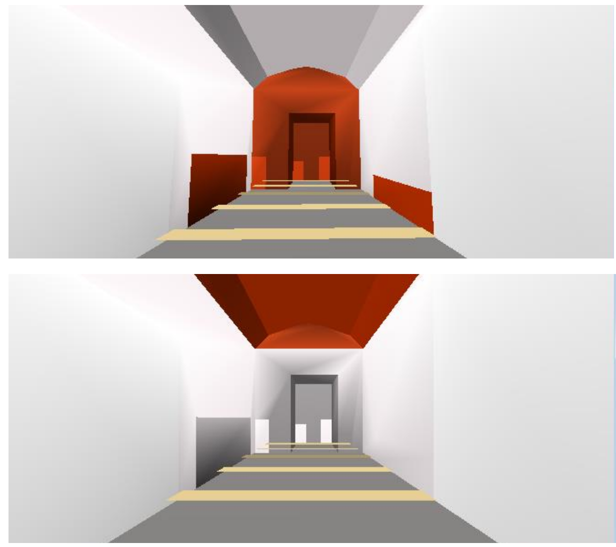

Figure 8: Panels on wall behind teacher and under the ceiling in the room T4.

Table 16: STI values assumed in room T4 for different scenarios

	Scenarios	STI
A	empty room	0.45
B	50 sqm panels opposite teacher's wall	0.63
C	50 sqm panels wall teacher side	0.67
D	50 sqm panels under the vault	0.70

Table 17: T30 values assumed in room T4 for different scenarios

Scenario (as for table 16)	Frequency, Hz					
	125	250	500	1 k	2 k	4 k
A	3.5	2.5	2.1	1.8	1.8	1.5
B	2.5	1.2	1.0	0.8	0.8	0.7
C	2.4	1.0	0.9	0.7	0.7	0.6
D	2.4	0.9	0.7	0.6	0.5	0.5

Table 18: C50 values assumed in room T4 for different scenarios

Scenario (as for table 16)	Frequency, Hz					
	125	250	500	1 k	2 k	4 k
A	-5.1	-3.4	-2.6	-1.8	-1.7	-0.6
B	-3.5	0.8	1.7	2.8	3.2	3.8
C	-3.3	1.5	2.7	4.2	4.7	5.3
D	-3.2	2.7	4.0	5.9	6.3	6.8

7 Discussion

The recent Italian regulations regarding the Minimum Environmental Criteria pay attention to the acoustic comfort inside the classrooms and refer to the UNI 11532 standard conditions. In this standard, appropriate values of the acoustic parameters T, STI and C50 are provided. During the design phase these parameters can be estimated with the use of software for architectural acoustics. In the specific case, a software based on the tracing of the sound beams was used. In fact, for the appropriate estimation of the acoustic parameters the classical formulas of the diffused sound field cannot be used, as this condition does not occur.

The diffuse field model occurs when the distribution of the sound pressure level is uniform and the reverberation time is invariant, a condition that in the classrooms under examination given their geometry does not occur. Because the classrooms have different dimensions and do not have the same geometry, acoustic measurements and an evaluation of the parameters have been performed for each of them. In rooms with a vaulted ceiling there are sound focusing conditions in the central part of the room, these effects are eliminated by covering partially the ceiling with sound-absorbing material. Moreover, given the large dimensions and parallel flat walls, extensive surfaces of sound-absorbing material are needed on the walls to reduce the detrimental flutter-echo effects.

With the help of the Odeon software, it is possible to estimate the minimum amount of sound-absorbing material to be inserted in order to obtain the objectives required by the CAM. The software based on the tracing of the sound beams allows the estimation of the parameters T, C50, and STI as the arrangement of the sound absorbing panels varies. For the five classrooms considered the provision that allows the achievement of the objectives of the CAM with the minimum amount of sound-absorbing material. Place of the panels on the ceiling and the arrangement that allows the CAM to be respected with the minimum amount of sound-absorbing material were obtained.

The most important acoustic aspect in the classrooms is the verbal communication. Therefore, the analysis focused on the acoustic parameters that influence speech intelligibility. During the measurements, the noise of the operation of the air conditioning systems was considered. The operation of the air treatment systems, involves an increase in the level of the background noise, an effect that is manifested above all in reverberant environments, and consequently creates a reduction in speech intelligibility.

Being a historical building there is not a centralized air treatment system, but the heating or cooling is done with single units. The values of the equivalent sound emission levels of these systems, when they are in operation, are lower than 30 dBA and therefore they are such as not to interfere with normal activities.

The amount of surface of sound-absorbing material to be inserted in environments for acoustic correction may change depending on the chosen material. In this case, a 4 cm thick polyester panel was considered.

The choice of a more performing sound-absorbing material involves a reduction of useful surface to be coated. In addition, acoustic measurements were performed in empty classrooms, in the absence of students; therefore, it has not been possible to investigate the contributions of people on the acoustic characteristics of the classrooms.

In classrooms the comprehension of speech could be improved by changing the arrangement of the desks with respect to the listener's position, with a provision that brings students closer to the teacher or the type of furniture could be changed, for example by replacing the wooden chairs with padded chairs that contribute to the reduction of excessive reverberation [27, 28].

The CAMs provide only the values of the acoustic parameters to be respected, but they do not give useful information about the achievement of these objectives. The CAMs provide indications on how to improve the understanding of the speech indicating solutions to increase the sound level of the components of the early reflections that reinforce the sound direct, in fact, as the level of direct sound increases, the intelligibility of speech improves [29]. In addition, the CAM do not say anything about the presence of the students. The acoustic conditions can change with the presence of students [30]. The presence of the students results in a reduction in reverberation time due to the sound absorption of people, but on the other hand, there would be a reduction in the sound level and the increase in background noise, due to the natural activities of the students. To improve the acoustic characteristics of the classrooms analyzed, since the historical and monumental building, invasive criteria for good acoustic design could not be considered [31].

8 Conclusions

The classrooms in the case study historical building, and in the majority of the historical buildings, do not have good acoustics. T measured values at 1 kHz well over 0.7 s, and so classrooms needed significant acoustic corrections. In fact, in the considered case study, as in many similar conditions, the actual coustic conditions are far from the Italian "Minimum Environmental Criteria" (CAM).

Through software simulations, this study has obtained useful information for each classroom geometry, and about the position where to install the absorbent material to have the best acoustic performance and respect aesthetic and historical criteria.

Future developments of the work will be directed towards the optimization of the considered acoustic parameters, so that with optimization techniques, the arrangement of sound-absorbing materials that allows the best acoustic comfort can be chosen in an appropriate manner. In addition, sound-absorbing materials could be used that are acoustically more performing so as to reduce the area to be covered. To improve the comprehension of the voice, it is necessary to proceed to an accurate design of the electroacoustic systems that take into account the dimensions and the geometries of the environments.

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