Research Article

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Global noise score indicator for classroom evaluation of acoustic performances in LIFE GIOCONDA project

Abstract: The LIFE GIOCONDA is an ongoing project that aims to provide an innovative methodology to the authorities for supporting the environment & health policies by involving the young people in the decision-making processes. The project suggests a web platform able to relate air and noise pollution data in the schools with the students' pollution awareness. GIOCONDA aims to enhance the awareness of students, teachers and local administrations on the noise issues in schools, presenting suitable tools to improve the public participative processes.

This paper presents a new method that has been developed within the Project. It aims to evaluate the acoustic performances of a classroom and to suggest the use of a global indicator based on a group of acoustic parameters compared with their limit values. Whit the new method the comparison between different classrooms or different schools becomes possible, together with a homogeneous evaluation of the priority for planning noise mitigation actions.

Several noise measurement campaigns have been performed to characterize the students' exposure in eight Italian schools. The results are useful to describe the acoustic performances of classrooms.

Keywords: Classroom Acoustics; Acoustic Measurements; Global Noise Score; Noise Protection; Noise Awareness

1 Introduction

The exposure to high noise levels is a well know issue in modern society, so much that the scientific community and the consultant bodies gave a lot of attention to it in the past decades. The problem is much more complicated inside the school environment, where the children and teachers need quietness for their activities [1].

Impairs cognitive performance in schoolchildren [2–7], as well as stress or voice problems for teachers [8, 9] can be caused by both the noise coming from outside or inside the classrooms. Indeed, several studies shown that high reverberation and high levels of background noise, due to external or internal noise, can seriously affect speech perception, short-term memory, task assignments and general understanding, resulting in a significant negative impact upon school and working performance and an induced hearing threshold shifts in the worst cases.

Therefore, the acoustical conditions in classrooms do not often fit the specific needs of young listeners.

Minimizing the noise and reverberation in classrooms thus become of relevant importance [7].

In this background, the LIFE GIOCONDA Project [10] (i GIOvani CONtano nelle Decisioni su Ambiente e salute, Young voices count in decisions on env& health), has been funded within LIFE+ Environment Policy and Governance (LIFE13 ENV/IT/000225), began in June 2014 and it will end in November 2016.

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The Municipality of Ravenna, the Environmental protection agencies of Emilia Romagna and Puglia (ARPA Emilia Romagna and ARPA Puglia), the University of Napoli "Suor Orsola Benincasa" and the Health Society of Valdarno Inferiore (Società della Salute Valdarno Inferiore) are partners of the project. The Institute of Clinical Physiology of the National Research Council (IFC-CNR) is the coordinator of the project.

The project has the purpose of filling the gap between young people and public administrations about environment and health issues, considering that young people will lead the environment and the health of tomorrow by means of their perception and behaviour. This is a chance to understand the gap between subjective perception and real pollution.

Indeed, providing accessible information for public decisions on environment and health is a priority of the current LIFE+ Environment Policy and Governance, supported also by the World Health Organization, which studied the effects of noise pollution on vulnerable categories [11, 12].

The Aarhus Convention [13] establishes several rights concerning the environment, among which the right to the "access to environmental information" and the right to the "public participation in environmental decision-making". The first one deals with the information about both the state of the environment, human health and safety, and the policies or measures taken to improve them. The second one drives the public administrations to involve population planning and programmes related to the environment.

After the Aarhus convention, several projects are born to enhance the information exchange between people and public administration. The GIOCONDA Project provides an innovative procedure to effectively support the young people involvement in the decision-making processes on environment and health. The procedure is based on the combination of air and noise pollution measurement results with the risk perception and willingness-to-pay (WTP) [14] related to environmental health issues. Since the project involves cities with different kind of pollution sources, a holistic approach [15] has been applied. Alongside the measurement campaigns, the students reported their risk perception on noise, air, waste and water pollution and also provide their WTP related to each issue. The combination of these data could allow the understanding of the gap between the perceived and the objective pollution. Some previous studies already investigated this gap [16–20] but this project aims to offer a further step in communicating the results to the surveyed students and to increase their awareness about the negative effect of a noisy environment on the learning process. Finally, an online platform will be developed in order to facilitate the application of environmental and health risk governance and policies.. The platform will include tools for the decision makers that may be useful to estimate the costs and benefits of policies regarding the air pollution and/or the noise exposure, while other tools will enable schools to measure the students' perception of their surrounding environment. As a further result, in the second year of implementation of the project, it will be possible for students to discuss and use the platform in order to suggest solutions to the public administrations.

In the international scientific literature many studies involved the effects of noise on teachers and students or the characterization of classrooms' acoustical performance [21, 21, 22]. Unfortunately, for the authors' knowledge, none suggested a method to properly evaluate a classroom and to allow their comparison.

In the present paper, an innovative method for the noise characterization of classrooms is presented. It is based on the noise data acquired during measurements campaigns performed in 2015 along the Italy and it develops a new global indicator that would allow a simpler evaluation of the state of the acoustic environment inside the schools. This innovative method has been applied in some pilot schools in order to test the reliability and the suitability for its application in Italy and Europe.

2 Schools involved in the project

The GIOCONDA Project involves eight schools belonging to four different project areas: Napoli, Taranto, Ravenna and Valdarno. In each project area, two schools have been chosen:

- a first grade secondary school, age from 11 to 13 (middle school MS);
- a second grade secondary school, age from 14 to 18 (High School HS).

The four areas are spread across all Italy:

- Valdarno is a portion of a rural area in Tuscany. The schools are in two small villages, San Miniato and Ponte a Egola. The San Miniato HS is in a very silent context, with few roads and a low traffic flow. The Ponte a Egola MS is along a regional urban link road, presenting a high traffic flow at low speed.
- Ravenna is a medium city, with the HS placed in the city centre, in a traffic-restricted area. The MS is in a quiet suburb placed near the sea.

Table 1: Description of the schools surveyed in the GIOCONDA Project.

School ID	School	Surroundings	Noise sources	Noise pollution (qualitative)	Building status maintenance
S1	MS Valdarno	Suburban	Main road	High	Good
S2	HS Valdarno	Suburban	Hilly local road	Low	Fair
S3	MS Ravenna	Suburban	Main road	Medium	Good
S4	HS Ravenna	Urban	Secondary road	Low	Good
S5	MS Napoli	Urban	Area with car parking	High	Poor
S6	HS Napoli	Urban	Area with public bus	Medium	Good
S7	MS Taranto	Suburban	Industrial area with highway traffic noise	High	Fair
S8	HS Taranto	Urban	Urban secondary road	Low	Fair
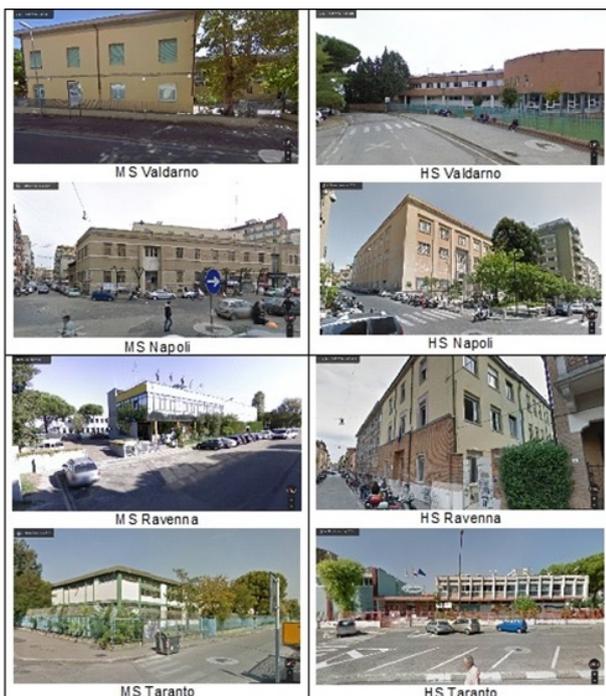
Figure 1: Schools views from Google Street.

A summary of context characteristics, main noise sources and qualitative judgements about both status of school buildings maintenance and noise pollution of the area, according to a first subjective judgment of the operator during the inspection, is reported in Table 1.

In each school, three classrooms have been characterized, evaluating both the noise exposure and the building acoustic characteristics. iPOOL, a spin-off company of National Research Council of Italy, has been put in charge for developing the whole procedure to evaluate the acoustic performances of the classrooms and for carrying out all measurement sessions. The investigated classrooms are described in Table 2.

3 Methods

3.1 Procedure to evaluate the acoustic performances

The following main steps are proposed in order to set-up a procedure to acoustically evaluate any classroom with a single indicator representing the judgment of the overall noise situation:

1. setting a list of significant acoustic parameters to investigate;
2. establishing a score range for each parameter;
3. establishing a "Global Noise Score" to be assigned to the classroom, with a related score range;
4. carrying out the measurement campaigns;
5. analysing the data and providing the results;

– Napoli is one of the biggest cities of south of Italy and both the schools are placed in the city centre, even if they are placed in different districts: the HS is in the historical centre and the MS is on a main road in the district of the railway station.
– Taranto is a big industrial city. The HS is located in the city centre, whilst the MS is located in the industrial area. High traffic levels are present around both the schools.

In Figure 1 the schools and theirs surrounding are shown.

The quality and intelligibility of speech in a classroom mainly depends on both the noise level and the amount of reflected sound, which increase the noise level and masks the speech itself. Thus, the noise and the reverber-

Table 2: Description of classrooms involved in the project.

School	Room	Floor	Position	Volume [m³]	Surface Façade [m²]	Surface Windows [m²]
S1	A	1st	Main façade	121.0	19.0	4.5
	B	1st	Main façade	153.0	28.0	25.0
	C	Ground	Back façade	166.0	23.0	8.0
S2	D	2nd	Back façade	147.5	21.0	8.5
	E	2nd	Back façade	195.0	30.0	13.0
	F	2nd	Main façade	134.5	19.0	7.5
S3	G	1st	Main façade	144.5	23.9	11.0
	H	1st	Main façade	166.5	27.5	13.5
	I	Ground	Main façade	182.0	30.0	14.5
S4	J	2nd	Back façade	152.0	31.0	15.0
	K	Ground	Back façade	159.0	33.0	4.5
	L	2nd	Back façade	156.5	25.0	3.0
S5	M	Ground	Main façade	146.0	35.5	4.0
	N	1st	Main façade	159.0	36.5	4.0
	O	1st	Main façade	154.5	35.5	4.0
S6	P	2nd	Main façade	236.0	37.0	11.5
	Q	3rd	Back façade	151.0	37.0	11.5
	R	2nd	Back façade	184.0	45.0	11.5
S7	S	1st	Main façade	123.0	20.5	10.0
	T	1st	Main façade	123.0	20.5	10.0
	U	Ground	Main façade	123.0	20.5	10.0
S8	V	Ground	Main façade	146.0	24.5	11.5
	W	Ground	Main façade	146.0	24.5	11.5
	X	Ground	Main façade	146.0	24.5	11.5

Table 3: Score ranges for each parameter.

Score	Evaluation	$L_{DAY-Ext}$ [dB(A)]	$L_{DAY-Int}$ [dB(A)]	$D_{2m,nT,w}$ [dB]	R'_w [dB]	RT [s]	STI
5	Very Good	< 50.0	< 45.0	> 48.0	> 50.0	< 0.80	0.75−1.00
4	Good	50.0−52.5	45.0−47.5	48.0−45.1	50.0−47.1	0.81−1.00	0.60−0.75
3	Sufficient	52.5−55.0	47.5−50.0	45.0−42.1	47.0−44.1	1.01−1.20	0.45−0.60
2	Poor	55.0−57.5	50.0−52.5	42.0−39.0	44.0−41.0	1.21−1.40	0.30−0.45
1	Very Poor	> 57.5	> 52.5	< 39.0	< 41.0	> 1.40	< 0.30

ation outline the acoustical environment of a classroom. Concerning the noise, outside the school it is mainly due to transport infrastructures and industrial areas, whilst inside the classroom it is also related to other sources, such as building services (heating, lighting, ventilation systems), teaching aids (overhead projector, computers) or the ongoing lesson. Reverberation describes the amount of reflected sound and it depends on the room volume and the acoustic characteristics of all the surfaces inside the room, as walls, ceiling, floor, desks and whiteboards.

Bearing in mind these considerations, a common set of six parameters, defined in accordance with international standards, is proposed:

– the L_{DAY} for investigating the exposure to external sources, calculated from:

1. external noise monitoring ($L_{DAY-Ext}$);
2. internal short-term measurements ($L_{DAY-Int}$);

– the following four parameters for investigating the building acoustics characteristics:

1. façade insulation: $D_{2m,nT,w}$ [23, 24];
2. wall insulation: R'_w [23, 24];
3. reverberation time: RT [25];
4. speech intelligibility index: STI [26].

Each parameter has been categorized in five classes: the higher one (score 5) has been chosen to fulfil the Italian limit values [27–30], which are very hard to be observed, the others have been set according to the scientific literature or to the international optimal values [31–35]. The score ranges proposed are reported in Table 3 and better explained in the following.

In Italy, the national regulation for environmental acoustic [19] requires the school areas to be in the lower class of acoustic zooning ($L_{DAY-Ext} < 50$ dB(A)), considering the exposed façade as representative for the whole school. Nonetheless, the schools are often placed near congested streets, as documented in several cases analysed in this project (Table 2), showing very high noise level (more than 70 dB(A)). The internal noise level with open

Table 4: Evaluation classes: scores and related performance.

Evaluation classes	
Score	**Acoustic performance**
26−30	Very good
21−25	Good
16−20	Sufficient
11−15	Poor
6−10	Very Poor

windows ($L_{DAY-Int}$) is not fixed by the regulation, thus the authors consider 5 dB(A) less than the corresponding class for external level.

The limits for façade insulation parameter $D_{2m,nT,w}$ and for wall insulation parameter R' of school buildings are defined in a specific decree [28]: $D_{2m,nT,w}$ must be higher than 48 dB(A) and R' higher than 50 dB(A). The national technical standard [32] sets a very low requirement of 38 dB(A) for $D_{2m,nT,w}$, that the authors used as base for the very poor score level.

In proper decrees, the Italian regulation defines the optimal values as a function of both frequency and volume of the room [28] and the limits of 1.2 s [27, 30] for reverberation time in classrooms. However 1.2 s is a value considered too high by the scientific community [31, 33, 37], thus the higher class has been set TR=0.8 s and the sufficient class has been considered equal to the law limit.

The STI index does not have a proper limit in the national legislation, however a scale of values is proposed according to the international standard [26]. The speech intelligibility is related to the signal to noise ratio (S/N), which is the difference between the speech and background noise in a room.

A qualitative judgment is assigned to each class in addition to the numerical score in order to enhance the students' understanding.

All the scores can be summed up to obtain the Global Noise Score of each classroom, reported in Table 6.

The total values range from 6, corresponding to the simultaneous minimum score for all the parameters, to 30 when each parameter has the maximum score.

A single indicator could allow the students to compare their classroom or school with other ones. Moreover, the simple metrics is easily understandable even for young people: the highest is the "Global Noise Score", the best is the environment of the classroom.

For each classroom, the "Global Noise Score" is obtained summing up the score of all parameters. So, the best is the acoustic situation in the classroom, the highest is the Global Noise Score, ranging from 6 to 30.

3.2 Measurements protocol

Both the external and internal noise levels influence the acoustic comfort in classrooms: with high noise the student pay less attention and the teachers have to raise their voice above the background noise. A detailed analysis of both noise levels is then necessary.

No railways or airports are located in the proximity of the studied schools and the main noise source is always the road traffic. However, in Napoli also the anthropic noise from markets and public spaces strongly affects the acoustic comfort of the classrooms, whilst in Taranto also some industrial sources are close to the schools.

The external noise level is acquired through a weekly lasting measurement, with the microphone placed at 1 m from the main façade and at 4 m height [36]. The internal noise level is obtained with short-term measurements lasting 30 minute with open windows, taking the average values from two different positions: centre of the room (student average listening position) and 1 m from the windows (student worst listening position). All short measurements were performed in the afternoon, without the students. In Italy the open windows is a common condition due to the warm average climate and to a general classroom overcrowding. Then, according to the guidelines of the Tuscany Regional Environmental Agency [38], a correction factor can be applied to the internal short term noise level to evaluate the average daytime noise level inside the classroom ($L_{DAY-Int}$). The procedure assumes that the internal and external noise levels have the same time-evolution.

Furthermore, from a single long term external measurement for each school and an internal long term measurement calculated in each class, some calculations are needed to obtain the daily noise level outside ($L_{DAY-Ext}$) the classrooms that are not facing the external measurement. An attenuation term "A" is calculated between the outside measurement and the internal one close to it. This atten-

uation is considered to be the same for the outside wall, thus the external noise levels where a proper measurement were not performed have been calculated by adding A to the corresponding internal noise levels

After the characterization of the environmental noise, the façade insulation have to be tested. Indeed, the interior sound quality is due to the external sources and by the building characteristics [39, 40], therefore the standardized level difference $D_{2m,nT}$ parameter is monitored using a pink noise generated by a dodecahedron emitter. This measurement allows the evaluation of the room insulation from the external noises.

Similar measurements are carried out to evaluate the insulation between the adjacent rooms and the corridors through the R parameter.

Finally, the acoustic characteristics of the rooms are evaluated: reverberation time and STI index were measured through the MLS signal.

4 Results

4.1 Exposure to external sources:

The external noise exposure levels daytime are reported in Table 5 together with the external levels in front of each classroom.

Due to various security constraints the external noise acquisition in S5 and S6 is not performed with a long-term external monitoring station, as in the other sites. Anyway, it was possible to evaluate the time evolution of noise and the equivalent noise level during the daytime through some short-term measurements in the morning, according to [38].

In Table 5 also internal levels with opened windows are reported, together with the classrooms position.

The environment surrounding the main façade is critical for all schools such as most cases, the measured levels exceed the local regulation limits. However, internal and external values show wide variations, depending on the location of the classroom respect to the main road.

It is relevant that lessons result seriously affected by noise in the classrooms of S1, S2, S5, S6, S7 and S8 schools, when windows are open. This clearly affects the school activities and the student's wellbeing, especially during the springtime.

In Figure 2 the judgement of classrooms in terms of both external and internal levels is reported, highlighting how even when a school is in a noisy context, the class-

Table 5: Schools and classrooms exposure levels. The internal level has been measured with opened windows (average value of two positions).

School	$L_{DAY-Ext}$ (School, main façade)	Room	$L_{DAY-Ext}$ (Room) [dB(A)]	$L_{DAY-Int}$ (Room) [dB(A)]
S1	71.0	A	71.0	60.1
		B	73.5	62.6
		C	58.9	48.0
S2	60.5	D	49.4	45.0
		E	53.1	48.7
		F	60.5	56.1
S3	60.1	G	60.1	39.6
		H	60.1	43.8
		I	60.1	37.9
S4	60.6	J	42.0	23.4
		K	37.2	33.9
		L	52.2	27.1
S5	71.0	M	71.0	56.9
		N	63.3	49.2
		O	62.3	48.2
S6	67.5	P	67.5	37.5
		Q	64.4	34.4
		R	64.6	34.6
S7	62.5	S	62.5	57.5
		T	61.7	56.7
		U	63.1	58.1
S8	54.0	V	54.0	55.1
		W	54.0	55.2
		X	54.0	56.2

rooms placed in a backside position can be exposed to low noise from external main sources.

4.2 Acoustic insulation of the vertical partitions

The measured $D_{2m,nT,w}$ and R' values in all the schools are reported in Table 6.

The walls insulation of façade presents $D_{2m,nT,w}$ values below the law limits, whereas insulation between the classrooms present R'$_w$ values slightly better. R'$_w$ is higher between the rooms than between rooms and corridors.

In some school (*e.g.* S1, S4) the façade insulation values are quite different among the three classrooms. The variability in S1 is mainly due to the conditions of doors and windows fixtures that show generally very bad conditions and in some case they were even broken.

In S1, S2, S3, S4, S5, S6 partition insulation values are quite different in the three classrooms and this variability is mainly due to different construction technology: in some

case partition is a load-bearing, otherwise is a false partition walls.

The rooms with no adjacent classrooms are less disturbed by adjacent lessons but at the same time they suffer more the noise coming from the corridor and stairs.

In Figure 3 judgement of classrooms in terms of external and internal insulations are reported.

4.3 Acoustical characteristics of classrooms

The parameters used in the study to describe the acoustical quality of classroom are the reverberation time (RT) and the intelligibility index STI [41, 42]. Table 7 reports the measured values.

Most of the classrooms have very high reverberation time values (>1.50 s) due to the big volume, with height greater than 4 meters. Some rooms (J, L, P in Table 5) present better values thanks to a false porous ceiling installed.

Table 6: Vertical partitions insulation.

School	Room	$D_{2m,nT,w}$ [dB]	R'$_w$ [dB]
S1	A	16.0	34.0
	B	15.0	38.0
	C	31.0	46.0
S2	D	22.0	31.0
	E	20.0	37.0
	F	27.0	44.0
S3	G	30.0	49.0
	H	29.0	27.0
	I	31.0	43.0
S4	J	35.0	43.0
	K	43.0	21.0
	L	25.0	42.0
S5	M	29.0	49.0
	N	32.0	27.0
	O	28.0	43.0
S6	P	26.0	30.0
	Q	33.0	43.0
	R	33.0	46.0
S7	S	24.0	42.0
	T	24.0	42.0
	U	28.0	42.0
S8	V	23.0	24.0
	W	23.0	24.0
	X	22.0	25.0

Table 7: Acoustical characteristics of the classrooms: reverberation time and STI index. (*) a false ceiling was installed.

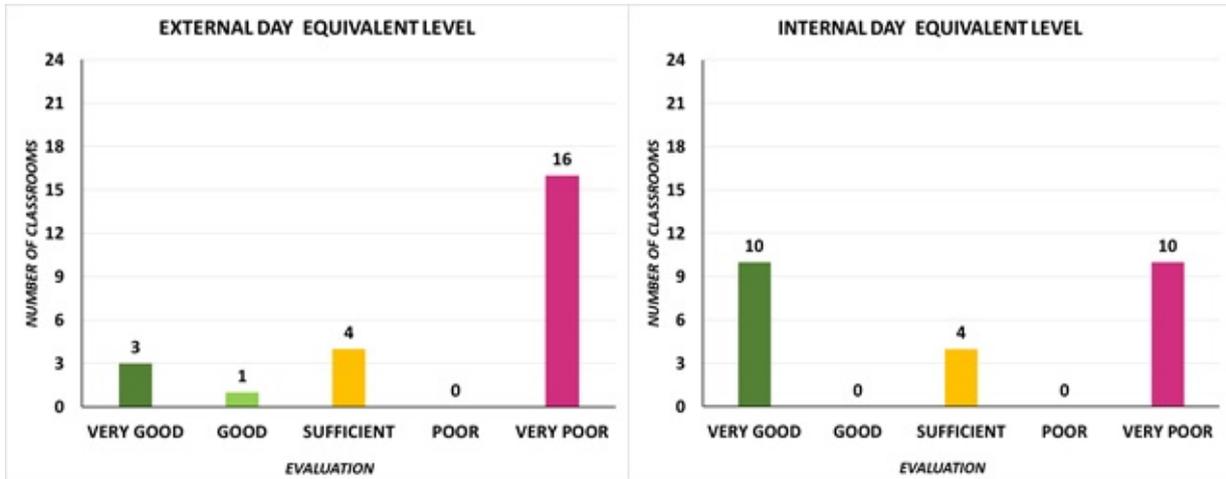| School	Room	RT [s]	STI
S1	A	2.45	0.43
	B	1.45	0.49
	C	1.77	0.51
S2	D	2.03	0.49
	E	1.78	0.47
	F	2.32	0.45
S3	G	1.45	0.58
	H	1.34	0.53
	I	1.60	0.52
S4	J*	0.92	0.66
	K	1.58	0.52
	L*	0.88	0.68
S5	M	2.36	0.45
	N	2.28	0.49
	O	2.05	0.50
S6	P*	1.27	0.62
	Q	2.40	0.43
	R	2.88	0.41
S7	S	2.07	0.48
	T	1.80	0.49
	U	2.84	0.43
S8	V	2.37	0.46
	W	1.89	0.46
	X	1.95	0.48

Figure 2: Day equivalent level outside and inside the rooms.
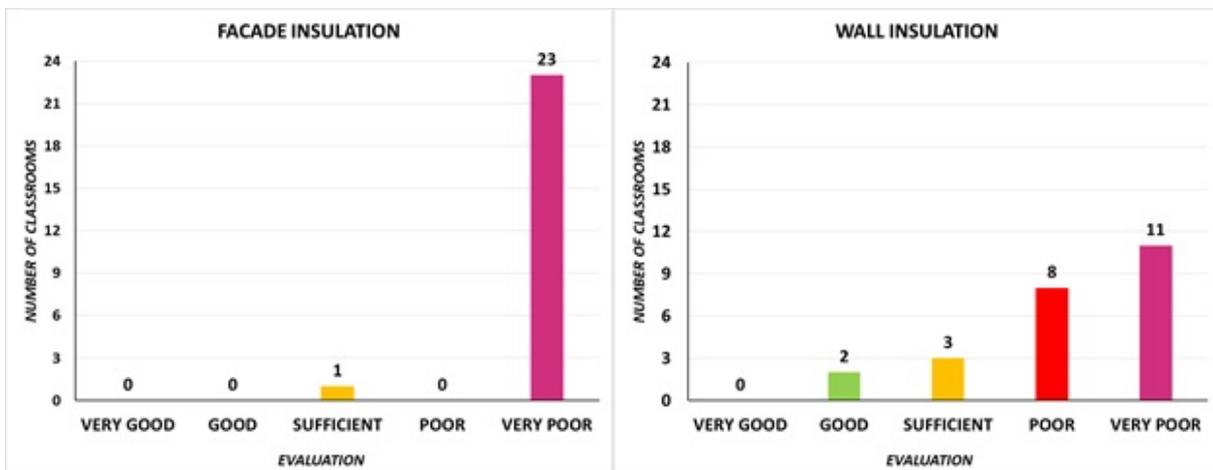

Figure 3: Insulation of the vertical partitions.

In Figure 4 judgements in terms of architectural acoustical parameters based on values in Table 5 without taking into account students' presence, are reported. However, people inside the room significantly affect values and further analyses are presented in the following.

4.4 Global noise score

In Figure 5, all the "Global Noise Scores" of the classrooms involved in the project are reported. A chromatic scale is used in order to quickly evaluate the acoustical condition of the classroom.

As foreseen, the most polluted classrooms are placed on the main road (Table 2). As an example, the rating summary for S2, where classroom F is the only one exposed on the main street, is reported in Table 7.

The use of these scores could help the students to identify the problems in their school and to encourage the local administrations to solve them. The project also intends to stimulate students to take actions whenever their own behaviour could improve their environment. Therefore, specific advices could be given after the project to improve the specific noise problems.

4.5 Simulation of classrooms' RT with "full-room" condition

The acoustical performance of a room, described by means of the RT and STI index, depends also on the absorption coefficient of all surfaces. Presence of people, operating like a diffusive and absorptive media, influences the room absorption coefficient. Thus, even though the Italian regulation takes into account only the acoustic parameters
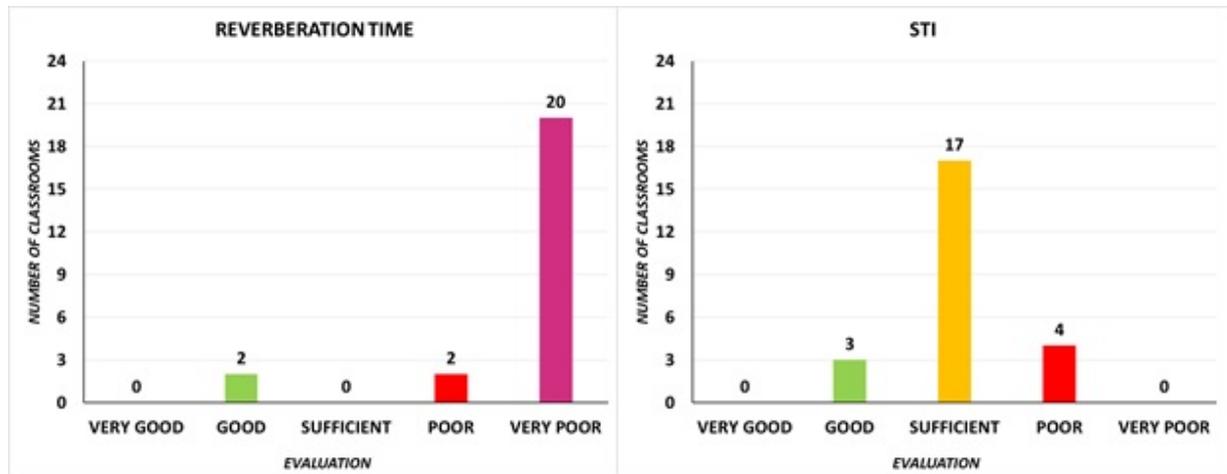
Figure 4: Reverberation time and STI.

Table 8: Scores (S) and evaluation for Valdarno schools.

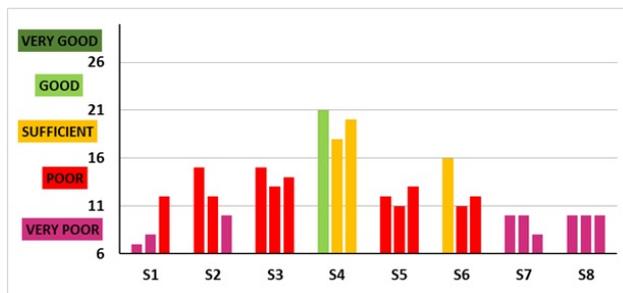| Room	$L_{DAY-Ext}$ [dB(A)]		$L_{DAY-Int}$ [dB(A)]		$D_{2m,nT,w}$ [dB]		R'_w [dB]		RT [s]		STI		Global Noise	Evaluation
	Value [dB(A)]	S	Value [dB(A)]	S	Value [dB]	S	Value [dB]	S	Value [s]	S	Value	S	Score	
D	49.4	5	45.0	4	22.0	1	31.0	1	2.03	1	0.49	3	**15**	Poor
E	53.1	3	48.7	3	20.0	1	37.0	1	1.78	1	0.47	3	**12**	Poor
F	60.5	1	56.1	1	27.0	1	44.0	3	2.32	1	0.45	3	**10**	Very Poor

Figure 5: Global Noise Score for the classrooms of GIOCONDA project.

computed in empty-room condition, the full-room condition has been also analysed in this project, as a pilot study using a data modelling, based on the acoustic absorption areas and coefficients reported in Table 9.

The presence of students does not exercise any influence on the measured noise level outside and inside the room, whilst it strongly influences the Reverberation Time [43] and consequently the STI index and to a lesser extent the $D_{2m,nT,w}$ and R'$_w$. Thus, the full-room condition has been simulated for the S2.

First of all, the acoustic absorption area in case of empty-room condition has been estimated from Sabine formula using the measured values of volume and Reverberation Time. Then, the full-room acoustic absorption area is estimated summing people absorption, using values reported in Table 9 and considering one student per each desk in the classroom. The new reverberation time and all other indexes have been obtained applying the Sabine formula, as reported in Table 10.

The acoustical comfort is better in the simulated full-room condition, thanks to the absorption due to the presence of students. The RT decreases of about 35% and STI increases of nearly the 15%, without considering noise due from students inside classroom. This analysis shows that before planning actions for improving the acoustical comfort in a school, it could be worthy to evaluate also the full-room condition, in order to obtain a realistic priority order among classrooms.

4.6 Comments and future developments

The main source of noise around the schools under study is the road traffic. According to the perceptual evaluation,

Table 9: Acoustic absorption areas and coefficients for people in the school.

Person	Area	Acoustic absorption coefficient					
	[m^2/person]	*125 Hz*	*250 Hz*	*500 Hz*	*1000 Hz*	*2000 Hz*	*4000 Hz*
MS and HS student seating	1.5	0.08	0.17	0.36	0.60	0.77	0.91
Teacher standing	3.0	0.12	0.19	0.42	0.66	0.86	0.94

Table 10: Comparison between empty classroom condition (measured parameters) and full-occupied classroom condition (simulated parameters).

School	Room	No. desks	$D_{2m,nT,w}$ [dB(A)]		R'_w [dB(A)]		RT [s]		STI	
			empty	full	empty	full	empty	full	empty	full
S2	D	26	22.0	20.2	31.0	29.2	2.03	1,31	0.49	0.56
	E	32	20.0	18.1	37.0	35.1	1.78	1.13	0.47	0.55
	F	30	27.0	25.2	44.0	42.2	2.32	1.50	0.45	0.52

Figure 6: Details of single parameters evaluation.

the perception of road traffic noise by the students is confirmed.

The insulation and absorption are critical in all the schools: the main observed problems are the low façade insulation and the high reverberation time.

As a consequence the $D_{2m,nT,w}$ resulted the worst parameter by far, being very poor in 24 classrooms out of the 25. The window fixtures, which always present a bad maintenance or are lacking of insulated glazing, are the main cause of low façade insulation in most of the cases. Very high reverberation is the second main problem observed.

A reverberation time higher than 1.5 s is spotted in 80% of classrooms, whilst the suitable values for correct speech intelligibility are close to 1.0, caused by the big volumes and the lack of false ceiling in several classrooms. Only 3 out of 24 classrooms have a false ceiling installed.

Unfortunately, most of the examined schools show bad results for several parameters, as reported in Figure 6. This is consistent with many other studies around the world, showing that school characteristics are often below requirements.

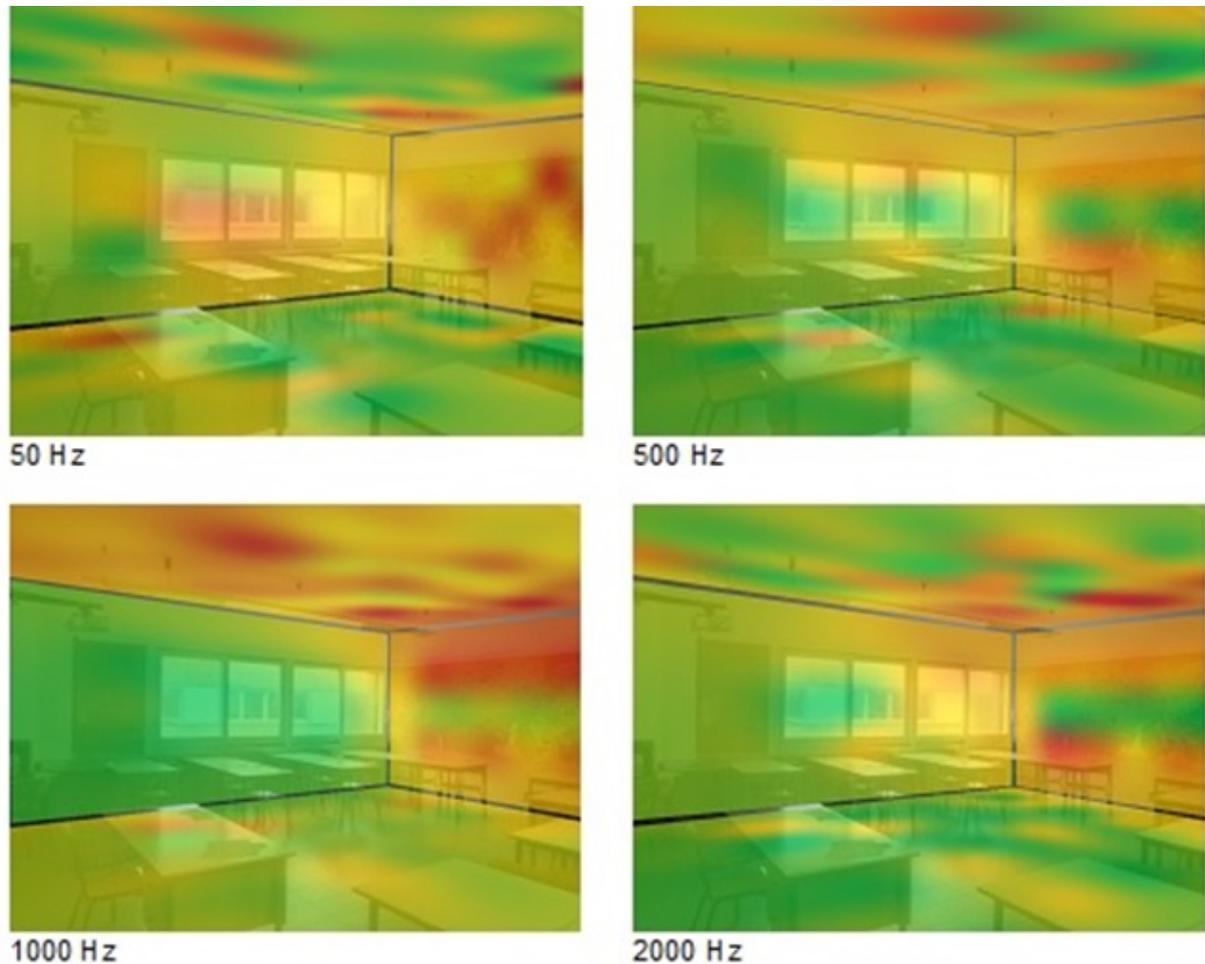GIOCONDA is carried out combining two monitoring systems: one based on the collection of data on air and

Figure 7: Solid Noise vibration mapping results for 1/3 octave band analysis in the F classroom of school S2. The scale is different for each frequency band: absolute values are higher at lower frequencies.

noise pollution in GIOCONDA's sites, the other based on risk perception of teenagers and their willingness-to-pay (WTP), collected with questionnaires. The environmental monitoring of both air pollution and noise, indoor and outdoor, provided a noise characterization of each school. The students produced "conceptual maps", "trees of problems and solutions", completed a questionnaire on risk perception, produced recommendations, they did interviews and peer-to-peer discussions.

The questionnaire on risk perception, which was part of a larger questionnaire, was modelled on the psychometric paradigm [44], assessing several important qualitative characteristics of the risks associated with environmental pollutants.

The specific results of risk perception questionnaires regarding noise will be object of a further work when all questionnaire results will be available. Anyway, preliminary results show some correspondence between noise measured and noise perceived by students.

Then, the results of acoustic measurements will be presented to the students in order to improve the awareness of pollution and the perception of health risks. These outcomes could encourage the use of the GIOCONDA platform to share environmental data, opinions and ideas, in order to improve the future environment.

5 Solid noise method

The general poor conditions found for classrooms' interior with windows and doors badly maintained, or false walls with holes, lead to the need of identifying which are the most critical elements. A new device developed by Noise-lab [45] has been tested in order to evaluate the propagation of vibrations in a classroom's surface due to a noise source in an adjacent room. Noise is transmitted to the receiver room by various architectonic elements, thus a mea-

sure of their vibration allows an assessment of their contribution to the overall noise transmission [46].

This method consists in placing an omnidirectional noise source in an adjacent classroom and measuring the vibrations of each surface in the receiver room with an accelerometer. A measuring points' grid has been established to evaluate every possible room elements and 6 seconds measurements were taken on each chosen point. Particular care has been given to characterize every possible architectural elements of the room, whilst keeping the number of points manageable in a reasonable time span.

A frequency analysis has been performed on each measurement point, obtaining 1/3 octave band levels for the acceleration signals. For each frequency the band maximum, minimum and average values have been computed and used to obtain a colour mapping. This mapping method aims to obtain a graphical overview of the measurement campaign that may allow the identification of the weak points in the noise propagation in a visual way understandable also by the inexpert students. Each measurement point has been then associated to a colour value and the overall result have been superimposed to a room picture. Figure 7 shows results for 50 Hz, 500 Hz, 1000 Hz and 2000 Hz centre band value. Red areas are associated to higher signal and green to lower values.

The noise source has been located in the adjacent room, separated by the wall on the right of Figure 7.

The preliminary results of this innovative method highlight that different frequencies show different behaviour of the room elements. The windows, as an example, contribute significantly to the noise transmission only at low frequencies, while at the higher ones the ceiling seems to be the strongest source. The partition wall between source and receiver room shows an inhomogeneous pattern of vibration above a threshold noise frequency. The central part of the wall is less vibrating due to a large corkboard on its surface, effectively acting as a sound absorber.

This kind of analysis appears to be very useful to visualize the critical path of sound propagation, allowing to directly act on the specific issues in the noise mitigation phase.

6 Conclusions

Noise in schools is a serious issue for the young vulnerable children and teachers, thus a good environment for learning and working is mandatory for improving the education quality. However, the learning environment in a school is the complex result of relationships between acoustical and psycho-acoustical, such as the internal and external noise as well as the attitudes of the schools' users. Therefore, in order to improve the schools' environment and facilitate a better learning in a wider perspective, the identification of problems by means of the only physical traditional approach could be not enough. At this purpose, the GIOCONDA project is a pilot study born to create a useful tool for schools and local authorities to highlight, discuss and solve the noise issues, and above all to raise in the citizens the awareness of improving the school environment quality. The set-up of a web platform for sharing data and ideas is a practical goal of the project, to connect data of air and noise pollution in schools with the students' pollution awareness, contributing to understand the gap between perception and objective pollution.

This paper showed the results of the noise measurements campaigns performed to acoustically evaluate several classrooms in the schools involved. A new index, named "Global Noise Score", has been proposed in order to better understand the acoustic performance of a classroom and to allow their comparison. The index is obtained by summing up each single score correspondent to a set of parameters: internal and external daily noise levels, façade and wall insulations, reverberation time and speech intelligibility (STI).

The results showed that most of the parameters do not comply with the law requirements for schools. The computed Global Noise Score confirmed how noise in schools is a serious issue that should not be neglected by local administrations. Indeed, only 4 classrooms over the 24 analysed report a Global Noise Score at least sufficient.

The most serious issue related to the learning process is confirmed to be the high reverberation time, thus further analyses on it are necessary to find a solution that really comply with the structural problems of each classrooms. The solid noise method has been found to absolve this purpose. Indeed, when the problem are localised, it came out that easy and low-cost actions could be often more efficient than costly mitigation on the external noise sources. Moreover, in some cases the greatest part of noise pollution in classrooms is due to internal sources (machineries, students). Thus, a simple good maintenance of the windows fixture and doors could improve the insulation, while the reverberation time could be reduced increasing the amount of acoustic absorption in the rooms by means of false ceilings and wall coverings.

The data provided by this study will be the first contribute to the GIOCANDA web platform and the Global Noise Score presented can be extended to other schools

contributing to spread the awareness of environmental health issues.

References

[1] M. Basner, W. Babish , A. Davis, M. Brinck, C. Clark, S. Janssen, S. Stansfeld, Auditory and non-auditory effects of noise on health, The Lancet volume 383, issue 9925, pages 1325–1332, 2014.

[2] B. M. Shields, J. E. Dockrell, The effects of environmental and classroom noise on the academic attainments of primary school children, Acoustical Society of America, 2008.

[3] B. Shield, J. Dockrell, The effects of noise on children at school: a review, Building Acoustics, volume 10 n.2 pages 97–116, 2003.

[4] M. Klatte, J. Hellbruck, J. Seidel, P. Leistner, Effects of Classroom Acoustics on Performance and Well-Being in Elementary School Children: A Field Study, Environmental behavior Sage pubblications, 2010.

[5] Neuman, Arlene, Wroblewski, Marcin, Hajicek, Joshua, Rubinsteiun, Adrienne, Combined effets noise and reverberation on speech recognition performance of normal-hearing children and adults, Ear & Hearing volume 31 pp 336–344, 2010.

[6] B. M. Shield, J. E. Dockrell, The effects of noise on children at school: a review, J. building acoustics 10, 97–103, 2003.

[7] M. Wroblrewski, D. E. Lewis, D. L. Valentine, P. G. Stelmachowicz, Effects of reverberation on speech recognition in stationary and modulated noise by school-aged children and young adults, Ear Hear 33, pages 731–744, 2012.

[8] J. Kristiansen, R. Persson, S. P. Lund, H. Shibuya, P. M. Nielsen, Effects of classroom acoustic and self-reported noise exposure on teacher's well-being, Environmental behavior Sage pubblications, 2013.

[9] D. Augustynska, A. Kaczmarska, W. Mikulski, J. Radosz, Assessment of teachers' exposure to noise in selected primary schools, Archives of Acoustics, volume 35, issue 4, 2010.

[10] GIOCONDA (i giovani contano nelle decisioni su ambiente e salute) Project, from http://gioconda.ifc.cnr.it/.

[11] B. Berglund, T. Lindvall, T. H. Schwela, Guidelines for Community Noise. World Health Organization. 1999. Retrieved 03/02/2015 from http://www.who.int/docstore/peh/noise/guidelines2.html.

[12] D. Francois, M. Vallet, Noise in Schools, World Health Organisation—Regional Office for Europe Pamphlet no.38. WHO; Germany, 2001.

[13] Aarhus Convention: UNECE Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters, 25 June 1998.

[14] T. Istamto, D. Houthuijs, E. Lebret, Willingness to pay to avoid health risks from road-traffic-related air pollution and noise across five countries, Science of The Total Environment, Volumes 497–498, 1 November 2014, Pages 420–429, ISSN 0048-9697, http://dx.doi.org/10.1016/j.scitotenv.2014.07.110, 2014.

[15] P. Woolner and E. Hall, Noise in Schools: a holistic Approach to the issue, International journal of environmental research and public health, 7, 3255–3269, 2010.

[16] E. Ascari, M. Chetoni, L. Fredianelli, F. Bianco, G. Licitra, L. Cori, Assessment of the noise quality of school rooms within the GIOCONDA project, Proceedings of ICSV22, Florence 2015.

[17] J. E. Dockrell, B. Shield, Children's perceptions of their acoustic environment at school and home. Journal of the acoustical society of America, pages 2964–2973, 2004.

[18] A. Astolfi, F. Pellerey, Subjective and objective assessment of acoustical and overall environmental quality in secondary school classrooms, The Journal of the Acoustical Society of America, 123, 163–173, 2008, from DOI: http://dx.doi.org/10.1121/1.2816563.

[19] P. H. T. Zannin, C. R. Marcon, Objective and subjective evaluation of the acoustic comfort in classrooms, Applied Ergonomics, 2007.

[20] L. T. Silva, I. S. Oliveira, J. F. Silva, The impact of urban noise on primary schools. Perceptive evaluation and objective assessment, Applied Acoustics 2016, from https://www.researchgate.net/publication/289500079_The_impact_of_urban_noise_on_primary_schools_Perceptive_evaluation_and_objective_assessment.

[21] C. Clark, R. Martin, E. Van Kempen, T. Alfred, J. Head, H. W. Davis, M.M. Hines, I.L. Barrio, M. Matheson, S.A.Stansfeld, Exposure-effect relations between aircraft and road traffic noise exposure at school and reading comprehension, American Journal of Epidemiology, volume 163, issue 1, pages 27–37, 2006.

[22] S. A. Stansfeld, B. Burglund, C. Clark, I. Lopez-Barrio, P. Fisher, E. Ohrstrom, M. M. Haines, J. Head, S. Hygge, I Van Kamp, B. F. Berry, Aircraft and road traffic noise and children's cognition and health: a cross-national study, The Lancet, volume 365, issue 9475, pages 1942–1949, 2005.

[23] UNI EN ISO 16283-1:2014 Acoustics – Field Measurement Of Sound Insulation In Buildings And Of Building Elements, 2014.

[24] ISO 717-1:2013 Acoustics – Rating of sound insulation in buildings and of building elements – Part 1: Airborne sound insulation, 2013.

[25] ISO 3382-2:2008 Acoustics – Measurement of room acoustic parameters – Part 2: Reverberation time in ordinary rooms, 2008.

[26] IEC 60268-16 Third edition 2003-05 Sound system equipment – Part 16: Objective rating of speech intelligibility by speech transmission index, 2003.

[27] Department circular n. 3150, Italy 22 may 1967.

[28] D.M. 18 december 1975, Italy – Norme tecniche aggiornate relative all'edilizia scolastica, ivi compresi gli indici di funzionalità didattica, edilizia ed urbanistica, 1975.

[29] D.P.C.M. 14 november 1997 Italy – Determinazione dei valori limite delle sorgenti sonore, 1997.

[30] D.P.C.M. 5 decembe 1997, Italy – Determinazione dei requisiti acustici passivi degli edifici, 1997.

[31] ANSI S12.60-2002 Acoustical Performance Criteria Design Requirements and Guidelines for Schools, 2002.

[32] UNI 11367-2010 Italy, Classificazione acustica delle unità immobiliari, procedure di valutazione e verifica in opera, 2010.

[33] UNI 11532-2014 Italy, Caratteristiche acustiche degli ambienti confinati, 2014.

[34] Building Bulletin 93: Acoustic Design of Schools. Department for Education and Skills, Stationery Office; UK, 2003.

[35] A. Astolfi, M. Giovannini, Acustica delle aule scolastiche, requisiti prestazionali, soluzioni di progetto, verifiche e calcolo in opera, Quaderni Rockwool, Retrieved 03/02/2015 from

http://download.rockwool.it/media/75055/acustica%20delle%20aule%20scolastiche.pdf.

[36] D.M. 16 marzo 1998, Italy, Tecniche di Rilevamento e misurazione dell'inquinamento acustico, 1998.

[37] J. Kristiansen, S. P. Lund, P. M. Nielsen, R. Persson, H. Shibuya, Determinants of noise annoyance in teachers from schools with different classroom reverberation times, Journal of Environmental Psychology, Volume 31, Issue 4, December 2011, Pages 383–392, ISSN 0272-4944.

[38] Piani Comunali di Classificazione Acustica - Linee guida tecniche per la predisposizione dei piani, ARPAT 2004. Retrieved 03/02/2015 from http://www.arpat.toscana.it/documentazione/report/ru_documentazione_linee_guida_classificazione_acustica.zip.

[39] M. Chetoni, M. Palazzuoli, Il benessere acustico nelle aule scolastiche: dalla progettazione al risanamento, Galileo, Pisa Association of engineers, n.2 2010.

[40] P. Henrique T. Zannin, D. Petri, Z. Zwirtes, Evaluation of the acoustic performance of classrooms in public schools, Applied Acoustics, Volume 70, Issue 4, April 2009, Pages 626–635, ISSN 0003-682X.

[41] Ha Knecht, PB Nelson, GM Whitelaw, LL Feth, Background noise levels and reverberation times in unoccupied classrooms: predictions and measurements. Am J Audiol, 2010.

[42] P. W. Barnett, Overview of speech intelligibility, Proceedings I.O.A Vol 21 Part 5, 1999, from http://dx.doi.org/10.1016/j.apacoust.2008.06.007.

[43] Classroom Acoustics I, publication of the technical committee on architectural acoustics of the acoustical society of America, 2003, from http://acousticalsociety.org/sites/default/files/docs/classroom_acoutics_1.pdf, http://dx.doi.org/10.1016/j.jenvp.2011.08.005.

[44] B. Fischhoff, P. Slovic, S. Lichtenstein, S. Read, B. Combs, How safe is safe enough? A psychometric study of attitudes towards technological risks and benefit, Policy Sciences 9, pp 127–152, 1978.

[45] www.noiselab.net.

[46] A. Aniorte, S. Domingo, Reticular noise method for acoustic insulation engineering, 39th International Congress on Noise Control Engineering, Internoise 2010.