

# Acoustics evaluation of school buildings

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## Abstract

This paper presents results of the acoustic evaluation of eight school buildings in urban and peri-urban areas of the city of Viseu.

Acoustics evaluation of school buildings was made by measurements of: reverberation time in classrooms, sound insulation between classrooms and between classrooms and corridors; impact sound insulation of floors and airborne sound insulation of façade. The sound insulation of façade was made with all elements closed and with natural ventilation conditions (banners or windows tilt mode).

It was found that only two studied school buildings meet, for the performed tests, the legal requirements established in Portugal. The remaining six school buildings revealed disabled constructive aspects in relation to the acoustic requirements of school buildings compromising the quality of education.

**Key Words:** Indoor environment quality, classrooms, acoustics of school buildings, noise

## 1 Introduction

It is crucial that acoustic and HVAC (Heating, Ventilation and Air Conditioning) design are gathered to ensure good acoustic characteristics for school buildings or other learning spaces where oral communication is an important part of the learning process. Excessive background noise or excessive reverberation interferes with oral communication and represents impairment to learning. The negative interference in learning caused by inadequate acoustics of classrooms has been established in several studies (eg [1], [2], [3]) and the main effect of noise in classrooms is to reduce speech intelligibility and the most affected are younger students, students who are hearing impaired, with disorders such as attention deficit/hyperactivity disorder, and with speech and language difficulties.

## 2 Performance standards for the acoustics of school buildings

In order to improve the quality of teaching were introduced performance standards for the acoustics of school buildings in most countries (eg [4], [5]). In Portugal performance standards for the acoustics of school buildings are currently defined in national law (Decree-Law N<sup>o</sup>. 129/2002 of 11 May [6] amended and republished by Decree- Law N<sup>o</sup>. 96/2008 June 9 [7]). Table 1 presents Portuguese acoustic legal requirements for school buildings.

Table 1 - Portuguese acoustic legal requirements for school buildings [6], [7].

| Parameter   | Legal requirements   |
|---|--|
| Airborne sound insulation of façade - $D_{2m,nT,w}$                     | $\geq 33$ (dB), in noisy areas<br>$\geq 28$ (dB), in quiet areas |
| Airborne sound insulation between classrooms - $D_{nT,w}$               | $\geq 45$ (dB)   |
| Airborne sound insulation between classrooms and corridors - $D_{nT,w}$ | $\geq 30$ (dB)   |
| Impact sound insulation between classrooms - $L'_{nT,w}$                | $\leq 65$ (dB)   |
| Reverberation time in classrooms - T                                    | $\leq 0,15V^{1/3}$ (s) (V - room volume)                         |

### 3 Characterization of studied school buildings

Table 2 presents the characterization of studied school buildings.

Table 2 - Characterization of studied school buildings.

| School code | Level of education          | School year built | n.º of students (2012/2013) | Distance from façade to the road traffic (m) |
|-------------|-----------------------------|-------------------|-----------------------------|--|
| A           | College                     | 1993              | 2300                        | 100  |
| B           | Lower secondary             | 1991              | 700                         | 50   |
| C           | Kindergarten and Primary    | 2004              | 90/290                      | 140  |
| D           | Lower secondary             | 1968              | 950                         | 200  |
| E           | Primary and Lower secondary | 1996              | 177/249                     | 80   |
| F           | Primary                     | 1958              | 166                         | 240  |
| G           | Primary and Lower secondary | 2011              | 125/216                     | 500  |
| H           | Primary and Lower secondary | 2011              | 85/160                      | 1100   |

### 4 Methodology

In each school building was performed an acoustic evaluation of a typical classroom, *ie* the classroom which represents the largest number of classrooms in each school building. In each classroom was evaluated the reverberation time, airborne sound insulation and airborne sound insulation of façade. The sound insulation of façade was made with all elements closed and with natural ventilation conditions (windows in tilt mode).

In addition to these parameters, in three school buildings, A (college), B (Lower secondary) and D (Lower secondary), the airborne insulation between the circulation corridor and the classroom was tested. The determination of impact sound insulation between classrooms was carried out in 5 of the 8 studied school buildings.

The tests were performed by accredited test laboratory, MonitarLAB, according with the following standards: ISO 140-5 [9]; ISO 717-1 [10]; ISO 3382-2 [11] (for determination of airborne sound insulation of façade elements and façades); ISO 140-4 [12]; ISO 717-1 [10] (for determination of the sound insulation index to air sounds between two compartments); ISO 140-7 [13]; ISO 717-2 [14] (for determination of measurements of impact sound insulation of floors); ISO 3382-2 [11] (to determine the reverberation time).

### 5 Results

Table 3 presents the results of performed tests.

Table 3 - Results of performed tests.

| School code | T (s) (classroom) | $D_{nT,w}$ (dB) (source/receptor) | $D_{2m,nT,w}$ (dB) (classroom) | $D_{2m,nT,w}$ (dB) (classroom) (with natural ventilation conditions) | $L'_{nT,w}$ (dB) (between contiguous classrooms) | $D_{nT,w}$ (dB) (source/receptor) |
|-------------|-------------------|-----------------------------------|--------------------------------|--|--|-----------------------------------|
| A           | 1,8 (A1)          | 36 (A5/A1)                        | 23 (A1)                        | 13 (A1)  | 58 (A5/A1)                                       | 23 (corridor/A1)                  |
| B           | 1,7 (B5)          | 38 (B6/B5)                        | 24 (B5)                        | 20 (B5)  | nd   | 32 (corridor/B5)                  |
| C           | 1,1 (C4)          | 49 (C5/C4)                        | 30 (C4)                        | 16 (C4)  | 60 (C5/C4)                                       | nd                                |
| D           | 1,7 (D1)          | 40 (D5/D1)                        | 25 (D1)                        | 19 (D1)  | nd   | 26 (corridor/D1)                  |
| E           | 0,8 (E5)          | 45 (E6/E5)                        | 32 (E5)                        | 22 (E5)  | nd   | nd                                |
| F           | 1,1 (F4)          | 47 (F2/F4)                        | 24 (F4)                        | 19 (F4)  | 50 (F2/F4)                                       | nd                                |
| G           | 0,6 (G5)          | 47 (G6/G5)                        | 39 (G5)                        | 24 (G5)  | 40 (G6/G5)                                       | nd                                |
| H           | 0,9 (H5)          | 39 (H6/H5)<br>44 (H7/H5)          | 28 (H8)                        | 19 (H8)  | 62 (H6/H5)<br>37 (H7/H5)                         | nd                                |

nd - not done

## 5.1 Reverberation time

The reverberation time,  $T$ , is the duration required for the space-averaged sound energy density in an enclosure to decrease by 60 dB after the source emission has stopped [11].

The reverberation time and the relationship between the signal (teacher's voice in our case) and the background noise (Signal-to-noise ratio (SNR)) are the most important parameters for the speech intelligibility (eg [4], [15]). The reverberation time suitable for a classroom depends on the SNR, the volume of the room and auditors. Younger students need smaller reverberation time for the same SNR than older students, and children under the age of 13 years are particularly susceptible to this parameter [3]. There is not, however, a consensus about the maximum reverberation time and the SNR required for a classroom, with the requirements changing from country to country [4].

In Portugal, the threshold value defined to the reverberation time in classrooms depends on the room's volume. Table 4 shows the reverberation times measured in the eight studied rooms and limit values set out in Portuguese legal requirements [6] [7]. It should be noted that, according to legal requirements [6] [7], the assessments *in situ* designed to verify compliance with the acoustic requirements of buildings should be taken into account a factor of uncertainty,  $I$ , along with the determination of the parameter.

As can be seen only in three schools the compliance with the reverberation time requirements is verified. In three other schools the measured reverberation time is approximately twice the threshold value defined in legal requirements [6] [7]. Note that only buildings C, G and H were built after publication of current legal requirements [6].

In addition to the classrooms studied from the most recent buildings, buildings designated by G and H, also the classroom belonging to the building E meets current legal requirements for the reverberation time. Figure 1 presents photographs showing the acoustic treatment of classrooms E5, G5 and H5.

Table 4 - Measured reverberation times and comparison with Portuguese requirements [6] [7].

| School and classroom code | Coatings with relevant influence on reverberation                                 | Volume (m <sup>3</sup> ) | Legal requirement $T \leq 0,15V^{1/3}$ (s) | $I$ (s) | $T$ (s) Measured | $T$ measured - $I$ (s) | Observation                     |
|---------------------------|---|--------------------------|--|---------|------------------|------------------------|---------------------------------|
| A1                        | Floor: cork tile  | 160                      | 0,81                                       | 0,20    | 1,8              | 1,6                    | Superior than legal requirement |
| B5                        | Floor: ceramics   | 112                      | 0,72                                       | 0,18    | 1,7              | 1,5                    | Superior than legal requirement |
| C4                        | Floor: linoleum   | 151                      | 0,80                                       | 0,20    | 1,1              | 0,9                    | Superior than legal requirement |
| D1                        | Floor: wood   | 168                      | 0,83                                       | 0,21    | 1,7              | 1,5                    | Superior than legal requirement |
| E5                        | Floor: linoleum<br>Ceiling: cork agglomerate                                      | 164                      | 0,82                                       | 0,21    | 0,8              | 0,6                    | Inferior to legal requirement   |
| F4                        | Floor: wood   | 152                      | 0,80                                       | 0,20    | 1,1              | 0,9                    | Superior than legal requirement |
| G5                        | Floor: linoleum<br>Ceiling: plasterboard with absorption                          | 173                      | 0,84                                       | 0,21    | 0,6              | 0,4                    | Inferior to legal requirement   |
| H5                        | Floor: linoleum<br>Ceiling (partial): Perforated Plasterboard with circular holes | 154                      | 0,80                                       | 0,20    | 0,9              | 0,7                    | Inferior to legal requirement   |




|   |   |  |
|---|---|--|
|  |  |        |
| School/classroom E5<br>Ceiling: cork agglomerate                                  | School/classroom G5<br>Ceiling: plasterboard with absorption                      | School/classroom H5<br>Ceiling (partial): Perforated<br>Plasterboard with circular holes |

Figure 1 - photographs showing the acoustic treatment of classrooms E5, G5 and H5.

## 5.2 Façade insulation

Background noise inside a classroom depends on the noise sources within the school (for example: contiguous rooms, corridors), as well as noise from external sources to schools. For good speech intelligibility, the background noise should not exceed 35 dB (A) [2], [5].

To minimize the neighbourhood noise there are two main aspects to be considered: first, the location of the school building regarding to external noise sources (eg, highways, railways, airports, industries) and secondly, the façade insulation of school buildings.

Schools according to Portuguese legal requirements [9] should be located in quiet areas. However, not all schools are located in quiet areas and therefore the legal requirements sets different limits depending on the location of the school, see Table 1.

In this study, in addition to the determination of airborne sound insulation of classrooms façades ( $D_{2M, nT, w}$ ) according to standards, *ie* with closed façade elements (windows, doors), was also determined the  $D_{2M, nT, w}$  with ventilation (partial opening of the windows). The reason for the evaluation of  $D_{2M, nT, w}$  with ventilation was the fact that we identify a poor ventilation in this classrooms and consequent poor indoor air quality characterized by high CO<sub>2</sub> concentrations, see Almeida *et al.*, 2013 [16]. Thus, because school buildings have only natural ventilation (except G and H schools), it is necessary to ventilate through classroom windows, which implies the reduction of the sound insulation of façade. The test results are shown in Table 5. The selected ventilation mode was the opening of 2 windows (windows in tilt mode) in the extreme of classroom façade.

Considering that for the verification of compliance with Portuguese legal requirements [6] [7], the value obtained for the sound insulation  $D_{2M, nT, w}$ , should be increased by the uncertainty factor (I) in the amount of 3 dB and considering the threshold value for quiet areas, there is compliance for school buildings C, D, E, G and H.

Further, according to the Portuguese legal requirements, when the translucent area is greater than 60% of the façade element in question, it must be added to  $D_{2M, nT, w}$  an appropriate adaptation term C or C<sub>tr</sub>, dependent of the dominant type of noise in emission. Only for the school building F occurs this situation and the C<sub>tr</sub> value is -1 resulting in  $D_{2M, nT, w}$  of 23 dB.

The school buildings A, B and F have airborne sound insulation of classrooms façades ( $D_{2M, nT, w}$ ) upper than legal requirements.

The loss of effectiveness of the façade of isolation by opening the windows for ventilation is very variable from one to another classroom since the type existing windows in each classroom differs considerably. Figure 2 presents photographs showing the façade elements.

Considering that the school buildings, evaluated under this study, during school hours, are exposed to continuous noise levels,  $L_{Aeq}$ , close to 55 dB (A) at the most exposed façade, with the exception of School A that is exposed to  $L_{Aeq}$  near 62 dB (A), (results published in Pinho *et al.*, 2013 [17]), the opening of windows for ventilation of classrooms, compromise the façade

insulation. The background noise from sources outside will rise the sound levels above the 35 dB (A) recommended inside an empty classroom [2], [5].

Table 5 - Measured airborne sound insulation of school façades.

| School and classroom code | Floor | Façade elements   | Façade area/<br>% glass area | $D_{2m,nT,w}$<br>(dB) | $D_{2m,nT,w}$ (dB)<br>(with opening for ventilation) |                              |
|---------------------------|-------|---|------------------------------|-----------------------|--|------------------------------|
| A1                        | 0     | Paredes: duplas com isolamento<br>Caixilharia: de alumínio com folhas oscilobatentes e bandeiras basculantes; vidro duplo (4+10+6 mm)   | 29(m <sup>2</sup> )/54%      | 23                    | 13   | 4 upper windows in tilt mode |
| B5                        | 1     | Paredes*: duplas sem isolamento<br>Caixilharia: de alumínio com folhas de correr e bandeiras basculantes; vidro simples (4 mm)          | 22(m <sup>2</sup> )/38%      | 24                    | 20   | 2 upper windows in tilt mode |
| C4                        | 1     | Paredes*: duplas com isolamento<br>Caixilharia: de alumínio com folhas basculantes; vidro duplo (4+10+6 mm)                             | 25(m <sup>2</sup> )/50%      | 30                    | 16   | 2 upper windows in tilt mode |
| D1                        | 0     | Paredes*: duplas com isolamento<br>Caixilharia: de madeira com folhas de abrir e bandeiras basculantes e fixas; vidro simples           | 25(m <sup>2</sup> )/54%      | 25                    | 19   | 2 upper windows in tilt mode |
| E5                        | 1     | Paredes*: duplas com isolamento<br>Caixilharia: de alumínio com folhas de correr e bandeiras basculantes; vidro duplo (4+10+6 mm)       | 24(m <sup>2</sup> )/33%      | 32                    | 22   | 2 upper windows in tilt mode |
| F4                        | 1     | Paredes*: simples<br>Caixilharia: de alumínio com folhas de correr e bandeiras fixas; vidro simples (4 mm)                              | 25(m <sup>2</sup> )/61%      | 24                    | 19   | 2 upper windows in tilt mode |
| G5                        | 1     | Paredes*: simples com isolamento exterior<br>Caixilharia: de alumínio com folhas oscilobatentes ou basculantes; vidro duplo (4+10+6 mm) | 26(m <sup>2</sup> )/58%      | 39                    | 24   | 2 upper windows in tilt mode |
| H5                        | 1     | Paredes*: simples com isolamento exterior<br>Caixilharia: de alumínio com folhas de abrir e basculantes; vidro duplo (6+10+6 mm)        | 26(m <sup>2</sup> )/45%      | 28                    | 19   | 2 upper windows in tilt mode |

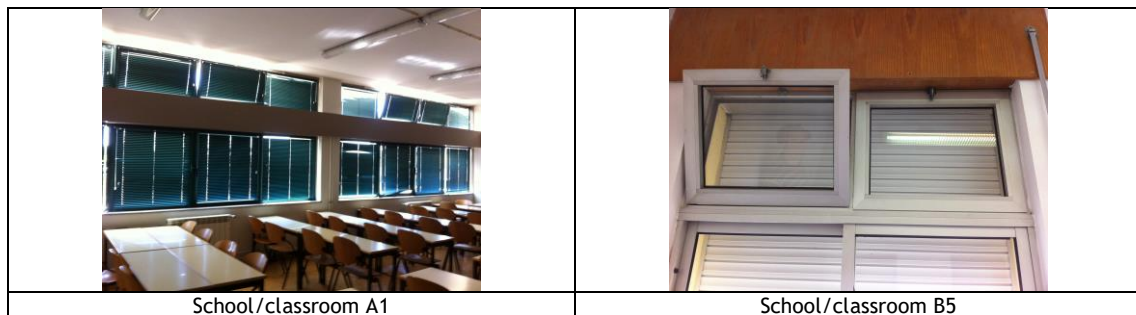




Figure 2 - Photographs showing windows opening mode selected for ventilation during test of airborne sound insulation of classrooms façades.

### 5.3 Airborne and impact sound insulation

As previously stated, the background noise within a classroom depends on the noise produced by external sources (e.g. roads, industrial and others) and by internal sources (e.g. contiguous classrooms, corridors, equipment's and others). The noise level within a classroom it depends not only the existing sources but also the acoustic characteristics of the building, namely: airborne sound insulation between classrooms and between corridors and classrooms and also the impact sound insulation between classrooms and between corridors and classrooms.

According to Portuguese legal requirements [6] [7], to assess airborne sound insulation between classrooms by *in situ* tests the value obtained for airborne sound insulation,  $D_{nT,w}$ , should be increased by an uncertainty factor (I) in the amount of 3 dB and the value obtained for impact sound insulation,  $L'_{nT,w}$ , must be reduced by an uncertainty factor (I) in the amount of 3 dB.

Measured airborne and impact sound insulation between classrooms and between classrooms and corridors are presented in Table 6. All school buildings tested comply with Portuguese legal requirements for impact sound insulation. Regarding the isolation air sound between rooms it is observed that 50% of school buildings do not comply with Portuguese legal requirements. The school building H introduces a separation between two rooms of different kinds and as such different solutions were tested, verifying that one of the solutions fulfills but not the other. The solution that meets involves the existence of a small room, separated by sliding doors containing storage cabinets, to separate the classrooms, see photos in Figure 3.

In three school buildings, A (college), B (lower secondary) and D (lower secondary) was tested the airborne sound insulation between the corridor and classroom because during time classes

also occur circulation in corridors. In that case we verify that school A and D do not comply with Portuguese legal requirements.

The worst results for airborne sound insulation were observed in school A. In school A there is poor integration of façade elements and between the corridor and the classroom where the existence of two doors with upper windows, ventilation grills on the doors and the mechanical ventilation system compromise the isolation air sounds, see photos in Figure 3.

Table 6 - Measured airborne and impact sound insulation between classrooms and between classrooms and corridors.

| School code | $D_{nT,w} + I$ (dB)<br>(source/receptor) | Separation elements   | $L'_{nT,w} - I$ (dB)<br>(Between contiguous classrooms) | $D_{nT,w} + I$ (dB)<br>(source/receptor) | Separation elements   |
|-------------|--|---|---|--|---|
| A           | 39 (A5/A1)                               | Paredes: alvenaria de tijolo furado<br>Pavimentos*: lajes maciças   | 55 (A5/A1)  | 26<br>(corredor/A1)                      | Paredes*: alvenaria de tijolo furado.<br>2 portas, sem vedantes, com grelhas de ventilação e com bandeiras                            |
| B           | 41 (B6/B5)                               | Paredes: alvenaria de tijolo furado   | nd  | 35<br>(corredor/B5)                      | Paredes*: alvenaria de tijolo furado.<br>1 porta, sem vedantes, com bandeira com pequenas aberturas de ventilação                     |
| C           | 52 (C5/C4)                               | Paredes: alvenaria de tijolo furado<br>Pavimentos*: lajes maciças   | 57 (C5/C4)  | nd                                       |   |
| D           | 43 (D5/D1)                               | Paredes: alvenaria de tijolo furado   | nd  | 29<br>(corredor/D1)                      | Paredes*: alvenaria de tijolo furado.<br>1 porta sem vedantes.<br>Três bandeiras interiores de lâminas orientáveis (abertas) de vidro |
| E           | 48 (E6/E5)                               | Paredes*: alvenaria de tijolo furado  | nd  | nd                                       |   |
| F           | 50 (F2/F4)                               | Paredes*: alvenaria de tijolo furado<br>Pavimentos*: lajes pré-esforçadas aligeiradas   | 47 (F2/F4)  | nd                                       |   |
| G           | 50 (G6/G5)                               | Paredes*: alvenaria de tijolo furado<br>Pavimentos*: lajes maciças  | 37 (G6/G5)  | nd                                       |   |
| H           | 42 (H6/H5)                               | Existe compartimento de 2,5 m de comprimento, entre as salas, com divisórias em alvenaria de tijolo furado e portas de madeira de correr sem vedantes | 59 (H6/H5)  | nd                                       |   |
| H           | 47 (H7/H5)                               | Paredes*: alvenaria de tijolo furado<br>Pavimentos*: lajes maciças  | 34 (H7/H5)  | nd                                       |   |

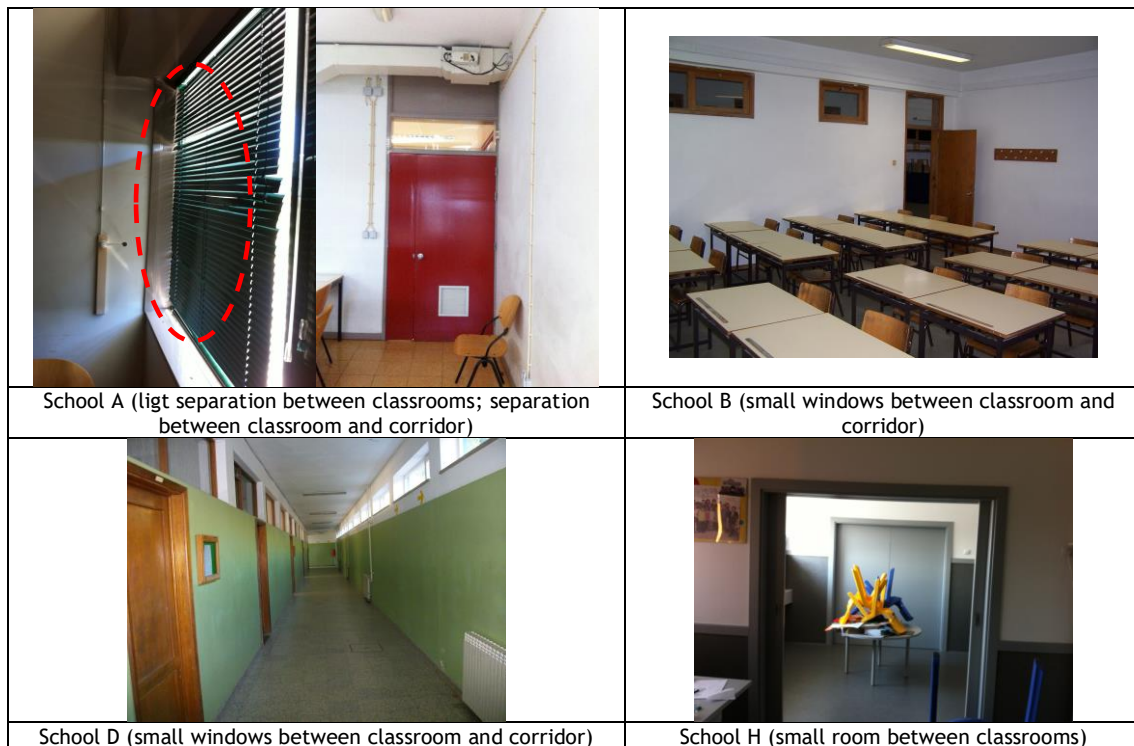


Figure 3 - Photographs showing wall elements between contiguous classrooms and corridors.

Note that in this schools were measured high noise levels inside the empty classrooms,  $L_{Aeq}$  exceeding 45 dB(A), 10 dB(A) above the level recommended by the World Health Organisation [2], [5] from inside noise sources (namely corridors and contiguous classrooms) (results published in Pinho *et al.*, 2013 [17]).

## 6 Conclusion

Only two of the tested school buildings, E (built in 1996) and G (built in 2011), comply, in the performed tests, with Portuguese legal requirements [6] [7]. The remaining six school buildings revealed disabled constructive aspects in relation to the acoustic requirements of school buildings compromising in that way the quality of education.

Note that 5 school buildings (A, B, C, D, F) have rooms that do not meet the reverberation time, and in 3 of them the reverberation times in classrooms are very high. It is also poor insulation to airborne sounds between classrooms for 4 of the 8 buildings tested (A, B, D, H) and poor insulation to airborne sounds from corridors and classrooms for 2 of the 3 buildings tested (A, D). The school buildings A, B and F do not comply also with airborne sound insulation of classrooms façades.

The study shows the need for acoustic quality design and *in situ* verification by carrying out standard tests for future school buildings. Also the existing school buildings acoustic performance needs to be assessed and corrective measures should be implemented to improve the quality of education in these buildings.

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### References

- [1] Hetu R.; Truchon-Gagnon C; Bilodeau S.A.: Problems of noise in school settings: a review of literature and the results of an exploratory study, *Journal of Speech-Language Pathology and Audiology*, 14(3), 31-38. 1990.
- [2] Berglund B.; Lindvall T.; Schwela D. H.: *Guidelines for Community Noise*. World Health Organization. 1999.
- [3] Shield B.N.; Dockrell J.E.: Invited Review Paper; The Effects of Noise on Children at School: A Review. *Journal of Building Acoustics*, 10 (2), 97- 116. 2003.
- [4] Vallet M.; Karabiber Z.: Some European policies regarding acoustical comfort in educational buildings. *Noise Control Eng. J.* 50 (2), 58-62. 2002.
- [5] ANSI/ASA S12.60-2010/Part 1 American National Standard Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools, Part 1: Permanent Schools
- [6] Decreto-Lei n.º 129/2002. D.R. SÉRIE I-A. 109 (2002-05-11) 4421-4428.
- [7] Decreto-Lei n.º 96/2008. D.R. SÉRIE I. 110 (2008-06-09) 3359-3372.
- [8] Decreto-Lei n.º 9/2007. D.R. Série I-A. 12 (2007-01-17) 389-398.
- [9] ISO 140-5:1998. Acoustics -- Measurement of sound insulation in buildings and of building elements - Part 5: Field measurements of airborne sound insulation of façade elements and façades
- [10] ISO 717-1:2013. Acoustics -- Rating of sound insulation in buildings and of building elements - Part 1: Airborne sound insulation.
- [11] ISO 3382-2:2008. Acoustics. Measurement of room acoustic parameters. Part 2: Reverberation time in ordinary rooms.
- [12] ISO 140-4:1998. Acoustics -- Measurement of sound insulation in buildings and of building elements - Part 4: Field measurements of airborne sound insulation between rooms.
- [13] ISO 140-7:1998. Acoustics -- Measurement of sound insulation in buildings and of building elements - Part 7: Field measurements of impact sound insulation of floors.
- [14] ISO 717-2:2013. Acoustics -- Rating of sound insulation in buildings and of building elements - Part 2: Impact sound insulation.
- [15] Nelson P.B.; Soli D.S.; Seltz M.A.: *Classroom acoustics II: Acoustical barriers to learnings*. Acoustical Society of America. Melville, NY, 2002.
- [16] Almeida R.M.S.F.; Pinho P.G.; Lemos L.T. de: Environmental quality in classrooms: preliminary results in terms of air quality and thermal comfort conditions. *Proceedings of 5th International Congress of Energy and Environment Engineering and Management (CIEM)*, Lisboa, Portugal, Jul 17-19, 2013.
- [17] Pinho P.G.; Almeida R.M.S.F.; Lopes S.M.; Lemos L.T. de: Indoor environmental quality in classrooms: preliminary results in terms of noise conditions. *Proceedings of 5th International Congress of Energy and Environment Engineering and Management (CIEM)*, Lisboa, Portugal, Jul 17-19, 2013.