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Typical acoustical performances of façades of Italian schools: the effect of the outdoor noise on the indoor acoustic comfort

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ABSTRACT

The paper deals with the façade sound insulation of Italian schools placed in Lombardy and Tuscany Regions. The selected sample consists of more than one hundred façades of Italian schools of all levels (from nursery to upper secondary school) and built in different time periods and building technology. For this reason, the selected sample can be considered as representative of typical Italian schools.

For each school, the façade sound insulation, the reverberation time, the average outdoor noise, the age of building and the main characteristics of the façade have been studied (kind of glass, kind of ventilation, dimension of the windows etc.). Based on these data, it has been studied the correlation between the main characteristics of the façades and the façade sound insulation and between the year of construction and the acoustic performance. These results are also referred to the complete building stock of the Italian school buildings based on a recent census realized by the Italian Ministry of School. Further considerations concern the influence of the noise coming from outdoor on the indoor acoustic comfort.

Based on the above-mentioned items, some indications are given on priority actions needed to improve the acoustic performance of school buildings.

Keywords: Façade sound insulation, Schools buildings, Acoustic comfort

I-INCE Classification of Subjects Number(s): 51.1.4, 89

1. INTRODUCTION

Many issues related to excessive noise in schools arise from their inclusion in noisy environments, or from their previous existence in silent environments that evolved in very noisy ones. The main strategy to limit the noise inside the school buildings is the façade insulation improvement. Regulatory requirements and classification schemes in Europe present a high degree of diversity; in particular, the regulatory requirements for façade sound insulation are different concerning not only the limit values but also the different descriptors in use in the different Countries. In previous study (1, 2) the different façade descriptors were analyzed. The regulatory requirements are divided into two main categories, related to: the performance of the building - global facade or single element of facade ($D_{2m,nT,w}$, $D_{2m,nT,w}+C_{tr}$ or R'_w) - and indoor sound level (L_{Aeq}, L_{den}, L_{pA}).

In Italy the façade sound insulation requirement is related to the performance of the type of building by $D_{2m,nT,w}$ and is independent from the outdoor noise.

In the next paragraph, the Italian regulation requirements are specified in details.

In the same way, the maximum noise level and the maximum reverberation time permitted in classrooms present a high degree of diversity in the European Countries. As an example, the World Health Organization (WHO) (3) sets the maximum indoor L_{Aeq} equal to 35 dB and the maximum reverberation time equal to 0.6 s.

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2. ANALYSIS OF THE ITALIAN SCHOOL BUILDING STOCK

Recently, the Italian government has carried out a census of all Italians schools of different level (pre-schools, primary schools, lower and upper secondary schools) in order to determine the needs of their improvement. Only nurseries and universities have not been investigated.

Globally, more than 42,000 buildings, (of which 33,800 are active), distributed in all Italian Regions, have been examined (4).Results are mainly referred to general aspects of the school buildings such as year of construction, property, dimensions and kind of building structure and of windows. The acoustic requirements were investigated only in a qualitative way and in particular concerning the presence of the following aspects:

1. general measures for acoustic protection;
2. acoustic protection from outdoor noise;
3. acoustic insulation between classrooms, corridors and other spaces;
4. acoustic insulation of floors.

Figures 1 to 3 show some results of this census, while figure 4 shows the detail of the analysis of "qualitative" acoustic requirements with reference to three regions of the Centre-North of Italy. The sample of schools belongs to two of them (namely Tuscany and Lombardy), while the third region (Emilia Romagna) is reported only as reference to another large Region. The number of schools in these Regions represents more than 30% of all Italian schools.

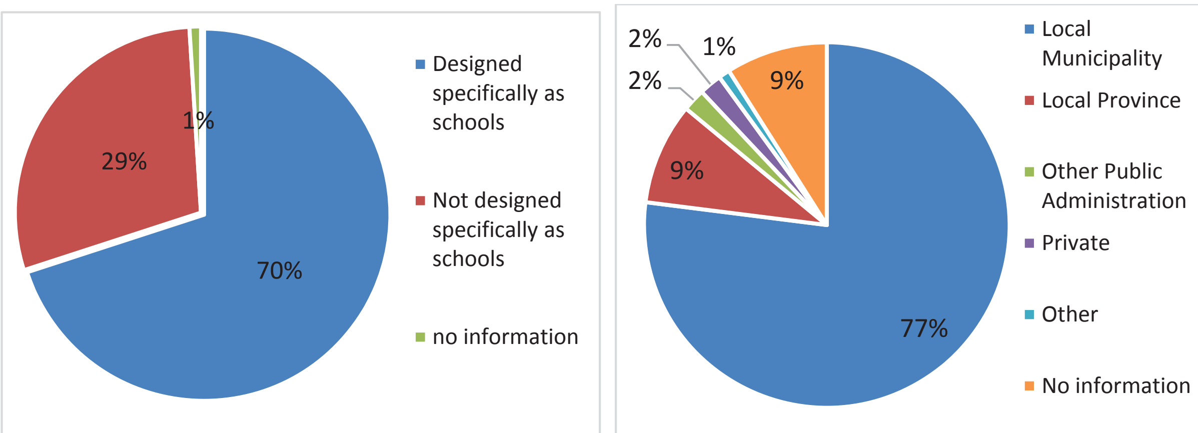


Figure 1 – Left: percentage of Italian building designed specifically as schools; right: property of Italian school buildings (4)

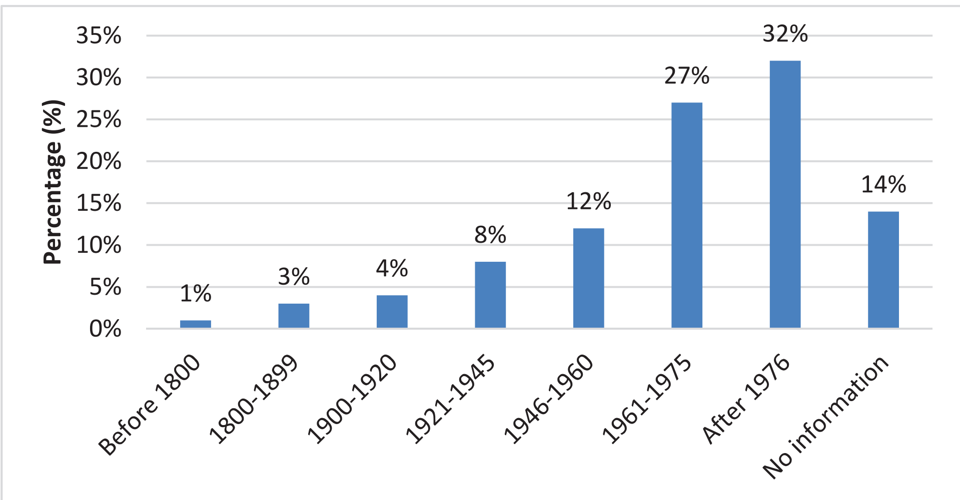


Figure 2 – Year of construction of Italian schools (4)

From figure 2, it is evident that more than 55% of building were built before 1976.

It is important to underline that the first dispositions on acoustic performance of schools were given by the Italian Decree 21 March 1970 (5), replaced in 1975 by the Italian decree on technical requirements for school buildings (6) that specifies both dimensional and physical properties and the relative limit values for new schools. The physical properties (habitability conditions) concern thermal, acoustic and lighting properties of school buildings and building components.

In particular, acoustic requirements concern the following parameters and limit values:

- Sound Reduction Index of external windows: $R_w \geq 25$ dB;
- Sound Reduction Index of air ducts and grid placed in the external wall: $R_w \geq 20$ dB;
- Sound Reduction Index of internal vertical partitions: $R'_w \geq 40$ dB;
- Sound Reduction Index of internal horizontal partitions: $R'_w \geq 42$ dB;
- Normalized Impact Sound Pressure Level of internal floors: $L_{nw} \leq 68$ dB;
- Maximum Sound Pressure Level of continuously operating service equipment: $L_{A,max} \leq 40$ dBA;
- Maximum Sound Pressure Level of discontinuously operating service equipment: $L_{A,max} \leq 36$ dBA;
- Maximum reverberation time of classrooms given as a function of frequency and volume of the room (as an example, the maximum value of the reverberation time for a classroom of 100 m^3 is about 0.9 s at 500 Hz).

More recently, some of these specifications have been replaced by those given by the Decree of the President of the Council of Ministers about the determination of building passive acoustic requirements, of December 1997 (7), and by the Italian standard UNI 11367:2010 (8, 9). In particular, according to this Decree (7), the façades of new school buildings must guarantee a sound insulation $D_{2m,nT,w} \geq 48$ dB. According to the personal experience of the authors, very few buildings constructed after the adoption of the national decree of December 1997 meet this limit value. Moreover, a sound insulation performance of 48 dB is very restrictive and difficult to obtain especially for refurbished buildings. The new acoustic classification set by UNI 11367 (8, 9) distinguishes the sound insulation requirements for schools in two levels of performance: basic performance, $D_{2m,nT,w}$ above 38 dB, and high performance, $D_{2m,nT,w}$ above 43 dB.

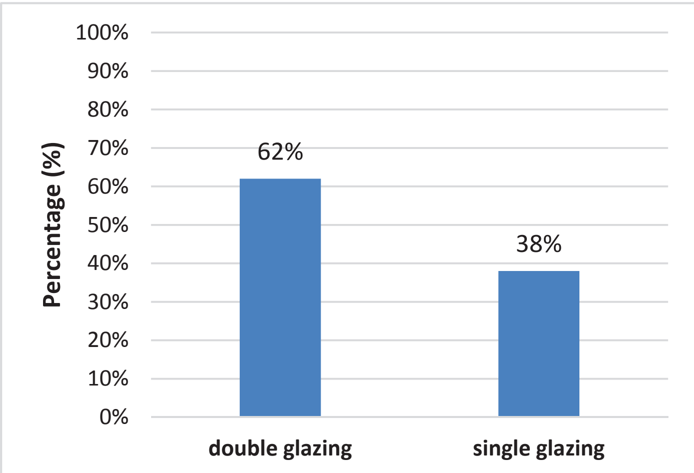


Figure 3 – Percentage of single and double glazing windows in Italian schools (4)

Figure 3 shows that more than 60% of Italian school buildings have double glazing windows; most of which are composed by two single glass panes separated by an air gap that have exclusively thermal purposes. In fact, buildings constructed before 1976 (more than 55% of the entire building stock) had almost exclusively single glazing windows and very poor sound insulation in general. Many of these buildings were renovated after the adoption of the 1975 national regulation on schools (6) with the substitution of the whole windows, or just of the glasses, to achieve better energy performances of the facades. Furthermore, we have to consider that in 1976 it was enacted Law n. 373 on the reduction of energy consumption that has spread the use of double glazing in new and existing renovated buildings, including schools (10), with a better air tightness of the new windows.

It is well known that the acoustic insulation of a double glazing window with two identical glass panes is only slightly better than that of a single glazing window with a glass pane of the same thickness, because of the effect of the resonance mass-spring–mass of double glass panes. The typical double glazing window used in Italy until the '90s is composed of two glass panes each 4 mm in thickness separated by an air gap in the range 6 to 12 mm; the mass-spring-mass resonance frequency of a 4/12/4 double glazing windows is around 220 Hz, where the acoustic insulation strongly decreases.

Figure 4 shows details of the national census on school buildings referred to three Regions of Centre – North Italy. It can be noted that less than 10% of schools has some kind of acoustic protection against outdoor noise (such as improved acoustic insulation windows, noise barriers or other).

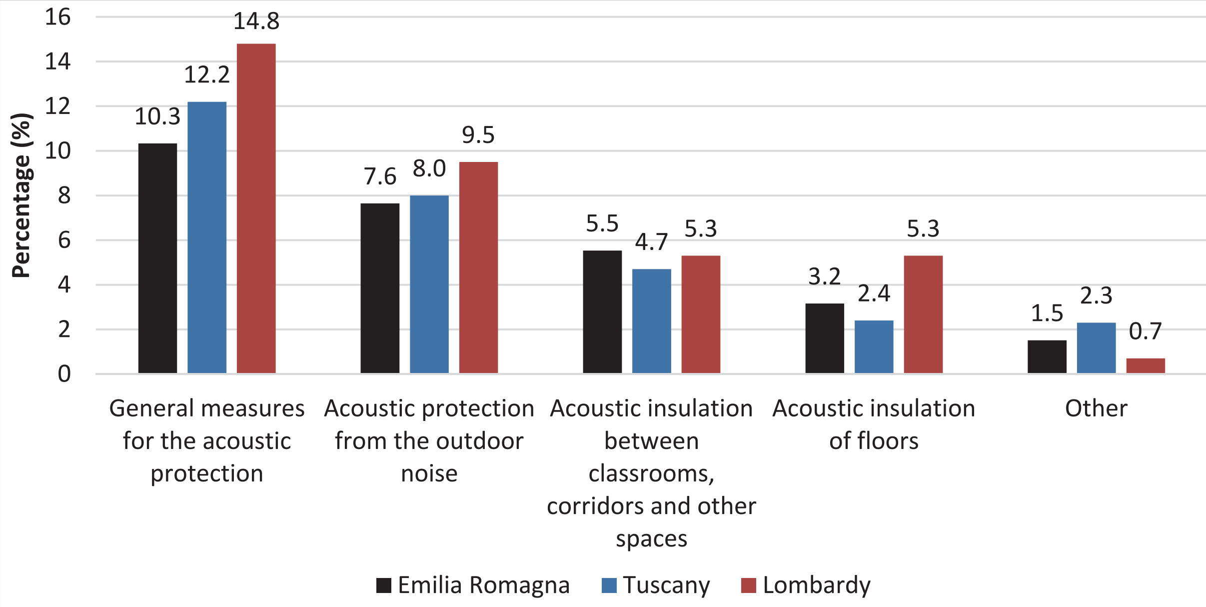


Figure 4 – Typology of measures against noise in the schools of Tuscany, Lombardy and Emilia Romagna Regions (information supplied by local authorities)

3. DESCRIPTION OF THE SAMPLE OF SCHOOL BUILDINGS ANALYZED

To better analyze the acoustical performances of Italian schools, the results of many field measurements carried out by the authors approximately in the last 10 years have been collected and analyzed. In particular, the database collected concerns the acoustic measurements carried out on 59 school buildings in 14 Municipalities and 2 Italian Regions (Tuscany and Lombardy). 97 façades have been analyzed and in 45 of these cases the standardized Façade Sound Insulation ($D_{2m,nT}$) have been measured both before and after the treatment to improve acoustic insulation. Globally, 142 results of façade sound insulation have been collected.

It is important to underline that in almost all the cases these measurements have been carried out as a consequence of a municipal strategy or airport strategy (11) for noise abatement in the school buildings. For these reasons, the selected sample of Italian school buildings could be seen as not representative of typical Italian school buildings but only of those with poor acoustic insulation or of those that had already been subject to a previous refurbishment, because their inclusion in a noisy environment. Anyway, the need of an acoustic refurbishment is established by the Italian Municipalities as a function of the exposure of the building to outdoor noise and not of the acoustic performances of the building envelope itself. Moreover, the selected sample includes all level schools (from nursery to upper secondary school) and built indifferent time periods and building technology. For this reason, the selected sample can be considered representative of typical Italian schools. At this purpose, from figure 5 it can be noted that the distribution by year of construction of the selected schools is similar to that of the entire national building stock.

For each school and façade analyzed the following information has been collected:

- school level (nursery, pre-school, primary school, lower secondary school, upper secondary school);
- year of construction (not the year of renovation);
- window frame material (wood, aluminum, iron);
- kind of glass (single, double or laminated). Note: a laminated glass is made of two glass panes, each separated by one PVB (Polyvinyl Butyral) film;
- presence of air vent in the façade;
- shading system (in particular, presence of roller shutter box) ;

- dimensions of classrooms, façades and windows;
- standardized façade sound insulation ($D_{2m,nT}$) from 100 Hz to 5000 Hz, weighted standardized façade sound insulation ($D_{2m,nT,w}$) and spectrum adaptation terms (C, C_{tr});
- reverberation time;
- average of outdoor sound pressure level (when measured).

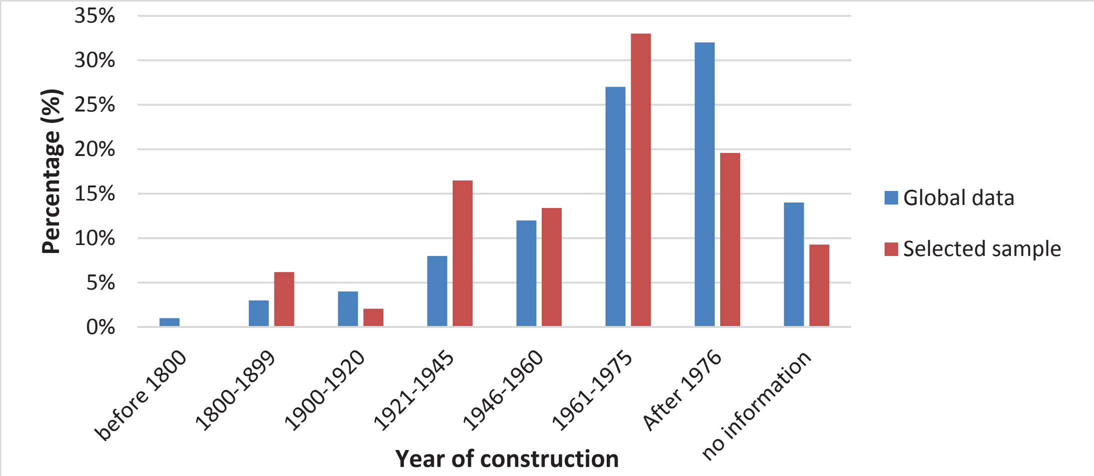


Figure 5 – Year of construction of the examined schools (selected sample) compared to values of the entire national building stock (global data) (see also figure 2)

Figure 6 shows the distribution by level of school. It is important to note that in Italy schools from nurseries to lower secondary schools are generally owned by the local municipalities while upper secondary schools are ownen by local provinces.

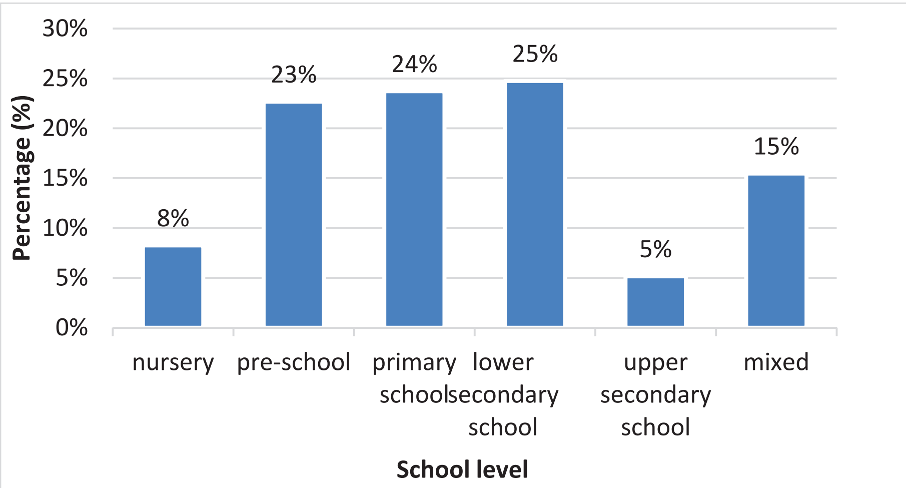
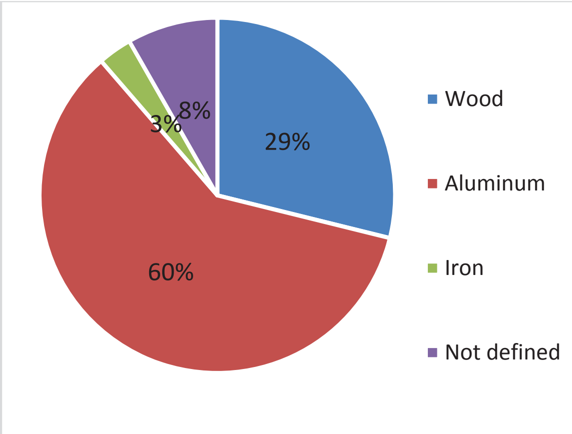


Figure 6 –School level of the examined schools (selected sample).

Figure 7 shows some detailed information about the window frame material and the kind of glass. This information is referred to the situation of the analyzed schools before the acoustic improvement (refurbishment) (the treatment to improve acoustic insulation, called “ante operam” situation). In fact, the acoustic improvement required, in almost all the cases, the substitution of the existing windows with windows with aluminum frame and double laminated glass.

Figure 8 shows the percentage of school façades with roller shutter box. The use of roller shutters is very frequent in Italian residential buildings but not so much in schools. This kind of shading system usually decreases the façades sound insulation because it represents an important path of airborne sound transmission.



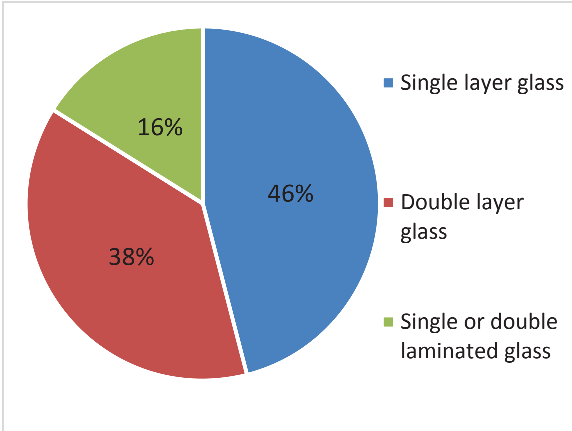


Figure 7 – Window frame material and kind of glass of the windows of the selected sample (ante operam)

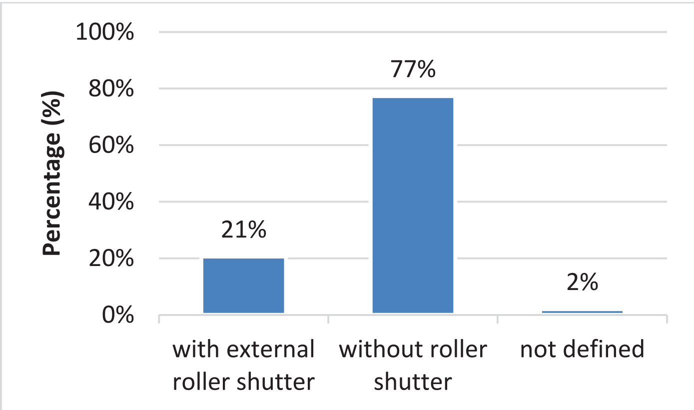


Figure 8 – Left: percentages of buildings with and without roller shutter box; right: an example of window with roller shutter box.

4. FAÇADE SOUND INSULATION

Figures 9 and 10 show the results of $D_{2m,nT}$ measurements for the analyzed schools. Results referred to corridors or gyms have been excluded in this analysis.

From figure 9 it can be noted that there is not a clear correlation between age of the school (year of construction) and façade sound insulation ($D_{2m,nT,w}$). On the other hand, previous studies pointed out a clear evolution of acoustic performances of Italian façades from the post war period to nowadays (12), but these studies were referred to residential buildings. The lack of correlation in the present study is because the school buildings were probably refurbished in the past and the information about the year of refurbishment is not known. The graph shows, with blue dots, the results of measurements carried out before the acoustic improvement (ante operam) and, with red rhombs, after these refurbishment (post operam). It can be noted that results of $D_{2m,nT,w}$ given by schools built after the adoption of the Italian decrees on acoustic requirements (7) are above the average but still do not satisfy the current limit value for school ($D_{2m,nT,w} \geq 48$ dB).

Figure 10 shows the average value of $D_{2m,nT}$ before (ante operam) and after (post operam) treatments, with error bar equal to 1 standard deviation of the measured data. The same results are reported also in table 1 as weighted value $D_{2m,nTw}$. Lower insulation performances are given by schools with windows with single glass panes. The improvement of acoustic performances is clear especially at higher frequencies probably because of the better air tightness of the new windows.

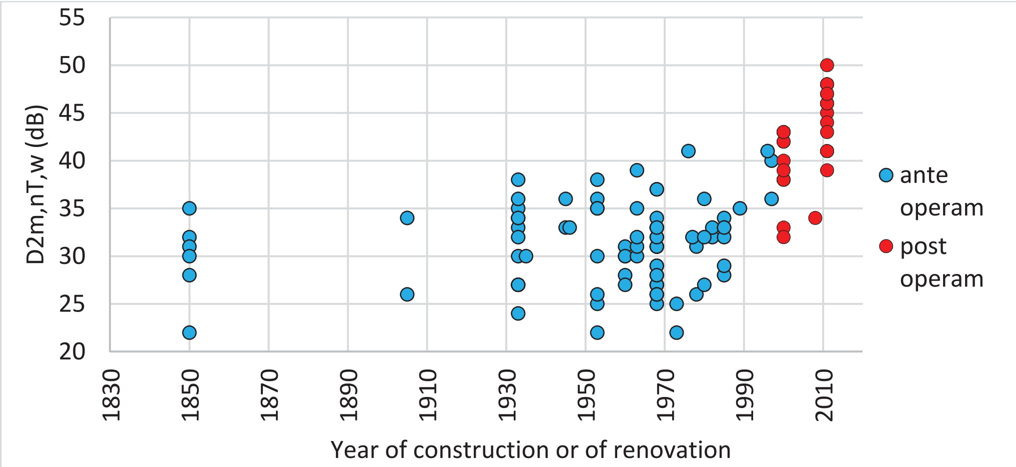


Figure 9 – Distribution of $D_{2m,nT,w}$ results as a function of the year of construction (or of renovation, for post operam measurements) of the building

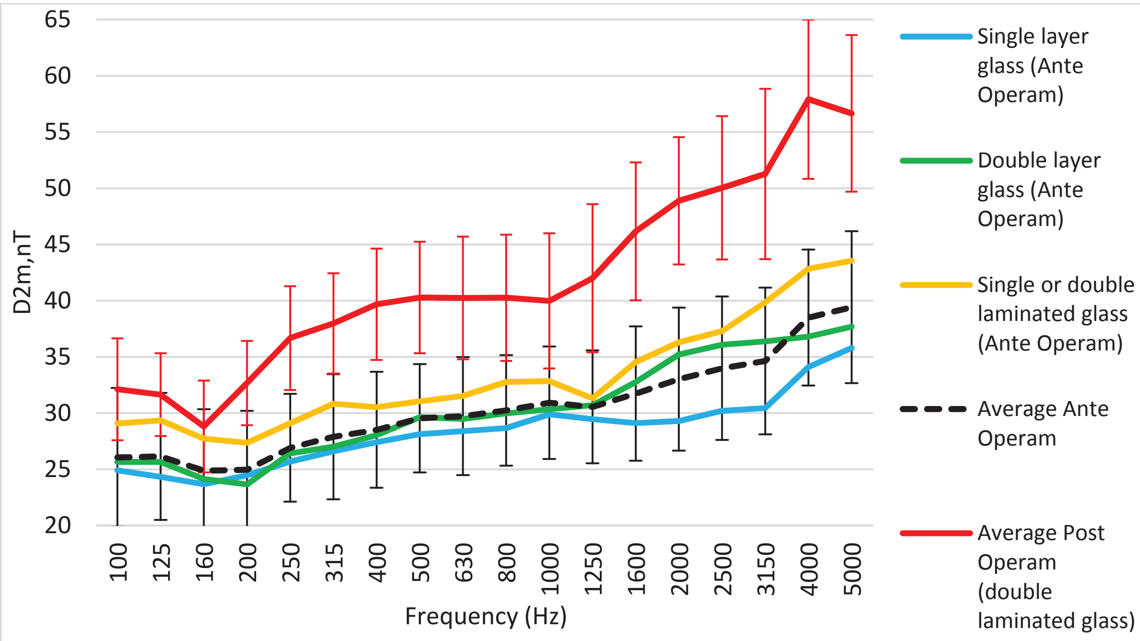


Figure 10 – Average values of $D_{2m,nT}$ as a function of the kind of glass installed in the windows (ante operam) and as ante and post operam global values (error bars = ± 1 standard deviation).

Table 1 - Average values of $D_{2m,nTw}$ and standard deviation as a function of the kind of glass installed in the windows (ante operam) and as ante and post operam global values.

	$D_{2m,nT,w}$ (dB)	**Standard dev. (dB)**
Single layer glass (Ante Operam)	28.7	3.8
Double layer glass (Ante Operam)	31.6	3.6
Single or double laminated glass (Ante Operam)	33.3	3.5
Ante Operam Average	**31.1**	**4.4**
Post Operam Average (double laminated glass)	**42.3**	**4.1**

4.1 Reverberation Time

Figure 11 shows the average reverberation time measured in all the classrooms considered in the present study. Error bars are equal to 1 standard deviation of the measured data.

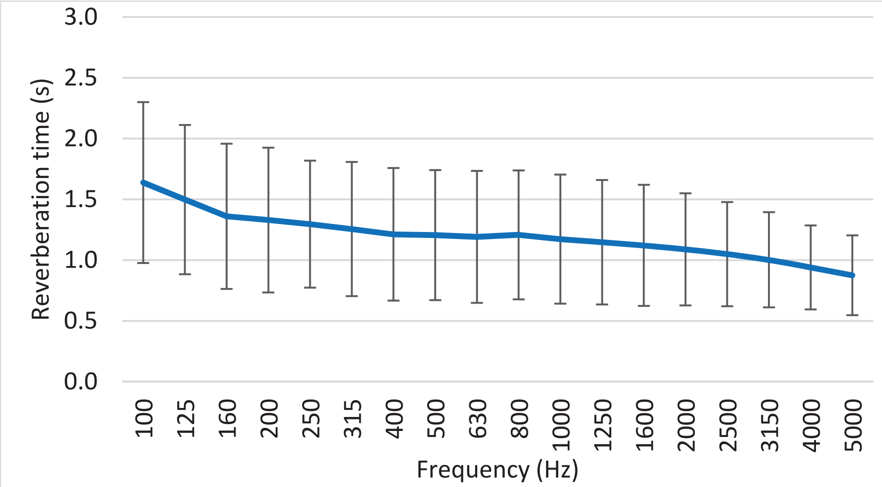


Figure 11 – Average value of reverberation time (error bars = ± 1 standard deviation)

In the Italian standard UNI 11532 (13) on the interior acoustic properties of confined spaces, an overview of the reverberation time reference values in the different countries is provided. In table 2 there is an extract of these values.

Limit value given by Italian legislation for reverberation time are function of the classroom volume. Considering the average value of the volume of the examined classrooms (160 m^3), the limit value according to the current Italian legislation (6) is about 1 s at the frequencies 500 and 1000 Hz.

The average reverberation time measured is quite high compared to the optimal values indicated by Italian legislation (6) and therefore, in order to enhancing the listening experience in the classroom, joint actions of protection from outdoor noise and room acoustic treatment should be planned.

In an interesting research on reverberation time and maximum background noise level in schools, Bistafa and Bradley (14) found that for very quiet classrooms, 100% speech intelligibility is possible with reverberation time at least 0.4-0.5 s. These values are consistent with the maximum reverberation time, 0.6 s, considered by WHO (3), but are far away from the average value found in the present study.

Table 2 – Maximum reverberation time values in furnished and unoccupied classrooms as per UNI 11352 (13)

Country	Reverb. time T (s)	Frequency (Hz)	Normative reference
United Kingdom	≤0.6 to 0.8	from 500 to 2000	BB 93
Italy	≤1.2	from 500 to 2000	Ministerial Circular 22/05/1967 N° 3150 and Decree 18/12/1975
Norway	≤0.6	from 125 to 2000	NS 8175:2008
USA	≤0.6 to 0.7	from 500 to 2000	ANSI S12.60:2002
Finland	≤0.6 to 0.8	from 125 to 4000	SFS E249
Sweden	≤0.5	from 125 to 4000	SS 25268:2007
France	≤0.4 to 0.8	from 500 to 2000	Decree dated 25/04/2003
Denmark	≤0.6	from 125 to 4000	SBI anvisning 218:2008
WHO	≤0.6	-	Pamphlet n. 31/2008

Note: For Italy this is the maximum permitted reverberation time, while the optimal values are function of room volume

5. EXPOSURE OF FAÇADES TO NOISE AND EFFECT ON INDOOR COMFORT

5.1 Typical exposure to noise of school facades

The sample of schools examined is exposed to an average traffic noise, in day-time period, equal to 64.2 dBA. This value could not be representative of all the Italian schools exposure as the sample is referred to schools in very noisy environment, as already underlined in paragraph 3. To better characterize the typical outdoor noise in Italian schools, it is necessary to refer to a previous study (15) carried out on a random sample of schools (i.e., not selected on the basis of poor acoustic insulation or inclusion in a very noisy outdoor environment and need for refurbishment). This study, referred to 43 schools (from nurseries to upper secondary schools) placed in Florence and in other small towns in the surroundings, was based on short-time measurements of road traffic noise on the most exposed façade. In this case, 53.5 % of the levels was lower than 60 dBA and the average value was 60.9 dBA.

It is not possible to give a unique value for the exposure of schools to road traffic noise: it depends on many factors and mainly on the volume of road traffic and its composition and on the distance of the school building from the road as well.

Nevertheless, the average value of about 61 dBA and the distribution given in Figure 12 will be considered indicative and assumed for the following estimations.

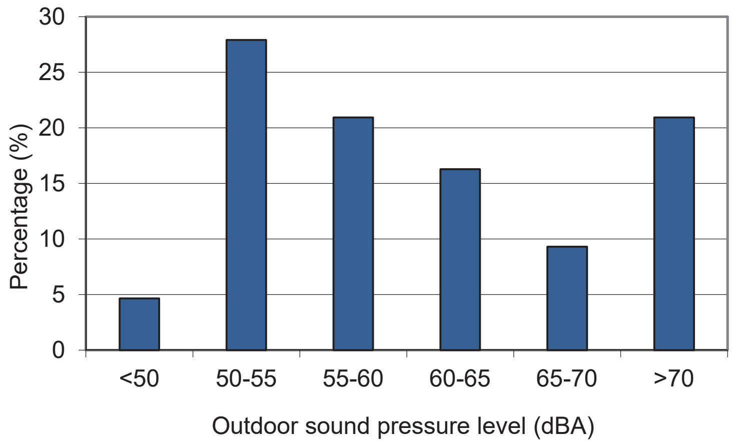


Figure 12 - Distributions of outdoor sound level due to road traffic noise assumed in the study (15)

5.2 Interference effects of external noise with teaching activities

It is well known that the sound environment of classrooms is mainly due to the sound coming from other interior spaces of the school (16, 17). However, in some cases, the outdoor noise can be problematic, especially for schools built near busy roads.

The analyzed schools were all built near busy roads or other noise sources (airport) because local authorities preliminarily selected them as the most critical for the exposure to outdoor noise (see also par. 3)

The estimation of the internal Sound Pressure Level, L_2, due to the sound coming from outdoor is based on eq. (1) described by annex E of EN 12354-3 (18).

$$L_2 = L_{1,2m} - D_{2m,nT} + 10 \cdot lg\left(\frac{T}{T_0}\right) \text{(dB)} \quad (1)$$

where:
$L_{1,2m}$ is the outdoor sound pressure level 2 m in front of the façade (dB);
$D_{2m,nT}$ is the standarized level difference, measured according to ISO 16283-3 (19);
T is the reverberation time in the receiving room (s);
T_0 is the reference reverberation time (0.5 s).

In the following, the outdoor environmental noise, $L_{1,2m}$, is based on the distribution reported in figure 12, that can be assumed as typical of the external environment of schools. The A weighted values of $L_{1,2m}$ reported in Figure 12 have been normalized at each frequency band with the spectrum given by EN 1793-3 (20) for road traffic noise while, for $D_{2m,nT}$ and T, the values measured for each analyzed façade have been used. Finally, from the results obtained at each frequency band with eq. (1), the A weighted values of indoor noise levels have been obtained.

Figure 13 shows the distribution, as percentage values, of the A weighted indoor noise levels in the examined classrooms both pre- and post-treatment .

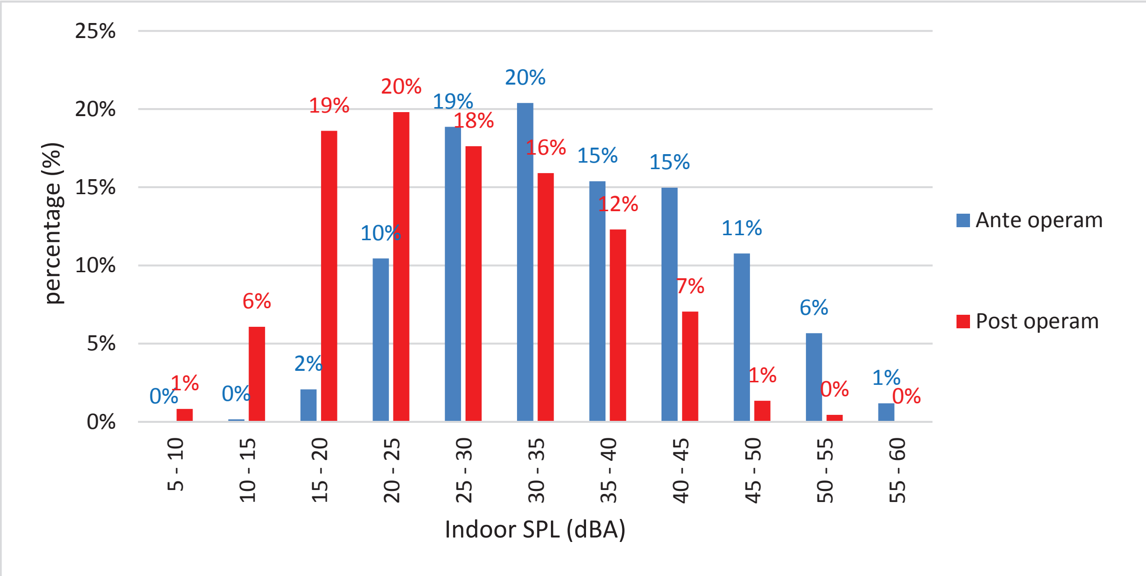


Figure 13 – Percentage of the values of indoor sound pressure level (SPL) ante and post operam calculated with reference to the typical distribution of outdoor SPL (traffic noise).

Results shown in figure 13 can be compared to the limit values given by Italian legislation or by other relevant national or international references.

The maximum equivalent indoor sound pressure level (SPL) due to road traffic noise, stated by Italian Decree of March 2004 (21) for schools, is 45 dBA; nevertheless this value is allowed only when it is impossible to reduce otherwise the outdoor noise.

According to the results shown in figure 13, only in 18% of the classrooms, before the acoustic improvement interventions, it is exceeded the limit value of 45 dBA for the indoor SPL due to traffic noise. After the acoustic refurbishment, just in 1% of cases this limit value is exceeded. Anyway, the limit value given by the Italian law must be considered only when it is not possible to reduce otherwise the external noise.

It is interesting to report the recent design guide for classrooms given by the United Kingdom Department for Education (22), that specifies upper limits for indoor ambient noise levels $L_{Aeq,30mins}$ during normal teaching hours (Table 3).

Table 3 - Upper limits for $L_{Aeq,30mins}$ as per (22).

Type of room	New build	Refurbish.
Teaching space for students with hearing and communication needs	30	35
Nursery school rooms, primary and secondary school classrooms	35	40
Offices	40	45
Dining room, atrium and circulation spaces	45	50

In this case, the maximum SPL for refurbishment of classrooms is 40 dB, but it must be noted that this value is averaged over a period of 30 mins and not during all the daytime period as in Italian legislation (21). Moreover, for rooms naturally ventilated (as in all the cases examined in this paper), indoor SPL must be measured or evaluated with ventilators or windows open as required to provide ventilation.

On the other hand, the limit value given by the WHO (3) for the equivalent A weighted SPL in classrooms is 35 dBA.

With reference to the guidelines of the UK Department for Education (22) and of the WHO (3), in the examined schools, 33% and 48%, pre-treatment, and 8% and 20%, post-treatment respectively would exceed the given limit values.

In summary it can be noted that the acoustic improvements have greatly reduced (from 48 to 20%) the number of schools exposed to indoor sound levels (due to external noise) above 35 dBA.

We can note that, according to previous studies, the reaction of children to environmental noise varies as a function of their age. In particular, Shield and Dockrell (16) found that younger children of primary schools are more affected by ambient and background levels of external noise, while the performance of older children of the same schools is more closely related to maximum noise levels. This suggests that the performance of older children (11 years old, in the studied case) is affected by the noise of individual events such as sirens, lorries or motorbikes passing the schools. For this reason, it does not seem correct to refer the limit values to the indoor equivalent SPL as in the case of the Italian regulation or other national or WHO regulations. Instead, attention should be paid to the maximum SPL due to specific noise events that could exceed the equivalent SPL of 15 or more dB. This topic will be specifically investigated in future developments of this study.

In a previous study (11), the façade sound insulation improvement due to refurbishment - in average the improvement of $D_{2m,nT,w}$ was around 14 dB - permitted to achieve a comfortable sound environment inside all the classrooms investigated. The $L_{VA,indoor}$ (where L_{VA} (11) is the index used for evaluation of airport noise according to the Italian legislation (23, 24)) at which the students are exposed decreases from an average value of 38 dBA to an average value of 27 dBA. In the case of the present study, the average improvement of the façade sound insulation was 11 dB that in general permits to achieve a comfortable sound environment inside the classrooms (see fig. 13), where the maximum of the statistical distribution of all the analyzed classrooms shift to the left, from 30-35dBA to 20-25dBA. These last values are consistent with the ones suggested by Bistafa and Bradley (14), in fact they found that the "ideal" and "acceptable" maximum background-noise level is 25 dB and 20 dB below the voice level at 1m in front of the talker respectively.

6. CONCLUSIONS

The most frequently recommended solution for reducing the negative impact of outdoor noise in buildings near busy roads or airports is to increase sound insulation (25). In particular, school buildings are the ones that need more attention as it is proofed that high noise exposure affects student academic performances. Annoyance caused by occasional noise events (16, 26) such as overflying aircraft, trains or sirens may affect children and teachers disproportionately to their contribution to the overall noise environment of a school.

In this study a sample of 97 façade belonging to a 45 schools is examined. The selected sample can be considered as representative of typical Italian schools, as it includes all level schools (from nursery to upper secondary school) and built in different time periods (the distribution of the sample is consistent with the distribution of all Italian schools) and building technology. The sample refers to schools exposed to an average traffic noise, in day-time period, equal to 64.2 dBA. This value could not be representative of all the Italian schools exposure and, to better characterize the typical outdoor noise in Italian schools, it was necessary to refer to a previous study (15) carried out on a random sample of schools of all levels.

Almost all the schools considered needed façade sound insulation refurbishment. The average improvement of the façade sound insulation was 11 dB that in general permits to achieve a comfortable sound environment inside the classrooms (see fig. 13) where the maximum of the statistical distribution of all the analyzed classrooms shift to the left, from 30-35dBA to 20-25dBA, referring to an average outdoor noise of about 61 dBA (15).

As expected, the refurbishment of façade to improve sound insulation led to no significant difference in the measured reverberation times pre-and post-treatment and therefore in the internal absorption coefficient. As high reverberation times affect the intelligibility and, in general, the acoustics comfort in a classroom, it is therefore necessary to plan the façade refurbishment and the acoustic treatment of classrooms together.

REFERENCES

1. Birgit Rasmussen & María Machimbarrena (editors), COST Action TU0901 – Building acoustics throughout Europe. Volume 1: Towards a common framework in building acoustics throughout Europe.
2. Casini D, Cellai G, Secchi S, Fogola J, Scamoni F. Urban noise and required facade acoustic insulation of buildings: the case of some agglomerations in Italy, Proceedings of the 22nd International Congress on Sound and Vibration, Florence, Italy, 12 – 16 July 2015.
3. WHO, Francois D, Vallet M. Noise in Schools, World Health Organisation—Regional Office for Europe Pamphlet no.38; WHO: Bonn, Germany, 2001.
4. http://www.istruzione.it/allegati/2015/Slide_Anagrafe_Edilizia.pdf, last accessed May 2016 (in Italian).
5. Italian Decree 21 March 1970 Norme tecniche relative all'edilizia scolastica, ivi compresi gli indici di funzionalità didattica, edilizia ed urbanistica, da osservarsi nella esecuzione di opere di edilizia (in Italian).
6. Italian Decree 18 December 1975 Norme tecniche aggiornate relative all'edilizia scolastica, ivi compresi gli indici di funzionalità didattica, edilizia ed urbanistica, da osservarsi nella esecuzione di opere di edilizia scolastica (in Italian).
7. Italian Decree 5 December 1997 Determinazione dei requisiti acustici passivi degli edifici (in Italian)
8. UNI 11367:2010 Building Acoustics - Acoustic Classification of Building Units - Evaluation Procedure and In Situ Measurements; UNI: Milan, Italy, 2010 (in Italian).
9. Di Bella A, Fausti P, Scamoni F, Secchi S. Italian experiences on acoustic classification of buildings, in Proceedings of InterNoise 2012, August 19-22 2012, New York, pp. 5598-5609
10. Italian Law 373, 30 March 1976, Norme per il contenimento del consumo energetico per usi termici negli edifici. (in Italian).
11. Torchia F., Ricciardi P., Scrosati C. and Scamoni F., Improvement of Façades' Sound Insulation of Schools near the Bergamo - Orio al Serio International Airport: Case Study, Building Acoustics 2015, 22 (2), 123 – 142.
12. Nannipieri E, Secchi S. The Evolution of Acoustic Comfort in Italian Houses, Building Acoustics · Volume 19, 2 (2012) 99–118.
13. UNI 11532:2014 Acustica in edilizia - Caratteristiche acustiche interne di ambienti confinati UNI: Milan, Italy, 2014 (in Italian).
14. Bistafa S. R. and Bradley J. S. Reverberation time and maximum background-noise level for classrooms from a comparative study of speech intelligibility metrics, J. Acoust. Soc. Am. 107, 861 (2000).
15. Borgheresi S., Casini D., Poggi A., Indagini acustiche presso siti scolastici e indicazioni per il risanamento del rumore ambientale, Proceedings of the 3th national congress of the Environmental Protection Agency – Piemont Region (ARPA Piemonte), June, 7-9 2006 (in Italian).
16. Shield B, Dockrell J. The effects of classroom and environmental noise on children's academic performance, 9th International Congress on Noise as a Public Health Problem (ICBEN) 2008, Foxwoods, CT.
17. Loreti L, Barbaresi L, De Cesaris S, Garai M. Overall indoor quality of a non-renewed secondary-school building, Energy Procedia 78 (2015) 3126 – 3131.
18. EN 12354-3, Building acoustics — Estimation of acoustic performance of buildings from the performance of elements - Part 3: Airborne sound insulation against outdoor sound.
19. ISO 16283-3:2016 Acoustics -- Field measurement of sound insulation in buildings and of building elements -- Part 3: Façade sound insulation.
20. EN 1793-3:1999, Road Traffic Noise Reducing Devices - Test Method for Determining the Acoustic Performance - Normalized Traffic Noise Spectrum.
21. Italian Decree 30 March 2004, Disposizioni per il contenimento e la prevenzione dell'inquinamento acustico derivante dal traffico veicolare (in Italian).
22. United Kingdom Department for Education, Acoustic design of schools: performance standards, Building bulletin 93, February 2015.
23. Ministerial Decree D.M. 31/10/97 Metodologia di misura del rumore aeroportuale (in Italian).
24. Ministerial Decree D.M. 20/05/1999 Criteri per la progettazione dei sistemi di monitoraggio per il controllo dei livelli di inquinamento acustico in prossimità degli aeroporti nonché criteri per la classificazione degli aeroporti in relazione al livello di inquinamento acustico (in Italian).
25. Saarinen A. Reduction of external noise by building façades: Tolerance of standard EN 12354-3, Applied Acoustics, 2002, 63(5), 529–45.
26. Crook M.A. and Langdon F.J. The effects of aircraft noise in schools around London Airport, Journal of Sound and Vibration, 1974, (3) 221 - 232.