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Effect of outdoor noise and façade sound insulation on indoor acoustic environment of Italian schools

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ABSTRACT

The paper deals with the effect of outdoor noise mainly due to traffic and façade sound insulation on indoor noise level and speech intelligibility in classrooms. Results refer to the complete building stock of the Italian school buildings based on a census of the Italian Ministry of Education.

The selected school sample consists of more than one hundred Italian schools of all levels (from nursery to upper secondary school) located in three Italian regions, built in different time periods and with different building techniques. The selected sample is representative of typical Italian schools.

The façade sound insulation and the reverberation time of each school have been measured. The average outdoor noise level of about half the investigated schools has been measured and, for each school, the age of the building and the main characteristics of the façade have been listed (kind of glass, kind of ventilation, windows size, etc.). Based on these data, the correlations between both the main characteristics of the façades and the year of construction and the façade sound insulation have been investigated. Moreover, the influence of the noise coming from outdoor on the indoor noise level, speech intelligibility and speech to noise ratio have been analysed with reference to the situations both before and after the works carried out to improve the acoustic performances of façades.

Results show that the indoor sound pressure level due to traffic noise is considerably reduced after the improvement of the façade acoustic insulation, while further treatments to indoor surfaces should be necessary to reduce internal reverberation time and to improve speech intelligibility.

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1. Introduction

Many issues related to excessive noise in schools arise from their inclusion in noisy environments, or from their original surrounding environment which has grown from silent to very noisy over the years. 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 used in the different Countries. The different façade descriptors were analysed in previous studies [1–3]. The regulatory requirements are divided into two main categories, related to:

- the performance of the building – global facade or single element of facade (weighted standardized level difference, $D_{2m,nT,w}$, weighted standardized level difference plus the spectrum adaptation term for A-weighted urban traffic noise, $D_{2m,nT,w} + C_{tr}$, or weighted apparent sound reduction index, R'_w);
- the indoor sound pressure level (A-weighted equivalent sound pressure level, L_{Aeq}, A-weighted day-evening-night sound pressure level, L_{den} or A-weighted sound pressure level, L_{pA}).

In the same way, the maximum unoccupied indoor noise level and the optimal reverberation time permitted in classrooms present a high degree of diversity in European Countries [4,5]. For example, the UK Building Bulletin 93 [6], for unoccupied existing classrooms, requires a maximum ambient noise level of 40 dB, $L_{Aeq,30min}$, plus a maximum reverberation time of 0.8 s, quoted in terms of the average in the 500 Hz, 1 kHz and 2 kHz octave bands.

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The World Health Organization (WHO) [7] sets the maximum indoor L_{Aeq} to 35 dB and the optimal reverberation time to 0.6 s. According to Picard and Bradley [8], the optimal value of the mid-frequency reverberation time in occupied classrooms, is estimated to be 0.5 s. As far as the noise level is concerned, an upper noise level of 40 dB(A) is considered acceptable for general purposes in the case of +12 years old children, but it should be less than 30 dB(A) in the case of 6–7 years old pupils.

In Italy, the first provisions on acoustic performance of schools were set by Italian Ministerial Decree 21 March 1970 [9] on technical standards relating to school buildings, replaced in 1975 by the Italian Ministerial Decree on updated technical standards relating to school buildings [10], 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 requirements of school buildings and building components. Some specifications concerning reverberation time, sound insulation properties and noise from equipment have been replaced by those set by D.P.C.M. (Decree of the President of the Council of Ministers) of 5 December 1997 [11], on the determination of building passive acoustic requirements. The D.P.C.M. refers to the Ministerial Circular 22/05/1967 n. 3150 [12] for reverberation time limit values. The recent Decrees 28 December 2015, n. 221 [13] and 11 January 2017 [14] recall the Italian standard UNI 11367 [15,16] as reference to be applied in cases of treatments aimed at increasing the energy efficiency [17,18] of schools and anyway for their renewal or new construction, awaiting the approval of new Regional standards for schools. According to the D.P.C.M. of December 1997 [11], the new school buildings must guarantee a façade sound insulation $D_{2m,nT,w} \geq 48$ dB, that is very restrictive and difficult to obtain. On the other hand, the UNI 11367 [15,16] distinguishes the sound insulation requirements for schools in two levels of performance: basic performance, with $D_{2m,nT,w} \geq 38$ dB, and high performance, with $D_{2m,nT,w} \geq 43$ dB; this last value is also the minimum requirement for new schools and hospitals according to the decree [14]. The UNI 11367 also requires a Speech Transmission Index in classrooms higher than 0.6 and sets the optimum value of reverberation time (T_{opt}), as average value between 500 and 1000 Hz, for unoccupied classrooms (s), as:

$$T_{opt.} = 0.32 \cdot log\,(V) + 0.03\ [s] \quad (1)$$

where V is the volume of the classroom (m^3).

An optimal degree of reverberation was found in literature for maximizing speech intelligibility and reducing the vocal effort of the teacher, in occupied primary school classrooms, which corresponds to a reverberation time at the average frequencies of about 0.7 s [5,19,20]. The recommended values of reverberation time in fully occupied classrooms for flexible teaching methods, considering flat across frequency from the octave bands of 2 kHz to 4 kHz, are instead between 0.45 s and 0.6 s (between 0.6 and 0.7 s in an unoccupied but furnished condition) for classrooms with less than 40 students and volumes below 210 m^3 according to Pelegrín-García et al. [4].

Italian legislation, as stated by Italian Decree of March 2004 [21], also establishes the maximum indoor sound pressure level, L_{Aeq}, due to road traffic noise in schools, to 45 dB, with closed windows; nevertheless, this value is allowed only when it is impossible to reduce otherwise the outdoor noise (with mitigation at the source or along the transmission path).

The improvement of façade sound insulation of school buildings, in general, leads to a sensible decrease of indoor exposure to outdoor noise and to an improvement of speech intelligibility as well.

This study, whose preliminary results were published in [22], has investigated the correlations between both the main characteristics of the façades and the year of construction and the façade sound insulation. In addition to what already analysed in [22], also the influence of the noise coming from outdoor on the indoor noise level and speech intelligibility is investigated. These correlations are evaluated on the basis of more than 100 façade sound insulation measurements, representative of the Italian façade building stock of schools, linked to the typical outdoor noise levels referred to Italian schools as evaluated in a previous study [23]. In some of these schools, where façades were refurbished to improve the acoustic insulation from outdoor noise, data referred to the situation both before and after the acoustic treatments of façades are reported and the effect of the façade insulation improvement is analysed.

2. Material and methods

2.1. Analysis of the Italian school building stock

The Italian government has recently carried out a census of all Italian schools of different levels (pre-schools, primary schools, lower and upper secondary schools) in order to determine whether or not they needed to be improved. Only nurseries and universities were left out of the investigation.

Globally, more than 42,000 buildings, (of which 33,800 are active), distributed across all Italian Regions, have been examined [24].

Results are mainly referred to general aspects of the school buildings such as year of construction, property, dimensions and kind of building structure and windows typology. 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.

Figs. 1, 2 and 4 show some general results of this census, while Fig. 3 shows the detail of the analysis of "qualitative" acoustic requirements with reference to three regions of Central and Northern Italy (out of 21 Italian Regions).

In Fig. 3 it can be noted that less than 10% of schools have some kind of acoustic protection against outdoor noise (such as improved acoustic insulation windows, noise barriers or other).

The sample of schools studied here belongs to three Italian regions, namely Tuscany, Lombardy and Piedmont which have around 33% of active schools.

Fig. 4 highlights that 55% of buildings were built before 1976. Fig. 2 shows that more than 60% of Italian school buildings have double glazing windows; most of which are composed of two single glass panes separated by an air gap that have exclusively thermal purposes. Indeed, buildings constructed before 1976 had almost exclusively single glazing windows (with glass thickness typically around 4 mm) and very poor sound insulation in general. Many of these buildings were renovated after the adoption of the 1975 national regulation on schools [10], that led to the substitution of whole windows, or just the glass panes, to achieve better energy performances of the facades. Furthermore, the enactment of Law n. 373 on the reduction of energy consumption in 1976 has spread the use of double glazing in new and existing renovated buildings, including schools [25], 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

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