ACOUSTICAL QUALITY FOR STUDENTS AND TEACHERS IN SECONDARY-SCHOOL CLASSROOMS IN ITALY

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1 INTRODUCTION

Research on the effects of noise and poor acoustics in schools over the past 30 years [1, 2, 3] has essentially concerned the effects of noise on children and teachers (annoyance and the effects of classroom noise on children's academic performance and teachers' health), and mainly regarded the transportation noise, and the most appropriate acoustic design to provide good speech intelligibility in classrooms.

Only a few studies have dealt with how students and teachers perceive acoustics during typical classroom use and most of them concerned single acoustical factors. Questionnaires have been administered to children in primary schools to assess their ability to discriminate in different listening conditions [4]. Questionnaires have been administered to university students to investigate the factors that affect the listening quality in university classrooms [5], and subjective surveys on perceived environmental quality and acoustical measurements have been carried out in secondary-school classrooms in Italy [6, 7, 8].

This paper provides a short review of some of the research results related to the two acoustical surveys in secondary-school classrooms in Italy, carried out in 2002 and 2005. The aims of the work were to compare objective acoustical data in different characteristic secondary-school buildings in one Italian scholastic district, to compare students' subjective data and analyse the questionnaires results for teachers in consideration of the results for the students.

2 SECONDARY-SCHOOL SURVEYS

In 2002, Astolfi et al. investigated overall environmental comfort in thirteen secondary-school classrooms in four school buildings that can be considered representative of the whole Turin Province scholastic district [6, 7]. The investigations were carried out in occupied classrooms by means of questionnaires and measurements.

The four school buildings that were the subject of the study were representative of buildings of different ages in inner and suburban city settings. The oldest one, the "Regina Margherita" (RM), is a sixty year old building located adjacent to an urban street. "C. Levi" (CL) and "B. Vittone" (BV) are buildings that are about thirty years old which are located in a suburban area, adjacent to a residential area. The newest building, "A. Gramsci" (AG), is about five years old and is in a suburban area far from noisy sources. This is the only building among those investigated, in which an absorbent false ceiling had been placed in the classrooms, but no particular attention had been taken concerning sound insulation.

The doors in the four school buildings were all obsolete, unsealed and had grilles for air transit. When the grilles were not positioned on the doors, they were located in the separating walls between the classroom and the corridor. The façade sound insulation, in terms of weighted standardized sound level difference, $D_{2m,nT,w}$, varied between 27 dB, in the three older buildings, and 35 dB, in the newer building, AG. The floors were covered with ceramic tiles, without a floating floor.

From two to three classrooms and one informatics laboratory occupied by approximately 20 teenage students, were tested for each school building. Acoustical measurements were carried out in thirteen school rooms and 249 students and 12 teachers filled in the questionnaires. The rooms had a parallelepipedal shape and volumes varying from 140 to 260 m³ for the classrooms, and from 230 to 330 m³, for the laboratories.

A subjective survey on perceived environmental quality was carried out in 2005 on fifty-one secondary-school classrooms in an old school in the Province of Turin, the “G. F. Porporato” (GFP), which had been a nineteenth century cavalry barracks. A questionnaire was delivered to 1006 students and 45 teachers. Acoustical measurements were carried out in eight of the fifty-one classrooms, these eight classrooms being representative of the different types of classrooms that were the subject of the survey [8, 9].

The fifty-one classrooms differ in volume and shape due to the variable layout of the floors. They can be subdivided into eight typologies with respect to the geometrical and acoustical features and to the position in the building. Most of them were renovated with special acoustical design features. The classrooms face onto a quiet street, a square or the internal courtyard since the main school building is a large three story square-court building.

The eight classroom types can be divided into four groups in relation to the volume: S1, M1, M2, M3, M4, L1, L2 and EL1 (where S stands for small, M for medium, L for large and EL for extra large). The volume range is between about 200 and 300 m^3, which is representative of medium sized high school classrooms in Italy, with the exceptions of a small classroom with a volume of 160 m^3 and a extra-large one with a volume of 466 m^3. A full acoustical sound absorption treatment was made in four of the eight classroom types (M1, M4, L1, EL1). This consisted in placing sound absorbing material on the ceiling, on the upper part of the lateral walls and on the back wall. The three classrooms S1, M3 and L2 were only partially renovated, and only one classroom, M2, was not renovated at all. This classroom was smooth plastered, and it has vaulted ceiling and large single glass windows.

The sound insulation intervention in almost all the classrooms mainly concerned the walls between adjacent classrooms, while the sound insulation from the corridors was not optimized. Façade sound insulation was good, apart from the older classroom type M2, but the students usually open the windows for ventilation. The floors were covered with ceramic tiles, without a floating floor.

3 DESCRIPTION OF THE SURVEYS

3.1 The measurements

The following quantities were obtained from the in-field measurements in the classrooms: the teacher’s vocal effort and noise level during regular lessons; the reverberation time in unoccupied and occupied conditions (RT_u and RT_o); the speech level, the A-weighted speech-signal-to-noise ratio (SNRA) and the speech transmission index (STI) for about six positions in the occupied classrooms.

In the GFP school the classrooms chosen for the measurements were representative of the eight selected types, but not all the types were used for all the analyses. As M4 was very similar to M3, it was excluded for the measurements of all the quantities, with the exception of reverberation time. It should be pointed out that in this school the classrooms were not fully occupied as they are during lectures, for this set of measurements. The percentages of occupation ranged from between 55% to 86%, compared to the average occupancy during regular class time obtained from the subjective survey.

Octave band reverberation time were obtained in both occupied and unoccupied conditions from the impulse response measurements using a sine-sweep signal generated by the 4128 Brüel & Kjær head and torso simulator placed at the teacher’s position.

The speech levels of the teacher's voice, based on 20 to 60 seconds recording of a continuous sample of speech (without pausing), were measured at 1 m in front of the teacher's mouth. The overall A-weighted speech level corresponds to the teacher vocal effort.
A sample of 13 teachers was tested in 2002 during the first survey in the four different schools, and 26 teachers were tested for the GFP survey. The corresponding free-field values, $L_{spA1m,\ free\ field}$, were calculated applying Barron and Lee's theory [10].

The equivalent A-weighted background noise levels, L_{Aeq}, based on a 3- to 6-minute recordings in the occupied classrooms during regular lessons, immediately after the teachers had spoken, were measured in each classroom at the centre of the room and at the teacher's position. These levels included noise from the corridor, from adjacent classrooms, from the courtyard and traffic (the latter only for urban schools). In order to obtain a correct measurement of the voice level, it was checked that the 1 m teacher's voice level exceeded the noise level at the same position by more than 10 dB over the entire frequency range.

The description and results concerning the speech level, SNRA and STI distribution in the occupied classrooms are shown elsewhere [8, 9].

3.2 The subjective survey for students and teachers

The subjective surveys were part of a large research project aimed at investigating environmental quality in classrooms, and at analysing all the environmental factors (thermal, acoustic, visual and indoor air quality) which contribute to the well being of occupants. The questionnaire, based on five point semantic differential scales, consists of six sections, on general information, thermal quality, indoor air quality, visual quality, acoustical quality and overall quality assessment, respectively.
The 2002 survey questionnaire was updated and used for the 2005 survey.

Questions on acoustical quality included evaluation of intensity and disturbance of different noise sources and of the overall background noise in the classroom, consequences of bad classroom acoustics, reverberation of the students' and teachers' voices, perceived vocal effort of the teachers, speech comprehension and satisfaction of the acoustical conditions.
In the first 2002 survey, fewer questions were included in the questionnaire: only the intensity of different noise sources and disturbance of the overall noise in the classrooms were judged by the students; among the different noise sources in the classroom, some of them were put together, for example, "Students talking in the classroom" and "Students moving in the classroom" were considered as a single source "Students talking and moving in the classroom"; the students were asked to cross only some of the consequences of noise among those present in a list.

The general information section was related, among others, to study benefit and the influence (or the importance) of the four environmental aspects on the students' school performances or on the quality of teaching. The overall environmental quality section was constituted by one single question on the general satisfaction of all the environmental quality aspects together.

The questionnaires were administered in the classrooms during regular lessons. In 2002, the students were asked to answer with reference to recent lessons, while in 2005, with reference to the winter period. In order to obtain coherent and realistic answers, the questionnaire was explained both to the students and to the teachers before they were filled in.

The useful samples consisted of 236 students for the first survey and 852 for the second. The samples were consistently reduced after the questionnaires referring to subjects with hearing impairments together with those answered by non native Italian speakers were disregarded and after that an analysis of consistency of the answers was made. The students had a mean age of 17.0 and 16.1, respectively for the two surveys, and there was a majority of females.
The questionnaire for the teachers was the same as that for students. A total of 57 teachers from the first and second surveys filled in the questionnaires, which were reduced to 54 (11 for the 2002 survey and 43 for the 2005 survey). An analysis of consistency of the answers was than made by

means of Mahalanobis and Cook distances [8] in a first explorative regression analysis of the overall satisfaction scores versus the satisfaction scores of other environmental aspects.

4 RESULTS

4.1 The objective survey results

The average reverberation times at the frequencies of 500 – 1000 – 2000 Hz are represented versus classroom volumes in Fig. 1, for unoccupied and occupied conditions. The figure shows an increasing RT with decreasing absorption in the classrooms.
In the GFP school, in order to check the reverberation time in fully occupied conditions, corrected RT_o values were calculated applying the Sabine formula, in which the total acoustic absorptions, obtained from the measured occupied reverberation time, were increased by an amount equal to the average absorption per student multiplied by the difference in the number of students for full and partial occupancy.
As far as the unoccupied classrooms are concerned, only five (24%) satisfy UK Building Bulletin 93 [11] which requires a maximum reverberation time, quoted in terms of the average in the 500 Hz, 1 kHz and 2 kHz octave bands, of 0.8 s. All these five classrooms had been acoustically renovated.
According to Picard and Bradley [3], the optimal values of the mid-frequency reverberation time in occupied classrooms is estimated to be 0.5 s. Only seven classrooms (33%) were close to this limit, and most of them have been acoustically renovated, confirming that acoustical treatment is also necessary in small occupied classrooms.

As far as the vocal effort is concerned, the free-field values at 1 m from the teacher's mouth are shown versus equivalent A-weighted background noise levels in Fig. 2. A mean value, referring to the whole sample of 64.6 dBA (s.d. = 3.8) denotes an average vocal effort between "Normal" (60 dBA) and "Raised" (66 dBA), according to the ISO 9921:2003 standard [12].

As for background noise, a mean value referring to the whole sample of 44.5 dBA (s.d. = 5.9) was obtained. This is higher than the *acceptable* target of 40 dB(A) as indicated by Picard and Bradley [3]. Without the informatics laboratories, the mean value is 43.4 dBA (s.d. = 5.8).

For the CL, BV and AG schools, located quite far from traffic arteries, the noise came mainly from inside the buildings, while for the RM school, it came both from inside and outside the building, as it was in an urban area. The average L_{Aeq} values for the schools, obtained by averaging the noise levels for two or three classrooms for each building excluding the informatics laboratories, were 44.6 dB(A) for CL, 45.8 dB(A) for BV, 43.8 dB(A) for AG (level corresponding to only one classroom because in the other one an exceptional level of 53.5 dBA was recorded), and 49.2 dB(A) for RM, respectively.

Informatics laboratories were noisier than the classrooms in the CL and BV schools, while in RM and AG no significant differences were observed between the noise levels measured in the classrooms and the laboratories. The RM school is, in fact, located in the centre of the town, and much of the noise in the building comes from traffic, both in the classrooms and in the laboratories, and this noise is much louder than the computer noise. As far as the AG school is concerned, this is a new school with sound absorption treatment in the rooms that can reduce computer noise inside the laboratories, which are located in the basement, far from the noisy corridors.

In the GFP school, all the classrooms look onto a quiet street or square, except S1 and M1, which look onto a courtyard, but no marked differences were observed between the two types of classrooms in this respect, which means that the noise mainly comes from inside the building. Most of the L_{Aeq} values were lower than the acceptable target of 40 dB(A), as indicated by Picard and Bradley, apart from the nonrenovated type M2, where the value was 44.3 dB(A), and the M3 type for which a level of 41.2 dB(A) was measured.

The linear regression analysis shown in Figure 2 attributed a 0.41-dB positive slope in speech level versus noise level due to the Lombard effect, which is comparable with other literature data. For example, a value of 0.63-dB was found by Picard and Bradley [3], when analyzing A-weighted levels for ambient noise and teachers' speech in occupied classrooms in literature. They also cited a 0.50-dB increase found by Lane and Tranel [13]. The EL1 classroom values were excluded from the linear regression since the Mahalanobis and Cook distances were much higher in this classroom than in the other classrooms, being equal to 0.36 and 4.10, respectively.

With the average values of 64.6 dB(A), $L_{spA1m,\ free\ field}$, and 44.5 dB(A), L_{Aeq}, for noise, the average signal-to-noise ratio (SNRA) in the middle of the room, at 4 m from the teacher's mouth for an average classroom of 230 m^3 (mean classroom volume) with an RT_o of 0.8 s (mean classroom RT_o), is 19.9 dB(A), calculated applying Barron and Lee's theory [10].

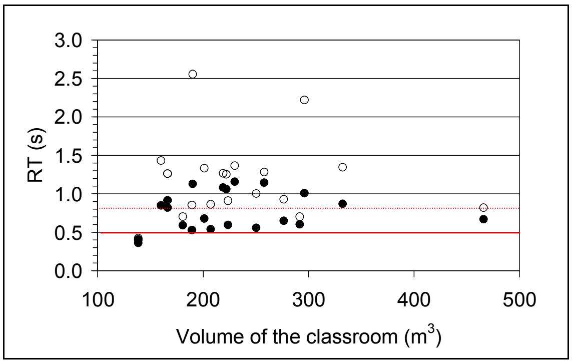


Figure 1 – Comparison of RT_o (black points) and RT_u (white points) versus the volume of the classrooms. The full line indicates the optimal value (0.5 s) for occupied classrooms as reported by Picard and Bradley [3], the dashed line indicates the optimal value (0.8 s) for unoccupied classrooms as reported in [11].

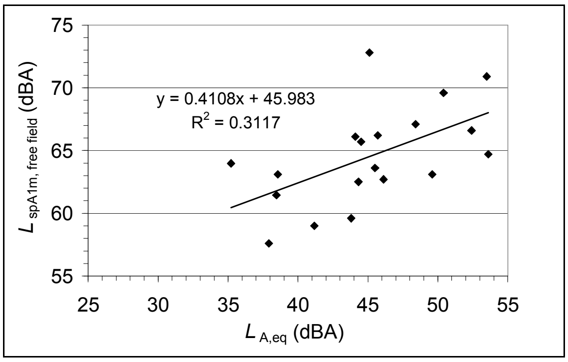
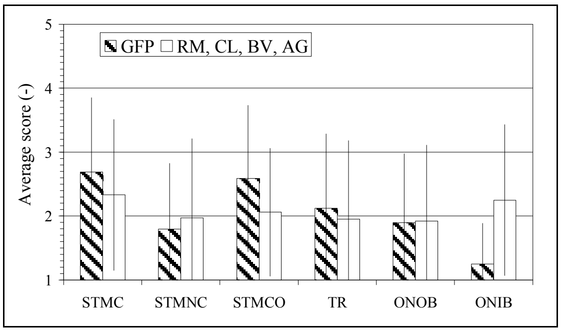


Figure 2 – Noise levels $L_{A,eq}$ versus voice levels at 1 m in front of the teacher in free field and best fit linear regression function.

4.2 The subjective survey results

The main results of the subjective surveys for students and teachers are presented in this section. All statistical analyses were carried out with the support of the SPSS® package.

The mean values and standard deviations of the intensity of different noise sources in the classrooms for students and teachers, are shown in Figure 3a and b, respectively. For the GFP survey (852 students and 43 teachers), the scores for the answers "Students talking in the classroom" and "Students moving in the classroom" were averaged in order to obtain the mean score for "Students talking and moving in the classroom". The same procedure was followed for the answers "Students talking in the neighbouring classrooms" and "Students moving or shuffling in the neighbouring classrooms" in order to obtain the mean score for "Students talking and moving in the neighbouring classrooms". The student's and teacher's answers in the informatics laboratories were excluded from the analysis in the 2002 survey, reducing the sample to182 students and 7 teachers. The 5-point scales are from "very low" to "very high". As far as the student's perception is concerned, the highest mean values were attributed to "Students talking and moving in the classroom" (STMC) and "Students talking and moving in the corridor" (STMCO). High values were also attributed to "Traffic" (TR) and "Other noise outside the building". For these last three mean scores, the reasons could be the low sound insulation of the doors and sometimes open windows. The reason for the high mean score for "Other noise inside the building" (ONIB) in the 2002 survey could be the presence of air grilles in the doors or in the separating walls between classrooms and corridors. As far as the teachers' perception is concerned, the same trend was shown as that of the students.



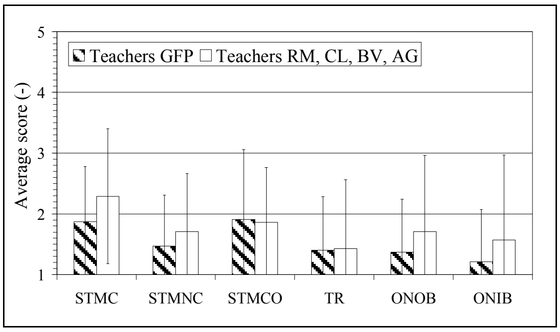


Figure 3a,b. Mean values and standard deviations of intensity of different noise sources in the classrooms for students and teachers. The five-point scale is bounded by the words "very low" (1) and "very high" (5). The following abbreviations are used for the noise sources: STMC for "Students talking and moving in the classroom", STMNC for "Students talking and moving in the neighbouring classrooms", STMCO for "Students talking and moving in the corridor", TR for "Traffic", ONOB for "Other noise outside the building", and ONIB for "Other noise inside the building".

The influence of the four different environmental aspects on the students' school performance and the quality of teaching was investigated from the different samples of students and teachers shown in Table I. Almost the same importance was awarded to the four aspects by the two groups of students, with a prevalence of influence of visual quality and acoustical quality, followed by thermal and indoor air quality. In particular, for the GFP school, the visual and acoustical quality was, with significant evidence, more important than thermal and indoor air quality, while for the other students, no significant differences emerged among the different kinds of environmental quality, even though visual and acoustical quality prevailed. In the teachers' answers, acoustical quality was surely the factor which was considered to have the most influence on their quality of teaching.

Table I: Influence of the four different environmental aspects on the students' school performance and quality of teaching: mean scores of the answers and 95% confidence intervals. The answers were based on a 5-point scale, ranging from 'very little' (1) to 'very much' (5).

Environmental quality aspect	2002 students full sample (236 ind.)		2005 students full sample (852 ind.)		Teachers full sample (54 ind.)	
	Mean	95% confidence interval	Mean	95% confidence interval	Mean	95% confidence interval
Acoustical	**3.96**	[3.83, 4.09]	**3.44**	[3.36, 3.52]	**4.31**	[4.01, 4.62]
Thermal	**3.75**	[3.61, 3.90]	**3.09**	[3.01, 3.18]	**3.57**	[3.25, 3.90]
Indoor air	**3.83**	[3.69, 3.98]	**2.94**	[2.85, 3.02]	**3.74**	[3.42, 4.06]
Visual	**4.02**	[3.90, 4.13]	**3.54**	[3.46, 3.63]	**3.85**	[3.55, 4.16]

Table II shows a comparison of the mean answer scores of some acoustical factors in the renovated and nonrenovated classrooms of the GFP school for students and teachers. Two samples of 852 students and 43 teachers were considered. Noticeable differences can be observed between the students' answers, and the t-tests strongly reject the hypothesis of no differences between the perceptions of the two groups of students. Not high differences in vocal effort emission emerged for teachers in renovated and nonrenovated classrooms, where the intervention basically concerned sound absorption improvements, and a mean score of about 3, corresponding to a "Normal" effort on the scale, was assigned. This subjective qualification corresponds to an objective one, since in the school, for a total of 26 teachers tested, an average $L_{spA1m,\ free\ field}$ of 62 dB(A) was measured, denoting a vocal effort close to “Normal” according to the ISO 9921:2003 standard [8, 12]. Nevertheless, other studies are necessary to investigate the factors that can influence the teacher’s vocal effort in more detail.

Table II: Mean scores of the acoustical answers, 95% confidence intervals and t-test significances for the differences of the mean scores between the renovated and nonrenovated classrooms for GFP students and teachers, on 1-5 discrete scales: satisfaction of acoustical quality from ‘very dissatisfied’ to ‘very satisfied’; reverberation of the teachers’ and students’ voices from ‘very dry’ to ‘very reverberant’; perceived vocal effort of the teacher from ‘very low’ to ‘very raised’; how well students (or teachers) comprehend the spoken words of the teacher (or students) from ‘very badly’ to ‘very well’.

Environmental quality aspect	Students					Teachers				
	Renovated classrooms (702 ind.)		Nonrenovated classrooms (150 ind.)			Renovated classrooms (34 ind.)		Nonrenovated Classrooms (9 ind.)		
	Mean	95% confidence interval	Mean	95% confidence interval	t-test for the difference of the means (p-value)	Mean	95% confidence interval	Mean	95% confidence interval	t-test for the difference of the means (p-value)
Acoustical quality	**3.09**	[3.04, 3.15]	**2.17**	[2.06, 2.28]	0.00	**4.15**	[3.92, 4.38]	**2.89**	[1.77, 4.01]	0.03
Voice reverberation	**2.06**	[1.99, 2.12]	**3.69**	[3.52, 3.87]	0.00	**1.94**	[1.60, 2.28]	**3.67**	[2.81, 4.53]	0.00
Vocal effort	**2.86**	[2.81, 2.92]	**3.43**	[3.31, 3.54]	0.00	**2.88**	[2.61, 3.15]	**3.22**	[2.48, 3.97]	0.35
Speech comprehension	**3.88**	[3.81, 3.95]	**3.07**	[2.90, 3.23]	0.00	**3.91**	[3.61, 4.21]	**3.00**	[2.46, 3.54]	0.00

Figure 4 shows the average scores of the frequency of a list of consequences caused by poor classroom acoustics for students in the GFP school. Only the mean values for the students who were not satisfied about the overall classroom acoustics (i.e., the 165 students that marked 1 and 2 on the correspondent five-point satisfaction scale) are reported. The most important consequences of the poor acoustics in the classrooms are “Decrease in concentration”, “Decrease in teacher’s voice perception” and “Decrease in students’ question perception”. Almost the same results emerged from the 2002 survey, as can be seen in Figure 5 [7].

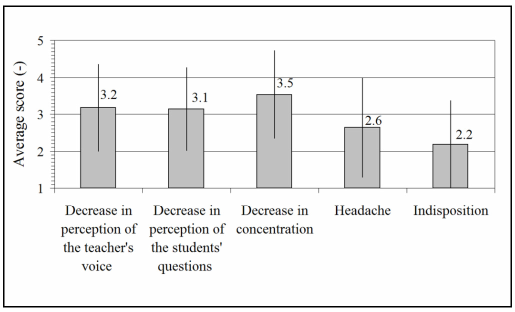


Figure 4. Mean values and standard deviations of the frequency of some consequences of poor classroom acoustics for the GFP school students. The five-point scale is from “never” (1) to “very often” (5).

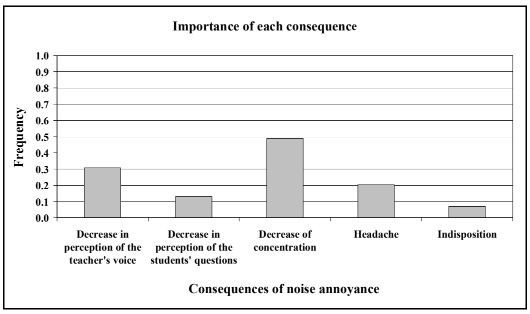


Figure 5. Frequency of the different consequences of noise annoyance for students in the four schools in the 2002 survey.

5 CONCLUSIONS

The classroom environment combines factors connected to heat, light, indoor air quality and sound. Acoustical quality is one of the most important aspects, but the influence on students' school performance and the quality of teaching also depends on non-acoustical features.

The results from acoustical measurements in Italian secondary-school classrooms have underlined the importance of sound absorbing treatments, even in small occupied rooms. The average noise level in an occupied classrooms is about 44 dB(A), while the average vocal effort is between "Normal" and "Raised". A slight correlation was found between the vocal efforts of the teachers and the L_{Aeq} background noise levels, showing about a 0.40-dB increase in speech level per dB increase in noise level. Other studies are however necessary to more clearly investigate factors that can influence the teacher's vocal effort.

As far as the subjective survey is concerned, the highest mean intensity scores were assigned to the noise produced by the students talking and moving in the classroom and in the corridor, and a problem of low sound insulation of the separating wall between classrooms and corridors was in fact pointed out. Students and teachers are aware of changes in classroom acoustics, since differences were observed in acoustical answer scores for renovated and nonrenovated classrooms, and, as an effect of bad acoustics, one of the most important consequence is a decrease in concentration.

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