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THE REFURBISHMENT OF THE PORTUGUESE PUBLIC SECONDARY SCHOOL NETWORK: AN ACOUSTICAL PERSPECTIVE

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Abstract
In 2007 a modernization program for the public secondary school network was initiated by the Portuguese government, with 4 pilot-projects in Oporto and Lisbon. This program will cover a total of 332 schools across the whole country until 2015 with an estimated investment of EUR 2,5 billion, being at the moment in its 3rd phase of intervention.
Due to the well-known importance of a school acoustical environment in the learning and teaching performance of students and teachers it is important to reflect on the challenges and goals of this project in this engineering field.
After the conclusion of some projects and its construction implementation we present in this paper some of the acoustical solutions proposed as well as the experimental evaluation of the construction interventions. Some conclusions on the criteria adopted will be discussed as well as the difficulties in the interaction with the other engineering criteria involved in the projects.

Keywords: Schools, classroom acoustics, project guidelines.

1 Introduction

The importance of acoustics in the learning environment has been known for several decades[1]. Although this aspect has been considered in the Portuguese legislation since 1987 [1] imposing limits for sound insulation and reverberation time in schools, it was only in 2002 that a new decree-law [2] specified acoustical criteria in accordance with European directives

[1] Actually, if we recall that modern Architectural Acoustics had its birth during the study of the Fogg Lecture Hall acoustics at Harvard University, conducted by W. C. Sabine, this matter is at least 100 years old.

and ISO standards. However, the implementation of these criteria in the construction of school buildings was scarce, due to lack of supervision and other legislation gaps. In 2007 and 2008 several new decree-laws were promulgated that not only established new noise and building acoustics regulations [3, 4] but also allowed a stronger presence of these matters in the construction of buildings. It is in this legal scenario that the governmental modernization program for the Portuguese public secondary school network was initiated.
In 2007 this modernization program started with 4 pilot-projects in Oporto and Lisbon. Taking the pre-existing schools, the program involves refurbishing the existing facilities and constructing new building blocks to accommodate the modern necessities of the XXI century schools[2].
This program will cover a total of 332 schools across the whole country until 2015 with an estimated investment of EUR 2,5 billion, being at the moment in its 3rd phase of intervention [5].
Amongst the several engineering fields called to support this huge task, acoustics has been, maybe for the first time, explicitly recognized as one of the priorities, together with hygrothermics, air quality, safety, accessibility and energy efficiency.
After the conclusion of over 20 projects by the author and its implementation we explore in this paper the evolution of the acoustical engineering contributions and present some of the acoustical solutions proposed as well as the experimental evaluation of the interventions.

2 The acoustical conditions of the pre-modernization schools

Although acoustics was not the main problem for most of the schools covered by this modernization program, the acoustical conditions of the majority of lecture rooms were very poor. High reverberation times (T_{60}), ranging from 1,5 s to 2,0 s (average between 500 Hz, 1 kHz and 2 kHz octave bands) were measured in classrooms with an average volume of 185 m^3. The obvious reason for this fact was the lack of sound absorbing materials. Curiously, the speech intelligibility was facilitated by the inexistence of HVAC systems and the respective radiated noise. However, warmer days required opening windows for ventilation, allowing exterior noise to contribute to the distraction of students. Adding to these problems were low airborne and impact sound insulation levels between classrooms and between circulations and classrooms.
Not only teaching spaces were affected by the poor acoustical conditions. Libraries, canteens, corridors and gymnasia were very seldom spaces with any acoustical comfort, which degraded the concentration of students and the performance of teachers.
During the preparation of the acoustical design of a few schools, some measurements were performed in order to characterize the existent acoustical conditions and support the design options. As an example Table 1 shows the results of measurements of the normalized airborne and impact sound insulation between classrooms performed in 2007 in two schools. For these two examples (which probably represent a worst case scenario) most of the results did not fulfill or were even close to the legal criteria.
Figures 1 shows the results of measurements of the reverberation time in 1/3 octave bands for classrooms in the same schools. Both classrooms have volumes – (a) 152 m^3 and (b) 216 m^3 – that would imply much lower reverberation times, below 0,8 s, to contribute to good speech intelligibility and acoustical comfort.

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[2] The secondary school network construction was began at the end of the XIX century, from which, 23% were built until the end of the 1960s. The remaining 77% correspond to the period of expansion of the school network from which 46% were built until the 1980s [5].

Table 1 – Sound insulation measurement results for the Gonçalves Zarco School in Matosinhos.

Test	Measuring direction	Result	Legal criteria
Airborne sound insulation	Horizontal	$D_{n,w}$ = 29 dB	≥ 45 dB
	Vertical	$D_{n,w}$ = 39 dB	≥ 45 dB
Impact sound insulation	Horizontal	$L'_{n,w}$ = 79 dB	≤ 65 dB
	Vertical	$L'_{n,w}$ = 59 dB	≤ 65 dB

Table 1 – Sound insulation measurement results for the D. Pedro V School in Lisbon.

Test	Measuring direction	Result	Legal criteria
Airborne sound insulation	Horizontal	$D_{n,w}$ = 38 dB	≥ 45 dB
	Vertical	$D_{n,w}$ = 42 dB	≥ 45 dB
Impact sound insulation	Horizontal	$L'_{n,w}$ = 69 dB	≤ 65 dB
	Vertical	$L'_{n,w}$ = 77 dB	≤ 65 dB

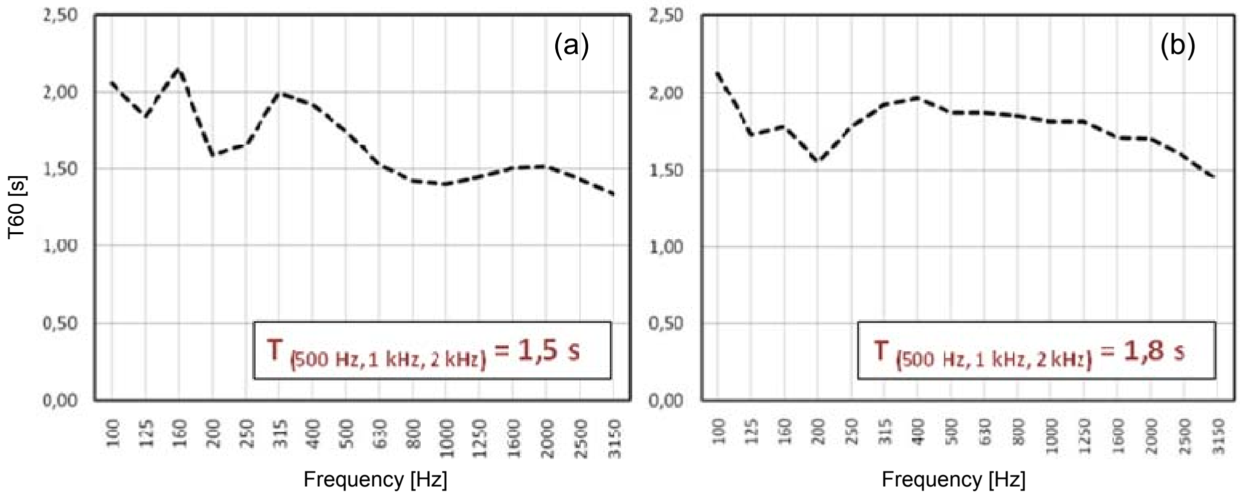

Figure 1 – 1/3 octave reverberation time measured in two classrooms of two different schools.

3 Main acoustical solutions implemented

The acoustical interventions in the schools covered three main aspects: 1) control of reverberation; 2) reinforcing sound insulation and 3) control of noise from the HVAC systems to be implemented.

3.1 Control of reverberation

The application of sound absorbing material was generalized to most of the school spaces where human occupancy was high. Not only classrooms received sound absorbing ceilings or walls but also refectories, gymnasia, lobbies, libraries, laboratories, and to least extent corridors, had some kind of reverberation time control implemented. For most of these spaces (classrooms, refectories, libraries) the acoustical criteria mandatory by law is given by equation 1:

$$T \leq 0{,}15 \cdot \sqrt[3]{V} \tag{1}$$

were T is the reverberation time averaged over the 500 Hz, 1 kHz and 2 kHz octave bands. Depending on the absorption coefficient of the applied solution, on the scattering provided by windows recesses and furniture and on the room height, the application of the solution over the total area of the ceiling allows the compliance with the criteria. Other solutions were envisaged, which only partially covered the ceiling (to allow for useful reflections) and walls, but the architectural demands had a strong influence and a reasonable compromise had to be achieved. This was particularly the case for the introduction of sound absorption in corridors, for which numerical (ray-tracing) methods were implemented to calculate the minimum absorption required to achieve the design goal. Figure 2 shows an example of the model built and an example of an implementation, where a central absorptive gap was made on the ceiling which also enables clear access to mechanical services maintenance.

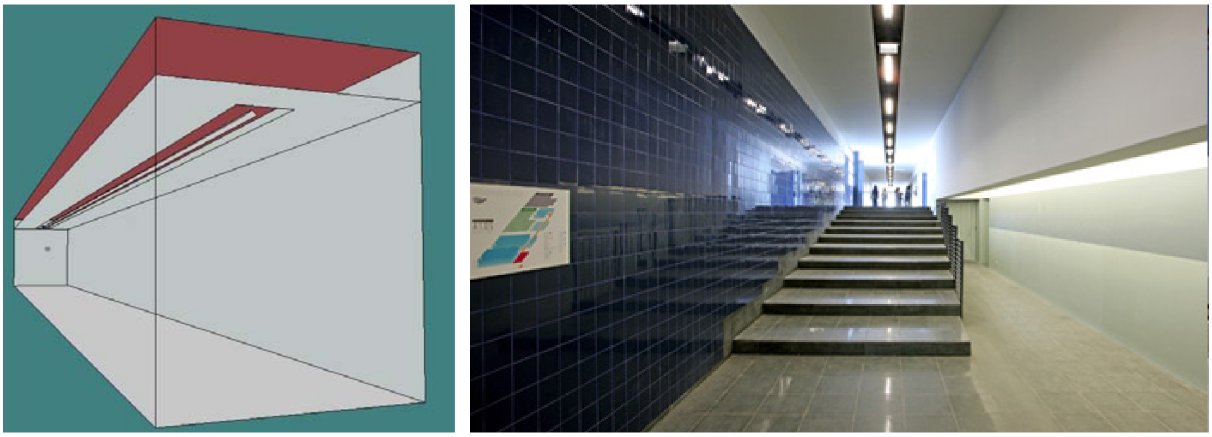

Figure 2 – Model and real implementation of sound absorption in corridors (the model and the picture representation do not represent the same case study).

3.2 Reinforcing sound insulation

The design of the existent facilities refurbishment was more delicate than the new constructions, because of cost issues. In these cases, a strict selection of walls to demolish and replace was made and solutions for improving the existing sound insulation were implemented, for example:

- Duplication of existing walls with gypsum boards and air spaces filled with mineral wool;
- Improvement of the sound insulation of exterior windows, mainly by replacing the existing glazing but also by closing air vents or designing new acoustical vents;
- Replacement of windows at the top of walls dividing classrooms and circulations, by brick or gypsum board partitions;
- Introduction of rubber sealing in classroom doors;
- Applying resilient floors or resilient layers on floors.

Figure 3 shows two examples of solutions implemented with gypsum boards to achieve the required sound insulation or to improve the existing insulation given by brick walls. Both solutions achieved results of 47 dB ≤ $D_{nT,w}$ ≤ 50 dB, measured after implementation.

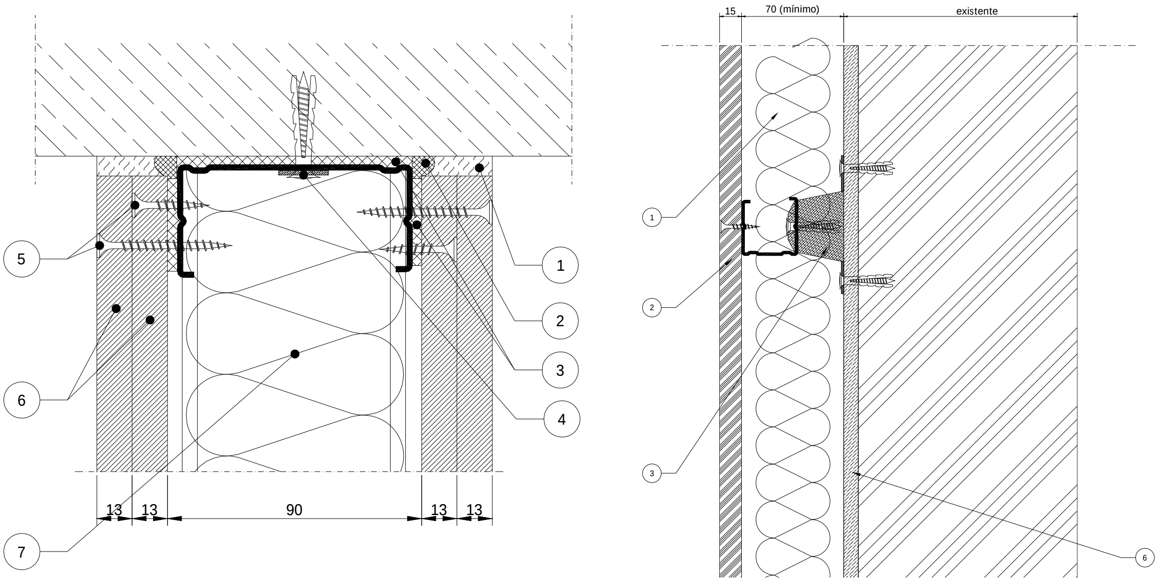

Figure 3 – Examples of new partitions solutions and reinforcement solutions for sound insulation.

3.3 Control of HVAC noise

Since introduction of HVAC systems was new to most of the schools, the acoustical design didn't have to deal with pre-existing equipments, which allowed the careful calculation of noise levels in dB(A) or RC MkII values. The usual solutions were implemented:

- Calculation and implementation of sound attenuators in HVAC equipments and between rooms to eliminate cross-talk;
- Design of acoustical louvers or openings for natural ventilation (the option for natural ventilation was dismissed after a few projects due to other engineering requirements);
- Design of anti-vibration systems for large equipments;
- Implementation of noise control measures to attenuate noise radiated to neighboring buildings.

Figure 4 shows an example of an acoustical opening designed to allow for ventilation from outside air whilst maintaining the façade sound insulation required.

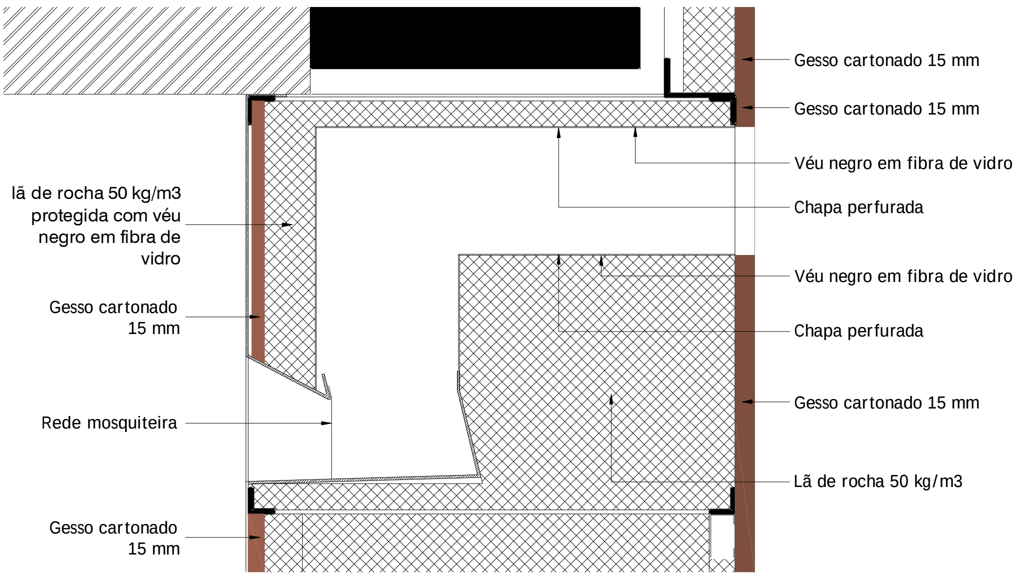

Figure 4 – Example of an acoustical opening for ventilation.

4 Measurement results after implementation

After completion of the construction works some of the previously evaluated schools were measured to allow a comparison and validation of the calculation and design procedures. The following figures show the results obtained together with the results before intervention to allow for a clear comparison.

Figure 5 shows the results obtained after replacing the side windows (located in the dividing wall between corridor and classroom) with brick, reinforcing the existing wall with gypsum board layers with mineral wool filled air cavity and applying rubber seals around the door frames.

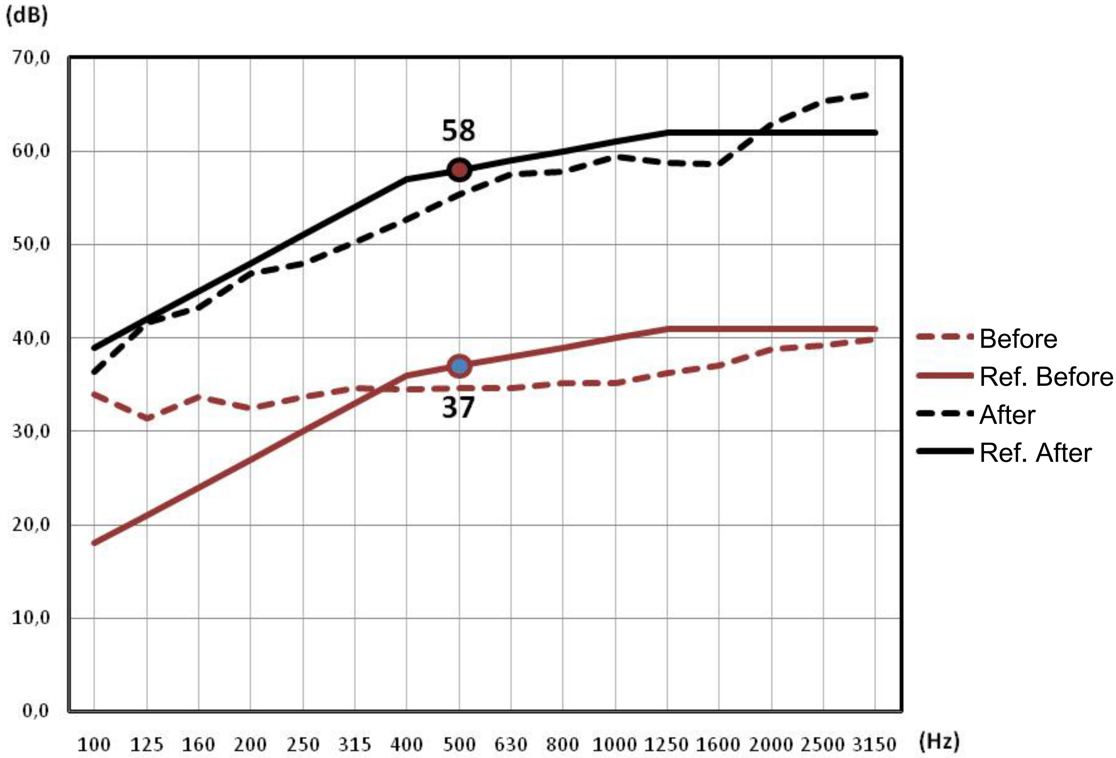

Figure 5 – Results of D_{nT} (horizontal) before and after intervention in the Gonçalves Zarco school in Matosinhos (reference curve also shown).

Figure 6 shows the results obtained after applying double layer gypsum board false ceilings with anti-vibration supports, before the sound absorptive treatment, to improve the performance of airborne sound insulation between vertically adjacent rooms. The improvement on the vertical impact sound insulation with this solution is also apparent in Figure 7, with a reduction of 17 dB.

The improvement on the reverberation time of the classrooms is clearly depicted in Figures 8 and 9. In these cases the sound absorptive material was only placed on the ceiling. All other surfaces are reflective. This aspect shows the importance of using reverberation time formulae that can distinguish the position of the absorptive and reflective materials such as the Arau-Puchades formula. In most cases this formula predicted results much closer to the measured values, whereas the Sabine formula (as expected) predicted the need of much less absorptive material to achieve the desired result. If this formula would have been used, the reverberation time could not be controlled according to the criteria. This is only true if the scattering provided by the furniture or walls is not enough. Since this is a more difficult parameter to access, we suggest the use of the Arau-Puchades equation.

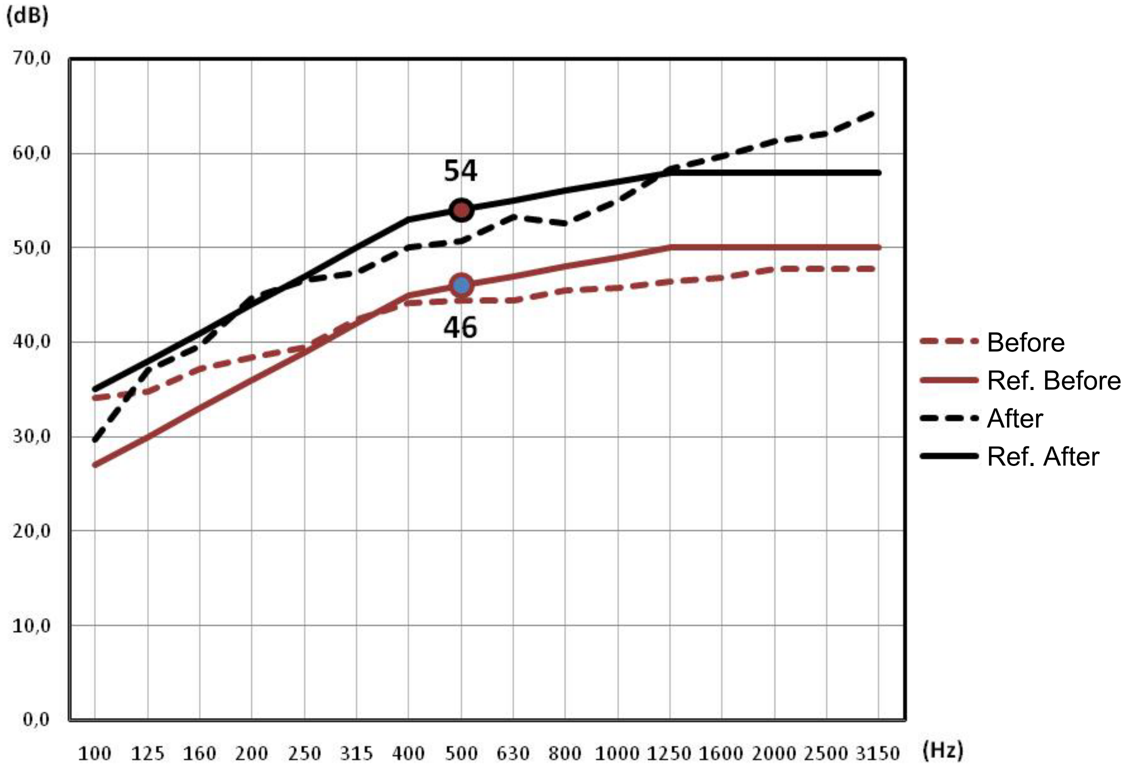

Figure 6 – Results of D_{nT} (vertical) before and after intervention in the Gonçalves Zarco school in Matosinhos (reference curve also shown).

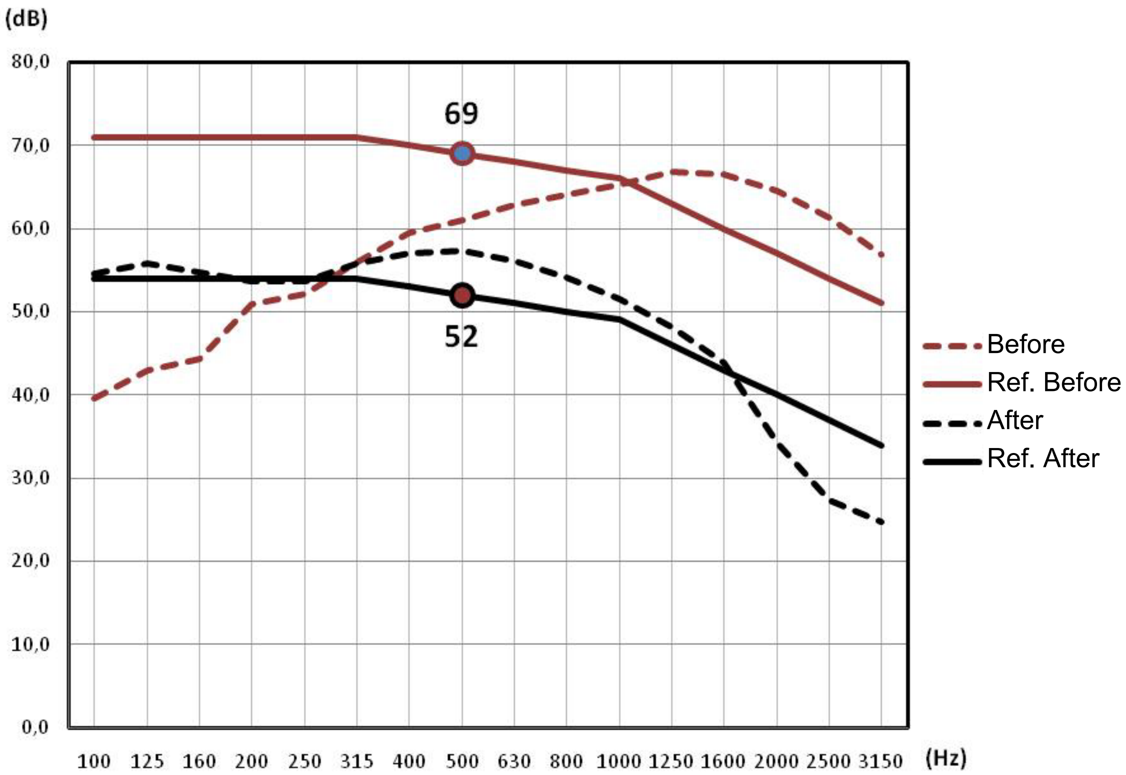

Figure 7 – Results of L'_{nT} (vertical) before and after intervention in the Gonçalves Zarco school in Matosinhos (reference curve also shown).

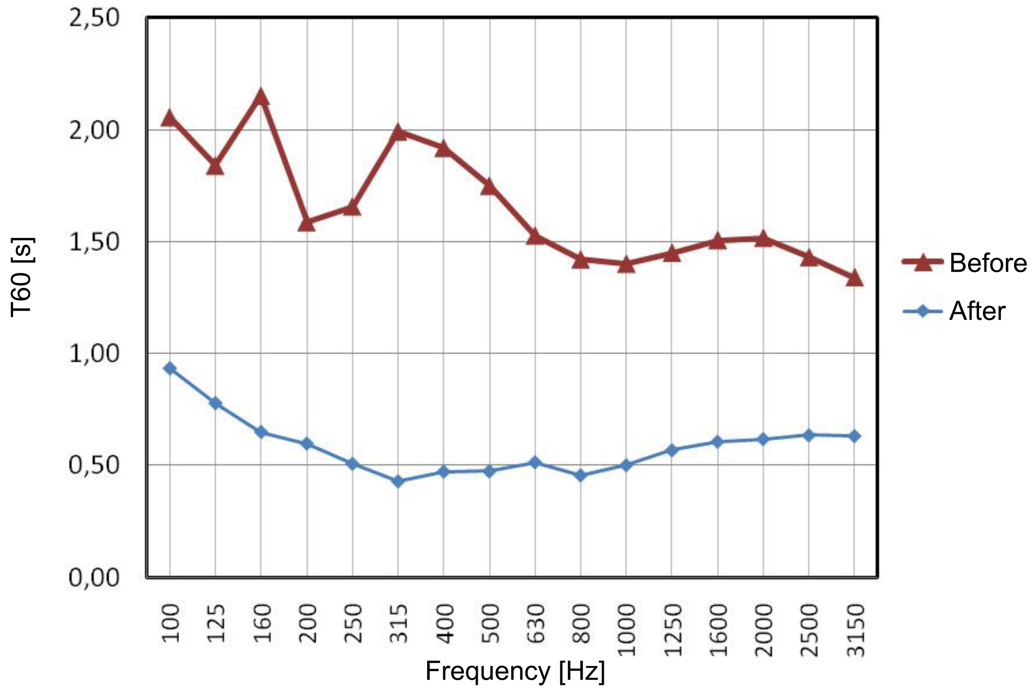

Figure 8 – 1/3 octave reverberation time measured in a classroom at the Gonçalves Zarco School in Matosinhos, before and after the implementation of reverberation control measures.

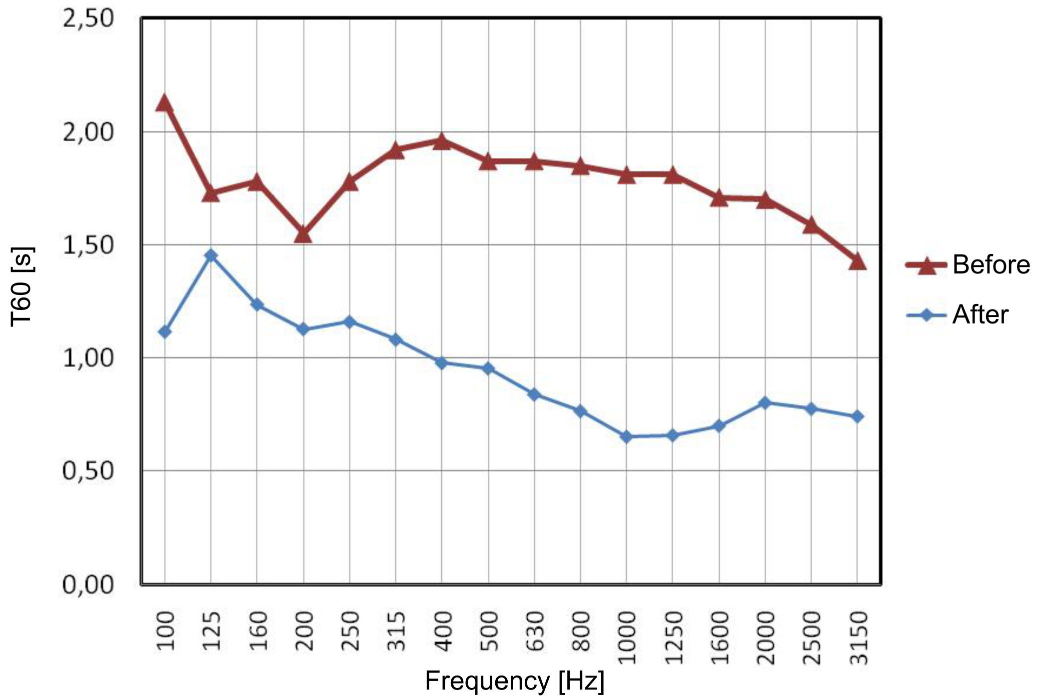

Figure 9 – 1/3 octave reverberation time measured in a classroom at the D. Pedro V School in Lisbon, before and after the implementation of reverberation control measures.

5 Conclusions

The modernization program for the Portuguese public secondary school network has enabled a significant improvement of the acoustical conditions in classrooms, canteens, laboratories, gymnasia and other spaces, contributing to a more healthy learning and teaching environment.
In this paper we showed some of the interventions performed in over 20 schools, as well as the results that allowed the validation of the design procedures and calculations.

Acknowledgments

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