Acoustic Improvement of School Buildings

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Abstract — This paper will analyze the different perspectives and approaches in terms of sound improvement techniques, noise absorption or sound insulation methods respond differently to noise and provide solutions to certain nuisances. Acoustic performance in school buildings can have a significant impact on student learning and teacher work, good sound insulation can facilitate teaching, communication between teacher and students, and between students, which is often a problem in schools, particularly in urban areas, due to different external and internal factors. The reasons for the use of different techniques will be presented, followed by a comparative study of different cases that have been carried out and the impact of the use of certain materials in the environment. The study shows that good acoustic qualities are relevant in school environments.

Keywords — Acoustic performance, teaching environment, noise, external factors, internal factors, materials.

I. INTRODUCTION

Students need quiet study and exam areas, but this is not always the case, there is evidence that excessive noise levels can lead to a poor learning environment. The student's ability to perceive and understand what is being said in the classroom is crucial to the process of learning. Sound insulation (or acoustic insulation) is aimed at reducing or minimizing the spread of indoor or outdoor noise, preventing you from being distracted by the noise in the next room or outside. When a sound wave hits a wall or surfaces it could be absorbed, refracted, reflected, diffused or diffracted, or transmitted. The average daily noise exposure of young people in schools in the United Kingdom is 72 dB(A), in Chile 70 dB(A) and Spain 76 dB; noise levels are well above the 35 dB(A) recommended by the WHO. Many countries in the world do have acoustic regulations in place to guide the design of school facilities. These standards define the noise levels, reverberation times, noise insulation needs, and so on, to help ensure that students' learning conditions are as good as possible and as well as teachers' working conditions. Unfortunately, most schools do not comply with these noise standards. There are different types of noise, airborne noises that are noises that move through the air (vehicle horns, radios, conversations or dog barking) and impact noises that are noises caused by something hitting something else (object or glass falling on the ground or people walking on a floor). They can, therefore, be external or internal to the building. In general, the location of schools is chosen according to accessibility, which is why they end up being built along the roads. Thus, measures to reduce road traffic noise are needed to meet the regulations on acceptable noise levels in schools. Several factors can influence the propagation of noise, such as the size of the room, its position, its shape, the type of use of the adjacent rooms, its internal finish, the position of the noise sources and their types, these considerations must be taken into account when designing a space with good acoustic treatment. High noise levels can lead to the following negative effects: masking speech and decreased hearing capacity, lack of focus, bad temper and less interest in student lessons, teachers raising their voice due to noise. In addition to the physical damage caused by exposure to excessive noise, continued exposure has been associated with elevated levels of stress, high anxiety, continued annoyance, depression, and fatigue (Grebennikov and Wiggins, 2006). Teaching and learning can be noisy activities, especially in music rooms or physical education classes, where children are encouraged to work in groups and must communicate. The objective of providing good acoustic conditions in schools is to promote clear communication between teacher and student and among students and do not interfere with study activities. Sound is characterized by its frequency in Hz (Hertz) and its pressure level in dB (Decibel).

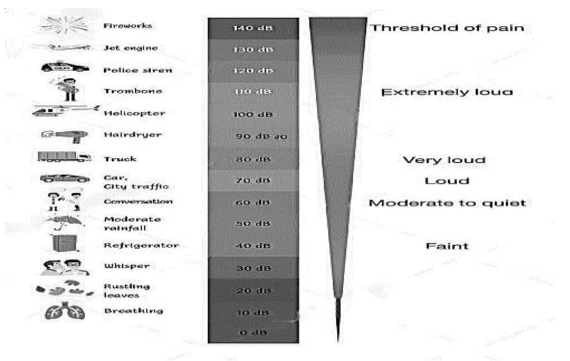

Fig (1) Noise level scale.

II. LITERATURE REVIEW

Speech-in-noise recognition tends to improve with age and adult-like performance is reached in adolescence, depending on the speech-in-noise listening condition (Fallon, Trehub, and Schneider 2000; Johnson 2000; Talarico et al. 2007; Vaillancourt et al. 2008). The findings of different studies have shown that children's understanding of speech is more influenced by adverse listening settings than that of adults. Children are more easily distracted by irrelevant sounds than adults, and thus less able to focus attention on the task in the presence of background noise (Dempster, 1993; Doyle, 1973; Gumenyuk, Korzyukov, Alho, Escera, & Naatanen, 2004). The listening challenges encountered by the student are much more complicated, as they require not only comprehension but also short-term memory and internal interpretation of spoken knowledge. In Maria Klatte, Jürgen Hellbrück, Jochen Seidel and Philip Leistner's (2010) study, the impact of classroom acoustics on speech perception was evaluated by comparing information from children whose classes varied in terms of indoor acoustics. To do this, it formed three groups RT_l, RT_2, and RT_3 based on reverberation times in the classrooms.

In RT_l, reverberation times in the classroom were less than 0.6 s (range 0.49 to 0.56), which is considered optimal for classrooms (based on WHO recommended values for schools, Berglund et al., 1999), with a total of 126 participants. In RT_2, reverberation times ranged from 0.69 to 0.92 s with a total of 175 participants. The third group RT_3 included classrooms with reverberation times greater than 1 s, this group included 97 participants. As a result of phonological processing, the analysis is based on 363 children, 103 from RT_I, 168 from RT_2 and 92 from RT_3.

A unifactorial analysis of the variance of the number of correctly resolved elements had a significant main reverberation effect in the classroom. The correct mean percent were 70.3, 64.7 and 61.7 in the RT_I (short reverberation), RT_2 (medium reverberation) and RT_3 (long reverberation) groups, respectively. Post hoc tests corrected by Bonferroni confirmed better performance in children in short reverberation classrooms (RT_I) compared to the method in long reverberation classrooms (RT_3) (Maria Klatte, Jürgen Hellbrück, Jochen Seidel and Philip Leistner 2010).

Chronic external noise (air, train or road traffic) has been the subject of several studies, including the effects resulting from exposure to this type of environment. "The evidence for effects of environmental noise on health is strongest for annoyance, sleep and cognitive performance in adults and children." (Stansfeld and Matheson, 2003, p. 253).

Several studies have found links between noise and reading problems and changes in cognitive functioning (Haines et al., 2001b; Evans and Maxwell, 1997). The results of a study of Munich children living near a former Munich airport, which was scheduled to close, or near the site of its new airport, showed that reading and other learning skills improved for children moving from a noisy to a quiet environment, while the opposite occurred for those moving from calm to noise (Richard Addo Sowah, Yankson A. Alfred, Derick Carboo, Adaboh R. K., 2014).

Research published in the journal Psychological Science, this led to the publication of a report evaluating the impact of aircraft noise on classroom learning by a federal committee in Chicago, USA in 1978. The Committee concluded that repeated exposure affects not only reading but also motivation, memory, language and speech acquisition (Johnson, 1980).

III. METHODOLOGY

The method used in this work is a descriptive and comparative approach. It is based on the collection of information and study results related to the topic and then the comparison of different case studies. To better understand the problem and find the appropriate solutions, the noise level must be established by measurements on site in line with the regulations in use.

A case study methodology is proposed to study the acoustic conditions of classrooms in two different countries, namely Brazil and South Korea. The data were collected on-site in previous studies, the classrooms for the studies were empty and chosen according to their location and orientation concerning different noise sources.

FINDINGS AND DISSCUSSION

BRAZILIAN SCHOOL CASE STUDIES-The verification of the acoustic quality of classrooms built to school building design standards was carried out by Paulo Henrique Trombetta Zannin and Daniele Petri Zanardo Zwirtes. 6 primary schools, were evaluated in the Curitiba region.

To simplify the process, the schools have been referred to as S1, S2, S3, S4, S5, and S6 to help identify the schools involved in this research. The results of this work were obtained by on-site measurements of reverberation time RT, sound insulation (acoustic insulation between classrooms and corridors, facades) and ambient noise (outside classrooms and inside classrooms), in dB and by the equivalent continuous sound level LAeq.

The ambient noise measurements were carried out according to Brazilian standards, reverberation time and sound insulation measurements according to international standards.

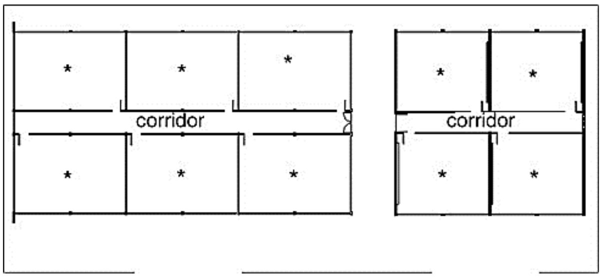

Fig (2) Classroom construction S1, S2, S5 & S6.Ref (9)

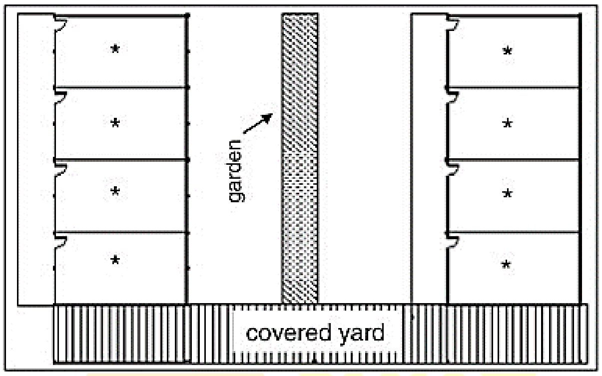

Fig (3) Classroom construction S3 &S4. Ref (9)

The exterior condition was assessed in conformity with the Brazilian standard, based on measurements taken on the sidewalks around the schools, the maximum allowable LAeq for school zones during the day according to the Brazilian standard is 50 dB(A). The results of the table show that S5 and S6 and S4 schools are in quieter areas compared to other schools. The measurement data in all the schools are above those defined by the standard.

School	Construction design	L_{Aeq} (dB)	L_{Amax} (dB)	L_{Amin} (dB)
S1	010	66.3	80.1	45.7
S2	010	66.2	91.2	41.7
S3	022	68.4	87.6	44.0
S4	022	60.5	75.1	38.3
S5	023	59.2	76.8	38.5
S6	023	51.8	73.9	39.5

Fig (4) Traffic noise near schools. Ref (9)

A study was made on internal environmental noise in classrooms. These surveys aimed to identify if the noise generated by one classroom could affect the surrounding classrooms. The Brazilian norm sets 40 dB(A) as a comfortable noise level in classrooms. However, the table shows that the noise levels are well above the limit set.Also, the proximity of sports fields and classrooms can contribute to an increase in internal environmental noise. Noise levels generated by physical education classes are high, which is very harmful to the learning process, due to noise pollution and student distraction.

School	Construction design	L_{Aeq} (dB)	L_{Amax} (dB)	L_{Amin} (dB)
S1	010	59.4	76.1	46.4
S2	010	63.2	76.0	51.9
S4	022	51.1	71.1	40.2
S5	023	59.1	70.3	52.1
S6	023	60.7	75.1	47.9

Fig (5) Noise generated by the surrounding classroom. Ref (9)

School	Construction design	L_{Aeq} (dB)	L_{Amax} (dB)	L_{Amin} (dB)
S1	010	66.7	81.3	54.4
S2	010	66.0	80.5	54.8
S3	022	74.6	88.7	52.6
S4	022	62.5	73.5	50.6

Fig (6) Measured values during recreative activities, but the classrooms were empty. Ref (9)

Sound levels during two different courses at school S3 and S6 were measured, these levels correspond mainly to the teacher's voice. The LAeq values are high (Figure 6), reflecting the amount of effort that teachers have to make. This effort is especially significant when there are physical education activities, which enhance the indoor noise in the classroom (Figure 5).

School	Construction design	L_{Aeq} (dB)	L_{Amax} (dB)	L_{Amin} (dB)
S3	022	74.0	85.6	53.8
S6	023	73.7	94.5	54.8

Fig (7) Measured values during class. Ref (9)

Sound insulation is essential in school environments where high levels of noise from road, air and rail traffic are present. The sound insulation between spaces is another important aspect, as in the schools S1, S2, S3, S4 where physical education classes are held close to the classrooms. The analysis of the soundproofing between classrooms and the corridor and the soundproofing of the facades was carried out in conformance with the international standard. The recommended soundproofing of facades according to ANSI (American National Standard Institute) S12.60 is 50 dB. As can be seen, the results obtained for the appropriate level are below this level.

School	Construction design	$R'_{45^\circ,w}$ (dB)
S1	010	15
S3	022	26
S6	023	21

Fig (8) Sound insulation of façades. Ref (9)

For soundproofing between classrooms and corridors, the recommendation of ANSI S12.60 is 45 dB. The following values result from the measurements made on schools S1 and S6. The levels of sound insulation between classrooms and corridors indicated in figure 8 are well below those specified by the norm.

School	Construction design	R'_w (dB)
S1	10	22
S6	23	13

Fig (9) Sound insulation between classrooms and corridors. Ref (9)

KOREN SCHOOL CASE STUDIES- In Korea, the allowable noise level for road traffic in schools near the road is less than 65 dBA during the day and 55 dBA at night in accordance with the law. For this survey, on-site measurements were carried out by Hong-Seok Yang, Hyun-Min Cho, Myung-Jun Kim, in 19 schools next to a road. They were divided into four categories according to the arrangement of the buildings, the difference between the indoor and outdoor noise levels was analyzed by type of arrangement: 5 parallel Type (P) schools: the roads and outdoor walls of the classroom are parallel to each other, 6 vertical Type (V) schools: the roads and outdoor walls of the classroom are perpendicular to each other, 4 vertical Type (PV) schools: the outdoor walls and 2 routes are crosswise and 4 corridor Type (H) schools: roads and class corridors are also in parallel.

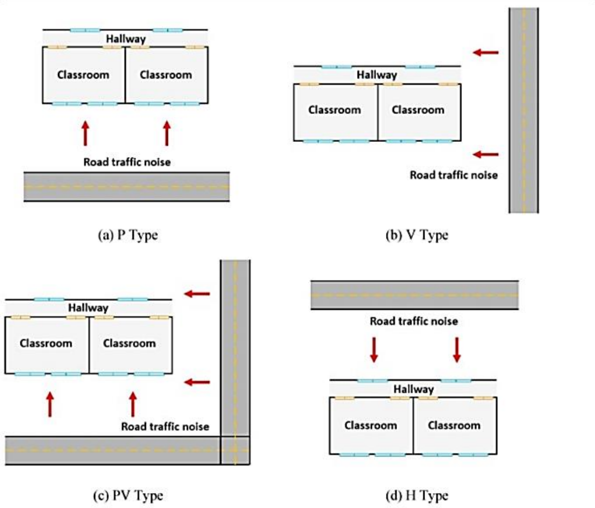

Fig (10) Type of arrangement. Ref (12)

Measurements were taken at different floors with unoccupied rooms and all windows and open doors at the same time, in places where external noise was predicted to have a high effect. The results showed a difference between indoor and outdoor noise levels in different types of classrooms. The noise level at the façade of each school was in the range of 50 to 70 dBA, the noise level in cases I (type V) and P and Q (type H) exceeded the standard of 65 dBA. As well, the indoor noise level for cases I and Q was 4 dBA higher than the indicated level of 55 dBA.

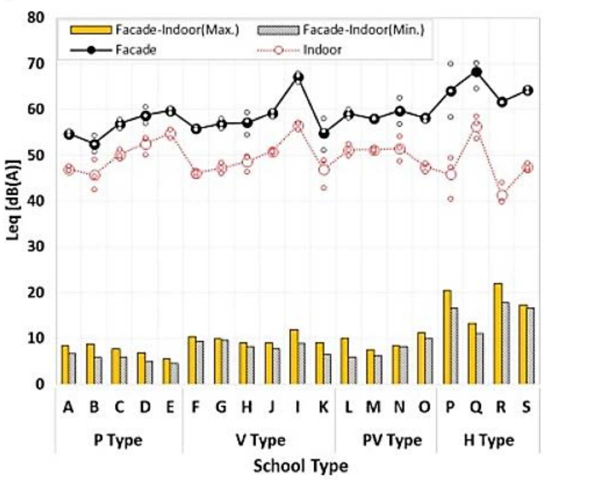

Fig (11) the noise level of road traffic in front of the facade. Ref (12)

The reason for these variations between the different types is their arrangement to the roads, the facing directly towards the roads or the use of a corridor between the class and the roads affects the noise propagation.

Classification	P Type (15 classrooms, 5 schools)	V Type (18 classrooms, 6 schools)	PV Type (12 classrooms, 4 schools)	H Type (12 classrooms, 4 schools)
Ave.	6.7	9.2	8.4	16.9
Max.	8.7	11.9	11.2	22.0
Min.	4.5	6.5	5.8	11.0
Std.	1.2	1.2	1.7	3.4

Fig (12) Noise reduction within classes. Ref (12)

Based on these 19 schools' experiments, it was found that the arrangement of school buildings is directly related to noise reduction or propagation. The highest reduction effect was seen when the corridor was a barrier for classrooms (type H) as opposed to the parallel arrangement (type P), which was the lowest. Thus, the most effective arrangement for noise control is type H, then types V, PV, and P. This suggests that a corridor can be considered as an option to reduce noise between roads and classrooms. The consequences are much the same in the first case study, where the orientation of the classrooms to the roads and the recreational spaces showed the significant propagation of noise indoors, which is a problem for students' ability to concentrate and understand. It also makes teaching more difficult and stressful for teachers. Young students are more willing to quickly feel boredom with the presence of distracting noise is very detrimental for their education and well-being.

Several methods can be used nowadays to reduce the effect of noise in schools depending on the context, both in terms of sound insulation and noise absorption. Methods of designing facades, the use of landscaped elements, interior finishes and many more, however, a preliminary examination must be carried out to establish the appropriate method. The use of landscaped elements has the advantage of being aesthetic and its biophilic nature can positively stimulate student productivity. Green noise barriers are an example of this integration of nature into sound insulation, which can provide a barrier against noise, based on the noise source (road, train, industrial or neighborhood), the location and dimensions of the wall can vary, the closest the wall to the source, the less it will have to be high this one can be used as a base for climbing plants. The layer of vegetation increases the density of the wall, which reduces the surrounding noise by about 5 decibels.

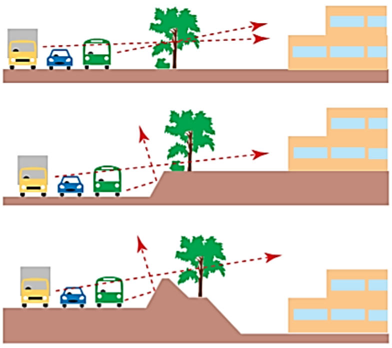

Fig. (13) Natural noise barriers. Ref (20)

Fig. (14) Green Wall Ref (27)

In terms of sound insulation techniques, we can differentiate between soundproofing and absorption, the materials that absorb sound minimize or prevent noise from bouncing back into a room or other spaces through barriers. These are generally light, porous sound waves and traps. Soundproofing materials that are generally dense, rigid or heavy materials (which can also be flexible) that prevent or minimize the transmission of noise through floors or ceilings, walls. Their mass reflects sound and prevents it from entering or leaving a room, usually in ceilings, floors, walls and even doors. There is a wide choice of materials and insulation techniques for walls, ceilings, floors, etc... this can be for example rock or glass wool, foam, silencers and acoustic baffles, polyethylene or acoustic panels. Acoustic panels can be used indoors for partitions or ceilings or outdoors for fences or facades, these panels come in different shapes and sizes. The reduction index, in general, varies according to the material thickness for soft PVC panels, for example, it is 35 dB on average made of thin material, it does not significantly increase the dimensions of walls and floors. Insulation at the openings should be studied, for example, thick glazing (8 mm) provides at least 30 dB(A) of insulation, but it will be very heavy, the window must be robust accordingly and asymmetrical double glazing can reach 35 to 40 dB(A). As far as mineral wools (glass and rock) are concerned, due to their low density, they are perfecty adapted to thermal insulation, but not very efficient in terms of noise, in their "bulky" form. There are therefore denser semi-rigid panels, which are sometimes directly associated with plasterboard or wood chipboard. Thus, their performance can reach on average for mineral wool alone in rolls: R = 37 dB(A) and mineral wool alone in panels: R = 40 to 45 dB(A). The combination of different systems ensures greater efficiency. In rooms equipped with acoustic ceiling panels, it was noted that each chair has reached an acceptable level of speech intelligibility.

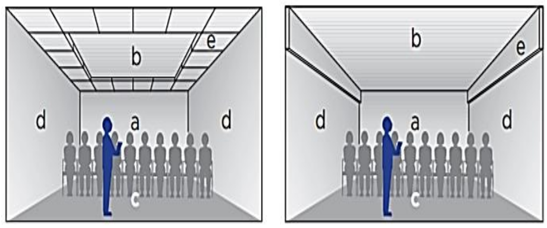

Fig. (15) Surface finishes in classroom Ref (20)

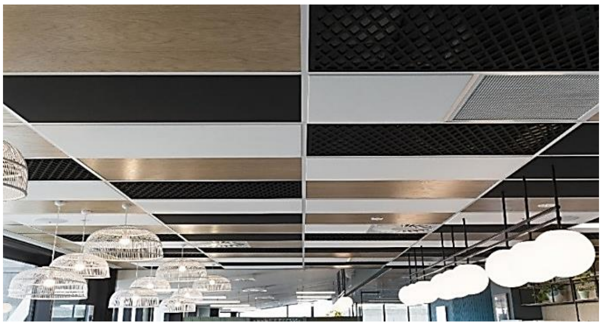

Fig. (15) Surface finishes in classroom Ref (20)

Fig. (16) Example of interior finishes. Ref (24)

Fig. (17) Example of the exterior panel. Ref (26)

Case of sound quality findings in terms of insulation composition: The college of Le Biéreau located in Belgium with a mixed construction principle (concrete & wood)

Fig. (18) Ref.31

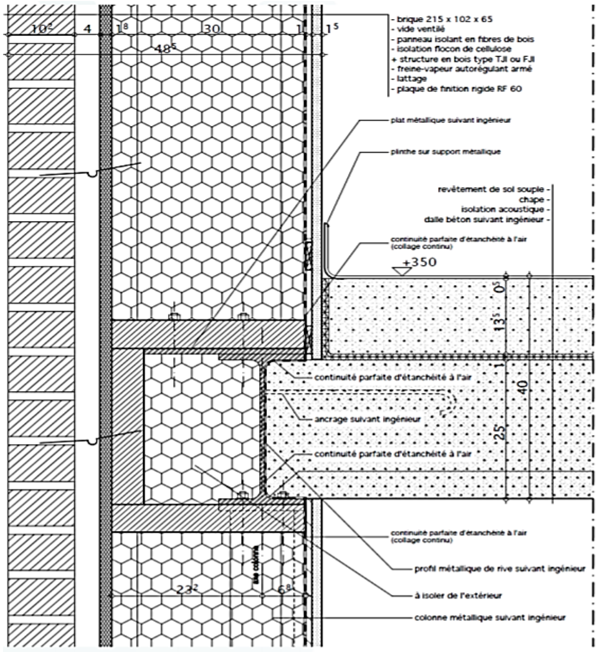

Fig. 19 Section Ref (31)

Airborne sound insulation between classes, teachers' room, sanitary facilities

DA = DnT,w + C (with DnT = L1 – L2 + 10 x log (*T*/*T*0))

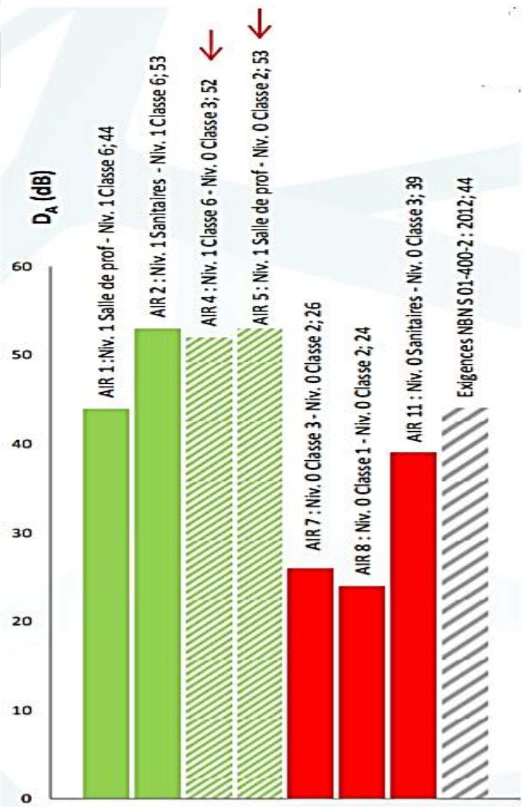

Fig. 20 Measurement of insulation Ref(31)

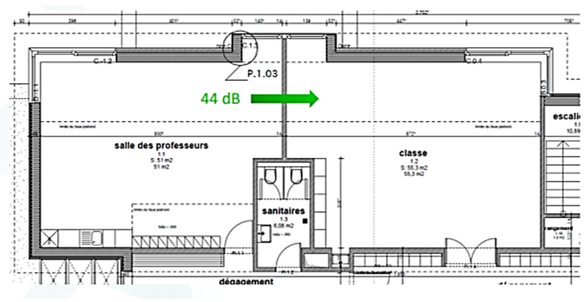

Fig. 21 Insulation for the room without a door between Teacher's room – Class Ref(31)

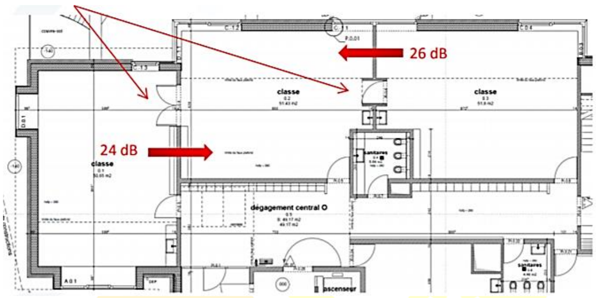

Fig. 22 Insulation for the room with a door between Class – Class Ref(31)

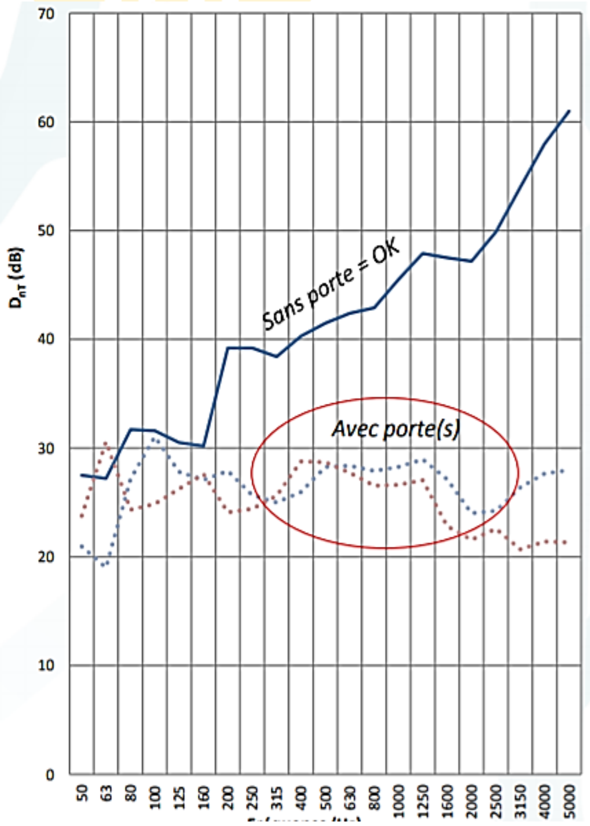

Fig. 23 Results Ref(31)

Airborne noise insulation between corridors and classrooms, teachers' rooms, sanitary facilities,...DA ≥ 36 dB (34 dB with tolerance)

DA ≥ 40 dB (38 dB with tolerance)

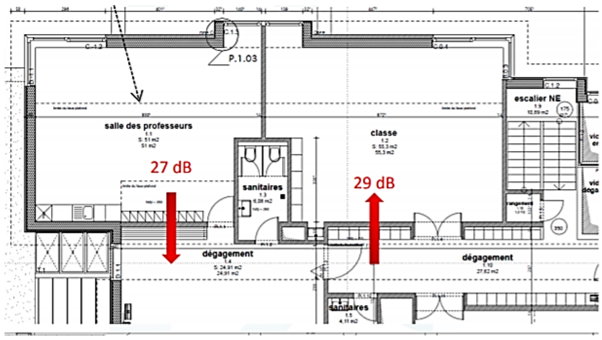

Fig. 24 insulation between corridors and classrooms, teachers' room Ref(31)

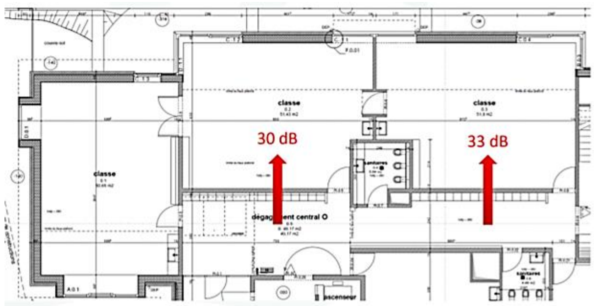

Fig. 25 insulation between corridors and classrooms Ref(31)

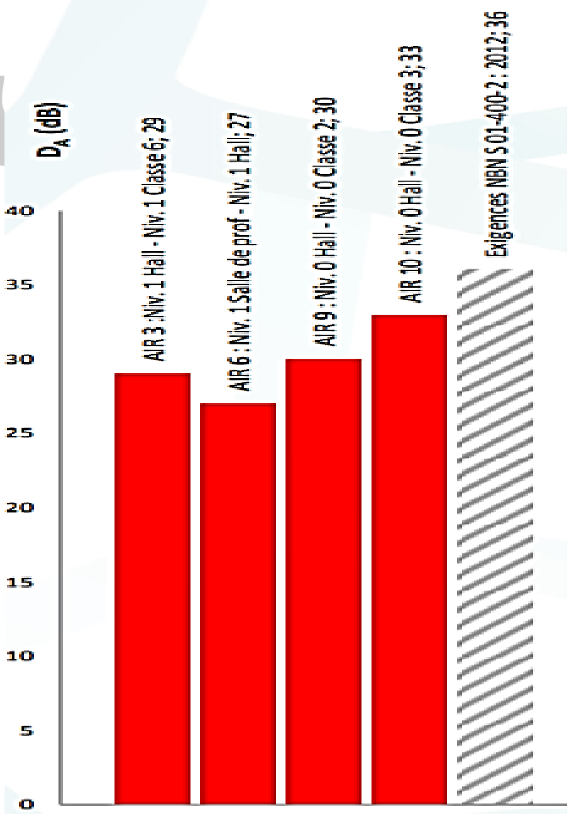

Fig. 26 Results Ref(31)

Insulation to impact noise between classes, teachers' room, halls, toilets.

$L'I = L'nT,w + CI$ (avec $L'nT = L2 + 10 \times \log (T0\ T))$The $L'I \leq 60$ dB (62 dB with tolerance)

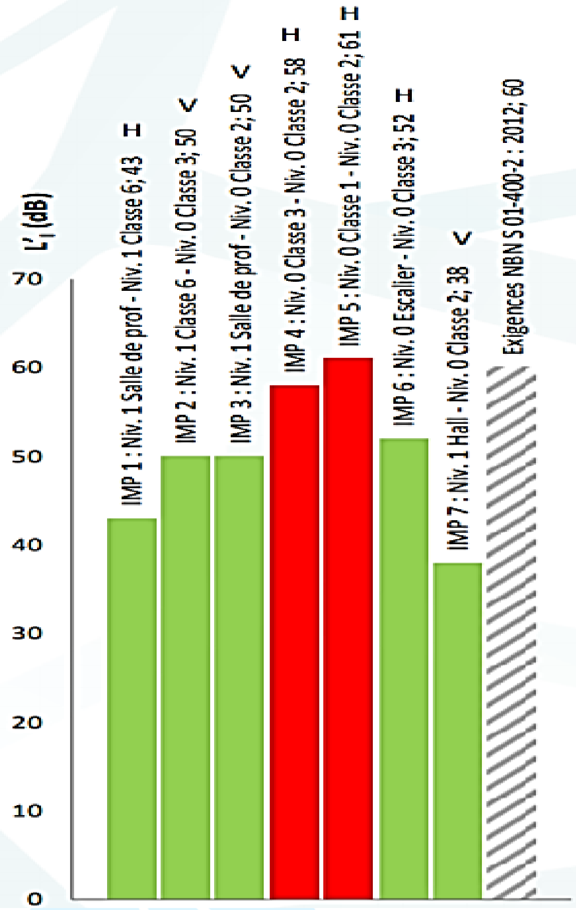

Fig. 27 Insulation to impact noise between classes, teachers' room, halls, toilets Ref(31)

As overall result, for this school the achievements in general are impact sound insulation (L'I) between different local (non-opening separation wall), airborne sound insulation (DA) between classes (non-opening separation wall) and limited performance for airborne sound insulation (DA) and impact sound insulation (L'I) between classes when the separation wall includes a door (limited door performance, noise transfer opening, sealing,...) and airborne sound insulation (DA) between a hall and a room.

IV. CONCLUSION

The consequences of noise exposure harm students and complicate their learning process, as teachers also suffer mentally and physically. Nowadays, speech is still the main means of teaching the course, so the students in the class must be able to hear the teacher. The acoustics of the classroom must, therefore, be good enough to ensure that the course is understood. Unfortunately, most schools do not have adequate acoustic treatment, but there are different methods and solutions to solve this problem depending on the source of the noise. Good classroom acoustics requires that ambient noise levels remain below the recommended limits, for low-noise levels, heating and ventilation systems must be chosen carefully and suitable acoustic insulation must be installed between the classroom and adjacent rooms. For room acoustics to be of reasonable quality, the recommended reverberation time requirements must be met. Reverberation times increase with the room size and decrease as sound-absorbing material is added to a room. From the different results, it can be concluded that the problems related to noise pollution relate to defects in architectural design and materials used for interior spaces. One of the design errors is the orientation of classrooms and their position in relation to sources of nuisance. All this underlines the poor acoustic conditions of schools and the need to intervene, there are different ways to solve these problems, solutions proposed by insulation companies after consultation by specialists. The provision of school equipment that promotes learning must, therefore, be a priority for the authorities and those responsible for the institutions concerned.

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