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3pSA5. Sound and noise in high school gymnasiums

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The goal of this research was to characterize the interior acoustics of high school sports facilities using objective parameters. In situ measurements were done in 68 school gymnasiums in Portugal (Volume from 450 to 16,190 m3 with a median of 4,720 m3) regarding LAeqBN (background noise without gym classes), LAeqPE (ongoing Physical Education classes), RT, and RASTI. The results for LAeqBN were from 30 to 59 dB with a median of 42 dB. For the LAeqPE were found values from 68 to 90 dB with a median of 80 dB. For the RT(500/1k/2k), room values from 2.5 to 8.1 s with a median of 4.8 s, were measured. The room average RASTI values were from 0.26 to 0.54 with a median of 0.34. These sports rooms proved to be highly reverberant, almost without sound absorbing materials, which might be harmful, especially for the PE teachers. The subjective perception of the teachers was analyzed through questionnaires where it was verified that they feel most discomfort when it comes to noise conditions. This was supported by the objective results obtained. A multicriteria method to assess the overall acoustic quality of school gymnasiums is presented. Ideal values for those acoustic parameters are presented.

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1 - INTRODUCTION

Physical education (PE) teachers spend their entire professional life in a particular type of school environment that is acoustically challenged. The main objective of this work is to characterize the interior acoustics of high schools sports facilities using objective acoustic parameters by in situ measurements. A secondary goal is to assess the subjective perceived quality of those spaces by PE teachers using questionnaires [1].
This study also formulates an "acoustical" overall classification for high school gymnasiums regarding their aptitude and acoustic quality.

2 - THE SAMPLE

The sample used was a set of 68 sports facilities in 50 high schools in the Portuguese coast-central coast region of Aveiro (Table 1 and Figures 1 to 9). Some schools have two gymnasiums of different dimensions. This sample is characterized by the architectonic parameters: Length (m), Width (m), Average height (m), Area (m^2), and Volume (m^3) as summarized in Table 2.

Figure 1 - Map of the sample used (50 schools) within the Aveiro district (coast-central Portugal) [1].

Table 2 - Statistical summary of the dimensions of the 68 gymnasiums tested.

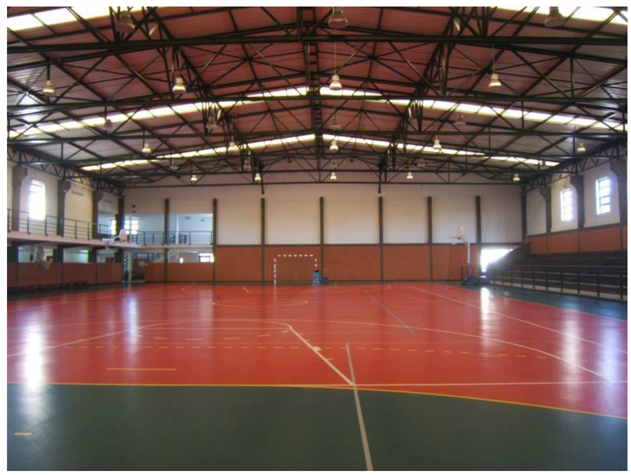
Parameter	Length (m)	Width (m)	Avg. Height (m)	Area (m^2)	Volume (m^3)
Minimum	10.2	9.3	4.3	98	450
Median	30.5	18.1	8.0	553	4720
Mean	30.8	19.7	7.5	664	6290
Maximum	53.2	32.5	12.3	1445	16190
St. deviation	12.5	5.6	2.0	413	4755

Table 1 – Sample of schools tested (68 gymnasiums in 50 schools) in Portugal [1].

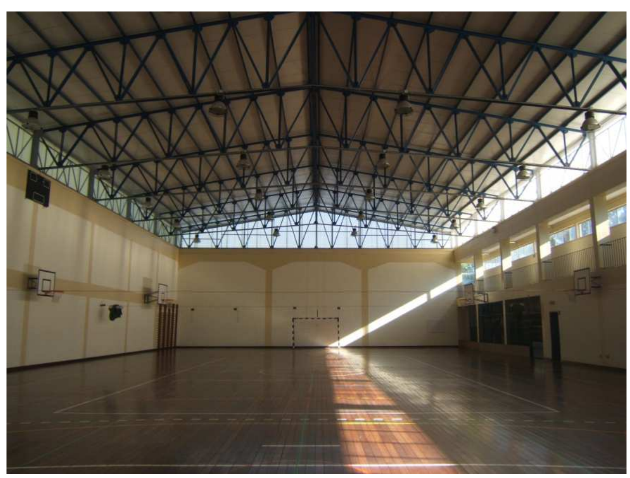
	School	Gym geometry (m)	
1	EB 2,3 Aires Barbosa, Esgueira	30x18x8	16x14x5
2	ES/3 Jaime Magalhães Lima, Esgueira	44x27x9	-
3	ES/3 Dr. Mário Sacramento, Glória	-	20x12x6
4	ES Homem Cristo, Glória	-	23x10x5
5	EB 2,3 João Afonso de Aveiro	40x20x9	-
6	EB 2,3 São Bernardo, Aveiro	30x18x8	16x14x5
7	EB 2,3 Castro Matoso, Oliveirinha	30x18x8	16x14x5
8	EB I Eixo	30x18x8	16x14x5
9	EB 2,3 Aradas	45x27x9	16x14x5
10	EB 2,3 Cacia	30x18x8	16x14x5
11	ES/3 Dr. João Celestino Gomes	40x20x9	-
12	EB 2,3 Ílhavo	27x21x9	-
13	EB 2,3 Gafanha da Encarnação	48x23x12	-
14	EB 2,3 Gafanha da Nazaré	50x29x10	-
15	ES/3 Gafanha da Nazaré	44x27x9	-
16	EB 2,3 + ES/3 de Vagos	49x27x12	14x9x4
17	EB 2 Albergaria-a-Velha	30x18x8	16x14x5
18	ES/3 Albergaria-a-Velha	40x20x9	-
19	EB 2,3 Branca	53x24x10	10x10x5
20	EB I São João de Loure	30x18x8	16x14x5
21	ES/3 Estarreja, Beduíno	44x27x9	-
22	EB 2,3 Padre Donaciano de Freire	30x18x8	16x14x5
23	EB 2,3 Dr. Egas Moniz, Avanca	45x26x11	-
24	EBI, JI Pardilhó	30x18x8	16x14x5
25	EB 2,3 Padre António Morais da Fonseca, Murtosa	45x27x9	16x14x5
26	EBI/JI Torreira	45x27x9	16x14x5
27	EB 2,3 Fernando Caldeira, Águeda	40x20x9	-
28	ES/3 Adolfo Portel, Águeda	40x20x9	-
29	ES Marques de Castilho, Águeda	-	22x14x7
30	EB 2,3 Aguada de Cima	43x23x10	-
31	EB 2,3 Fermentelos	45x27x9	16x14x5
32	EB 2,3 Valongo do Vouga	30x18x8	16x14x5
33	EB 2,3 + ES/3 Sever do Vouga	45x26x10	-
34	ES Mealhada	-	21x17x7
35	EB 2,3 Pampilhosa do Botão	50x28x8	-
36	EB 2,3 Oliveira do Bairro	40x20x9	-
37	ES Oliveira do Bairro	44x27x10	-
38	EB 2,3 Dr. Fernando Peixinho, Oiã	-	14x14x6
39	EB 2,3 António Dias Simões, Ovar	40x20x9	-
40	EB 2,3 Florbela Espanca, Esmoriz	40x20x9	-
41	ES Júlio Dinis, Ovar	44x27x9	-
42	EB 2,3 Maceda	30x18x8	16x14x5
43	EB 2,3 Mons. Miguel Oliveira, Válega	30x18x8	16x14x5
44	ES Esmoriz	44x27x9	-
45	EBI S. Vicente de Pereira de Jusã	30x18x8	16x14x5
46	EB 2,3 Anadia	40x20x9	-
47	ES Anadia	25x22x6	18x22x5
48	EB 2,3 Vilarinho do Bairro	44x22x8	-

Figures 2 and 3 – Sports facilities n. 3 and n 4.

Figures 4 and 5 - Sports facilities n. 8 and n. 9.

Figures 6 and 7 - Sports facilities n. 31 and n. 40.

Figures 8 and 9 - Sports facilities n. 42 and n. 44.

3 - METHOD

The acoustic parameters measured in situ were:

- L_{Aeq}BN, Sound pressure levels of the background noise, without Physical Education (PE) classes or any other activity or occupation. One measuring position was used (during five minutes) in each of the 68 gyms tested (Figure 10). Every measurement was made at a height of 1.3 m.
- L_{Aeq}PE, Sound pressure levels with ongoing PE classes. One or two measuring positions were used (during five minutes) in the 68 gyms tested (Figure 11) and, in each, during five minutes. Every measurement was made at a height of approximately 1.3 m.
- Reverberation Time (s) from 125 to 4k Hz (octave bands) using EN ISO 3382 [2]. Three measuring positions (Figure 12) were used in each of the 14 gyms tested. In each position two readings were done changing 30º the microphone angle. The final result at each position was the RT arithmetic average. Every measurement was made at a height of approximately 1.3 m.
- RASTI (Rapid Speech Transmission Index) was measured in 8 or 5 positions according with the gym size (Figures 13 and 14) and, in each, with three readings of 32 s each (sound source at 1.5 m high).

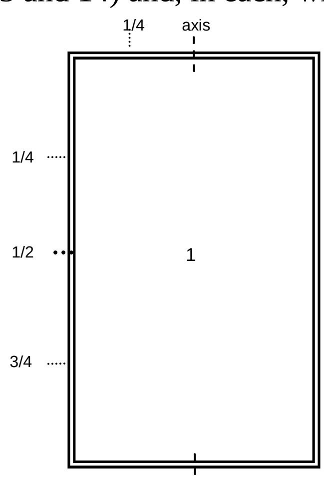


Figure 10 - LAeq_BN (Background Noise, no occupation) measuring positions.

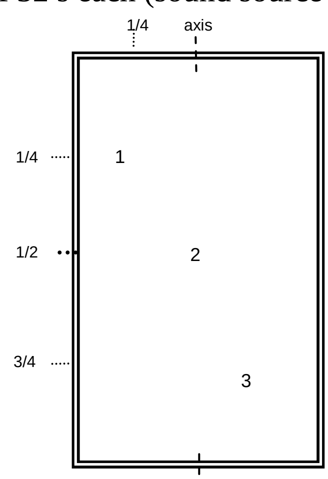


Figure 11 – LAeq_PE (during PE classes) measuring positions - large gyms (in smaller gyms position 3 was not measured).

The equipment used was a sound level meter B&K 2260, a sound source B&K 4224 and a RASTI set B&K 4225/4419.

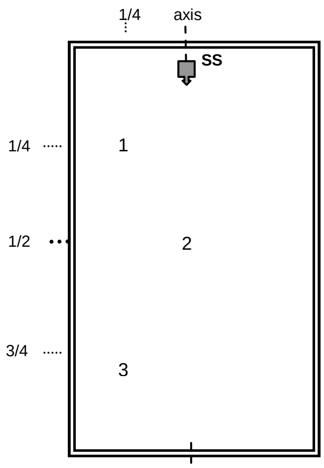


Figure 12 - RT measuring positions (*SS* - sound source).

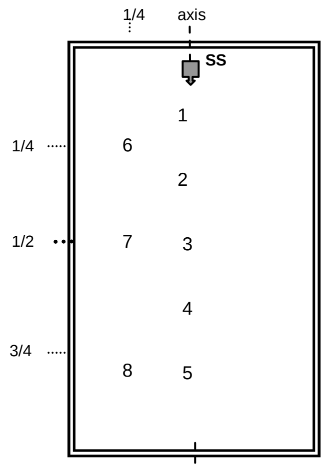


Figure 13 - RASTI measuring positions (*SS* - sound source) - larger gyms.

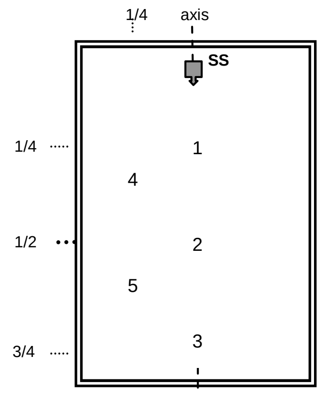
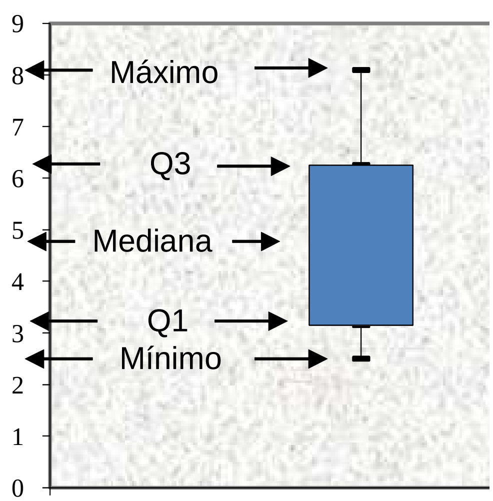


Figure 14 - RASTI measuring positions (*SS* - sound source) - smaller gyms.



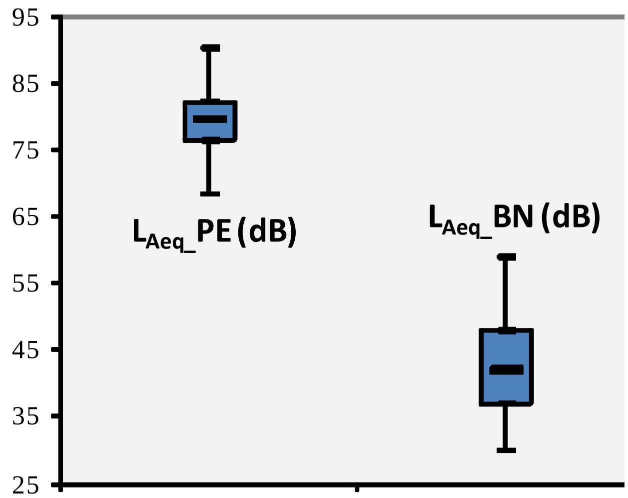


Figure 15(left) - Typical box and whiskers plot.
Figure 16 (right) - Box plots of the sample description (68 rooms) for the parameters LAeq_PE (leftt) and LAeq_BN (right).

4 - RESULTS

4.1 - Dispersion plots

In the analyses diagrams of data dispersion are used (box and whiskers plots). A typical example is show in Figure 15. Each diagram shows the maximum and minimum values and the box contains the central 50% of the distribution, from the lower to the upper quartiles (Q1, 25% and Q3, 75%). The median is marked by a horizontal line within the box.

4.2 - Sound levels, Reverberation Time and RASTI

Figure 16 presents the dispersion of the results regarding the sound levels (Background noise and with PE classes) in the 68 rooms tested. Table 3 displays the main statistical analyses results.
It was show that about 40% of the rooms present a L_{Aeq_PE} larger than the 80 dB that is usually seen as the borderline for a totally safe working environment for a typical 8 hour-day-work load (as ruled by the European Union Directive 2003/10/CE [3] and it is law in the 28 EU countries).
Almost 10% of the rooms showed a L_{Aeq_PE} above 85 dB, a nearly critical value for a daily standard workplace.

Table 3 - Statistical summary for the parameters L_{Aeq}_PE (during PE classes) and L_{Aeq}_BN (background noise, no activity) (68 rooms). P10, P90 - percentile of the 10% and 90% values.

L_{Aeq} (dB)	Minimum	P10	Mean	Median	P90	Maximum	St. error
BN	30.0	34.0	42.4	42.0	50.3	59.0	6.7
PE classes	68.4	74.7	79.6	79.6	84.6	90.2	4.3
ΔL (=L_{PE}-L_{BN})	38.4	40.7	37.2	37.6	34.3	31.2	-

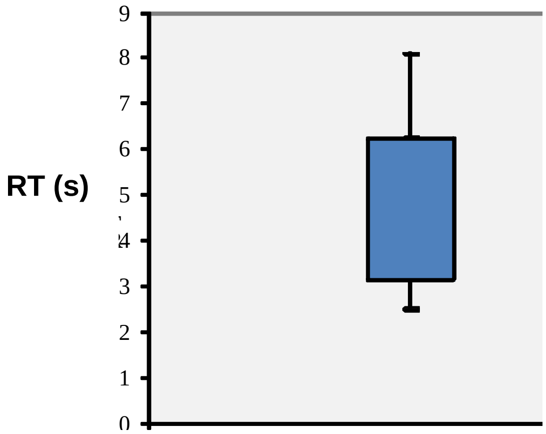
Table 4 - Average (500/1k/2k Hz) Reverberation Time values measured (14 rooms) and the accordance with the 2008 Portuguese legislation [4].

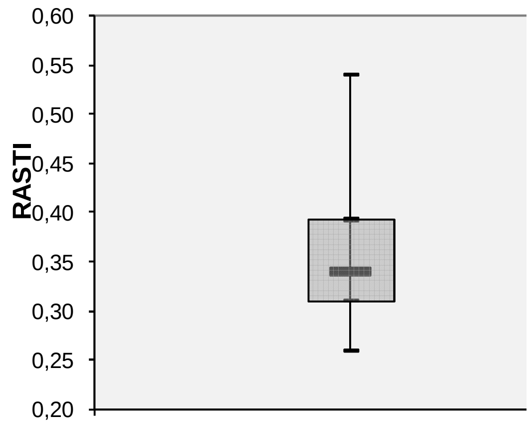
Gym n.	Volume (m^3)	RT (s) Avg. 500, 1k, 2k Hz	Max. RT (s) by 2008 PT legislation	Accordance with 2008 PT legislation
2	11812	6.3	3.4	No
3	8391	4.2	3.0	No
6	4694	5.1	2.5	No
7	14058	6.4	3.6	No
23	12396	8.1	3.5	No
35	8227	5.9	3.0	No
39	11912	7.1	3.4	No
40	5778	6.1	2.7	No
45	1848	4.4	1.8	No
46	1227	2.6	1.6	No
49	1486	2.6	1.7	No
50	1458	2.5	1.7	No
58	1550	3.3	1.7	No
67	2338	3.1	2.0	No
Average	6227	4.8	2.5	-
St. Dev.	4808	1.9	0.8	-

Table 4 shows the Reverberation Time results for the 14 rooms tested (also seen in Figure 17) and Table 5 displays an overall statistical summary. It is seen that those RT values are well above the Portuguese legislation for school gyms ($T_{[500,\ 1k,\ 2k]} \leq 0{,}15*V^{1/3}$, V volume, m^3 [4]). Many authors and sources indicate a maximum RT between 1.0 and 2.2 s [5 to 13].
Table 5 also shows the RASTI overall statistical summary of results for the 68 rooms tested (also seen in Figure 18).Those RASTI values are well below the minimum recommended target of 0.45 (Table 10). On this sample, around 75% of the gyms present an average value below 0.43.

Table 5 - Statistical summary for the RT (500/1k/2k Hz) (14 rooms tested) and RASTI, avg. results (68 rooms tested). P10, P90 - percentile of the 10% and 90% values.

	Minimum	P10	Mean	Median	P90	Maximum	St. error
RT (s)	2.5	2.6	4.8	4.8	6.9	8.1	1.9
RASTI	0.26	0.29	0.35	0.34	0.43	0.54	0.06





Figures 17 (left) and 18 (right) - Box plots of the sample description for the parameter RT (14 rooms) (left) and RASTI (68 rooms) (right).

4.3 - Relationships among parameters

The Table 6 displays the LAeq_PE controlling for the type of activity (only one class was using each gym at the measuring time). A statistical test showed that the LAeq_PE average values do not vary significantly with the type of activity.

Table 6 – LAeq_PE results controlling for type of activity (only one class in each gym).

Modality	N. of rooms in sample	Mean L_{Aeq} (dB)	St. deviation (dB)
Handball	4	80	2.8
Athletics	1	73	-
Badminton	1	77	-
Basketball	5	79	2.4
Dance	2	80	3.5
Football	1	79	-
Gymnastics	21	77	4.6
Volleyball	6	80	4.0
Roller skating	1	80	-

The Figure 9 shows the variation of LAeq_PE values regarding the number of classes using the gym at the same time (one, two or three classes). The low R^2 value of 0.20 reveals that only about 20% of the LAeq_PE variation seems to be explained by the number of classes present. The regression line slope suggests that there is about a 2 dB(A) raise in the LAeq_PE for an increase of one more class (from one to two or three classes).

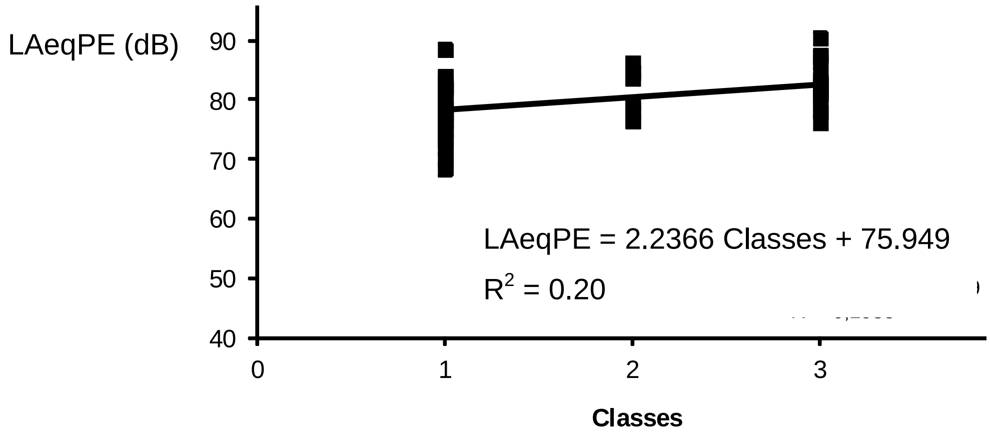
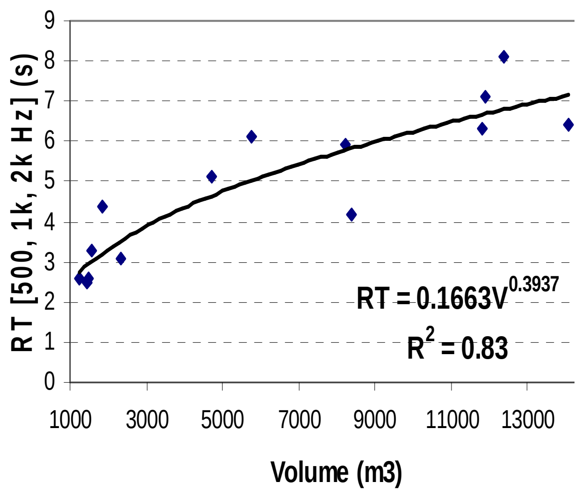
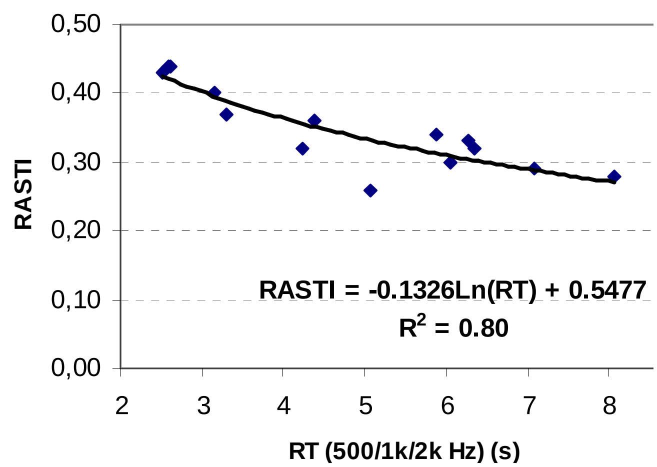


Figure 9 - Relationship between LAeq_PE and the number of classes (from 1 to 3) present in the gym at the same time (68 rooms).

Figure 10 shows the relationship between average RT (500, 1k, 2k Hz) and the room volume (m^3). About 83% of the RT variation can be explained by the room volume. Figure 11 presents the relationship between the average room RASTI and the average RT (500, 1k, 2k Hz) where it is shows that 80% of the variation in the RASTI average values can be explained by the RT.





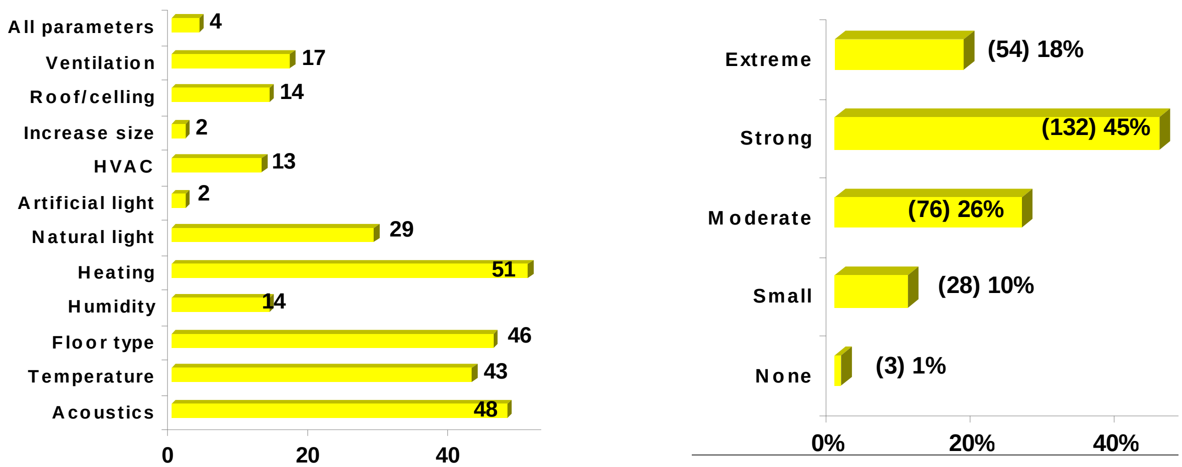
Figures 10 and 11 - Relationships (14 rooms) between average RT [500, 1k, 2k Hz] values and RASTI or Volume.

5 - SUBJECTIVE ANALYSIS

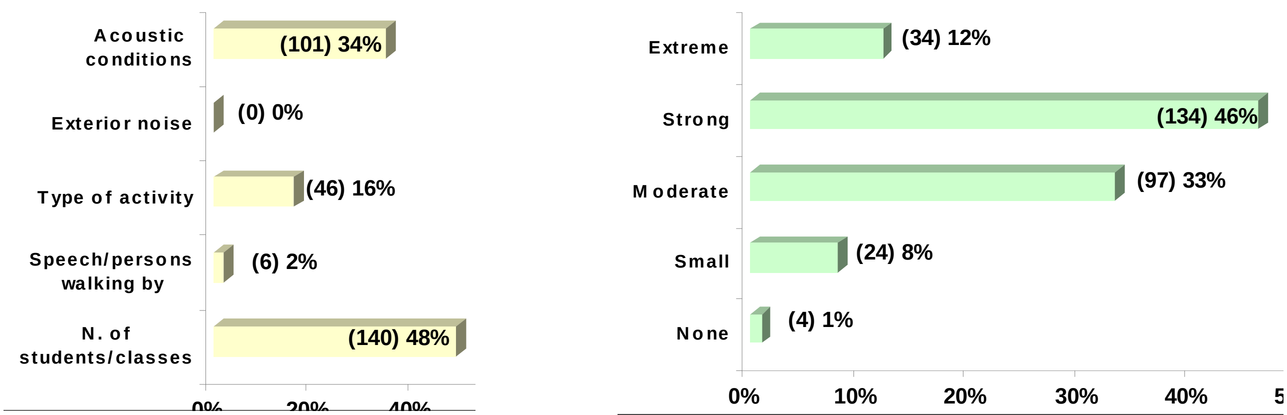
The subjective perception of the PE teachers was analyzed through questionnaires. The sample is composed by 293 PE teachers (55% males). Most of the teachers are between 30 and 39 years old (46%) or between 40 and 49 years old (32%). A majority (54%) has been a PE teacher from 11 to 20 years as 21% has that profession for more than 20 years.

From seven possible important parameters relating to the *global comfort quality of the gyms* (accessibility, floor type, artificial light, natural light, temperature and acoustics/noise), 44% of the teachers chose *acoustics/noise* as the most important, against 22% for *floor type* and 17% for *temperature*.

One question asked which *parameter they would change in the gym if there were no financial restrictions*. As seen in Figure 12 the most answers (with possible multiple selection) are *Acoustics* with 48 and *Heating* with 51 (out of 293 PE teachers).
Figure 13 shows the answers about the *grade of noise annoyance* where 45% state as *Strong* and 18% as *Extreme*.
Figure 14 displays the answers about what the PE teachers think as *the major cause of "noise" in the gym*. The number of classes is stated by 48% and the *overall gym acoustics conditions* by 34%.
Regarding the *voice level during classes*, PE teachers indicated (46%) that they needed a *Strong* voice effort, as 12% even related an *Extreme* voice effort (Figure 15). With this type of *Strong* or *Extreme* voice effort stated by 58% of PE teachers in a work environment (about 6 h a day with 80- 85 dBA) their health is going to be affected, in the long run.



Figures 12 (left) and 13 (right) - Number of answers regarding to *what to improve in the gym regardless of cost* (left) and to *the level of noise annoyance in the gym* (right).



Figures 14 (left) and 15 (right) – Number and percentage of answers regarding to *the factor that contributes the most to the noise in the gym* (left) and regarding *the level of voice effort needed to be understood by all students.*

6 - MULTICRITERIA METHOD

A multicriteria method to assess the acoustic overall quality of high school gymnasiums was designed using six parameters:

- LAeqPE (with PE classes) (with a weight in the multicriteria method of 40%);
- LAeqBN (background noise, no activity) (with a weight of 10%);
- RT [avg. 500/1k/2k Hz] (with a weight of 30%);
- RASTI (Rapid Speech Transmission Index) (with a weight of 10%);
- DnT,w (weighted standardized level difference, with interior walls to acoustic sensitive spaces) (with a weight of 5%);
- D2m,nT,w (standardized airborne sound insulation index with exterior) (with a weight of 5%).

A "normalized" number (_N) from 0 (worst) to 20 (best) was given to each parameter value to achieve an overall AGI (*Acoustics Gym Index*):

$$AGI=0.4*LAeqPE\_N+0.1*LAeqBN\_N+0.3*RT\_N+0.1*RASTI\_N+0.05*DnT,w\_N+0.05*D2m,nTw\_N$$

Table 7 - The six parameters involved in the multicriteria method to determine an AGI (*Acoustics Gym Index*) and their normalized (_N) values.

LAeqPE (dB)	**LAeqPE_N**	**LAeqPE (dB)**	**LAeq_PE_N**	**LAeqPE (dB)**	**LAeqPE_N**
< 70	20	[78 – 80[	15	[88 – 90[	8
[70 – 72[	19	[80 – 82[	14	[90 – 92[	6
[72 – 74[	18	[82 – 84[	13	[92 – 94[	4
[74 – 76[	17	[84 – 86[	12	[94 – 96[	2
[76 – 78[	16	[86 – 88[	10	≥ 96	0
L_{Aeq}BN (dB)	**L_{Aeq}BN_N**	**L_{Aeq}BN (dB)**	**L_{Aeq}BN_N**	**L_{Aeq}BN (dB)**	**L_{Aeq}BN_N**
< 30	20	[39 – 42[	14	[51 – 54[	6
[30 – 33[	19	[42 – 45[	12	[54 – 57[	4
[33 – 36[	18	[45 – 48[	10	[57 – 60[	2
[36 – 39[	16	[48 – 51[	8	≥ 60	0
RT 500/1k/2k	**RT_N**	**RT avg.**	**RT_N**	**RT avg.**	**RT_N**
[0.0-0.5[	16	[2.0-2.5[	16	[4.0-5.0[	6
[0.5-1.0[	18	[2.5-3.0[	14	[5.0-6.0[	3
[1.0-1.5[	20	[3.0-3.5[	12	≥ 6.0	0
[1.5-2.0[	18	[3.5-4.0[	10		
RASTI	**RASTI_N**	**RASTI**	**RASTI _N**	**RASTI**	**RASTI _N**
[0.00 – 0.10[	0	[0.40 – 0.45[	9	[0.70 – 0.80[	18
[0.10 – 0.20[	1	[0.45 – 0.50[	10	[0.80 – 0.90[	19
[0.20 – 0.30[	5	[0.50 – 0.60[	14	[0.90 – 1.00]	20
[0.30 – 0.40[	7	[0.60 – 0.70[	17		
DnT,w (dB)	**DnT,w_N**	**DnT,w (dB)**	**DnT,w_N**	**DnT,w (dB)**	**DnT,w_N**
≥ 50	20	[42 – 44[	14	[34 – 36[	6
[48 – 50[	19	[40 – 42[	12	[32 – 34[	4
[46 – 48[	18	[38 – 40[	10	[30 – 33[	2
[44 – 46[	16	[36 – 38[	8	<30	0
D2m,nT,w (dB)	**D2m,nT,w_N**	**D2m,nT,w** (dB)	**D2m,nT,w_N**	**D2m,nT,w** (dB)	**D2m,nT,w_N**
≥ 40	20	[32 – 34[	14	[24 – 26[	6
[38 – 40[	19	[30 – 32[	12	[22 – 24[	4
[36 – 38[	18	[28 – 30[	10	[20 – 22[	2
[34 – 36[	16	[26 – 28[	8	< 20	0

Table 7 presents the normalized grading (_N) for each of the six parameters used in the multicriteria method. The grading of this AGI is show in Table 8. Table 9 shows the calculated AGI for the 14 rooms where RT values were measured (for DnT,w and D2m,nT,w a neutral grade of 10 was given to all rooms because no measurements were done). In this sample 64% have an AGI grade of *Bad* (all but the smaller rooms, below 2,400 m^3).

Table 8 - AGI (*Acoustics Gym Index*) grading.

AGI	[0-6[	[6-10[	[10-13[	[13-16[	[16-18[	[18-20]
Grade	*Very Bad*	*Bad*	*Fair*	*Good*	*Very Good*	*Excellent*

Table 9 - Multicriteria grading of the 14 rooms tested regarding AGI (*Acoustics Gym Index*).

Gym n.	AGI	Grade	Gym n.	AGI	Grade	Gym n.	AGI	Grade	Gym n.	AGI	Grade
2	8.1	*Bad*	23	9.1	*Bad*	45	9.5	*Bad*	50	14.3	*Good*
3	8.9	*Bad*	35	7.3	*Bad*	46	13.1	*Good*	58	12.7	*Fair*
5	8.8	*Bad*	39	8.9	*Bad*	49	14.9	*Good*	67	12.7	*Fair*
6	8.7	*Bad*	40	8.3	*Bad*						

7 - CONCLUSION

In situ measurements were done in 68 school gymnasiums in Portugal regarding L_{Aeq}BN (background noise without gym classes), L_{Aeq}PE (ambiance noise with ongoing Physical Education classes), RT and RASTI.

The measured results for L_{Aeq}BN were from 30 to 59 dB (median of 42 dB); L_{Aeq}PE from 68 to 90 dB (median of 80 dB); RT(500/1k/2k) room average from 2.5 to 8.1 s (median of 4.8 s); RASTI room average from 0.26 to 0.54 (median of 0.34).

The study showed that the sound levels vary according to more than one variable but especially with the number of students. Increasing the number of classes on the same room gives an increase of about 2 dB(A) per class. It was not concluded that the type of sports practiced could influence the sound levels.

The RT and RASTI values measured are inappropriate especially in the larger gyms (Volume above 2400 m^3). The rooms are very reverberant (due to almost no sound absorbing materials and their highly reflective surfaces) and speech intelligibility is insufficient, not providing comfort and environmental quality for teaching classes, and might even be harmful, especially for the PE teachers regarding the high LAeqPE measured.

The subjective perception of 293 PE teachers was analyzed through questionnaires and it was verified that they feel the most discomfort when it comes for noise conditions and there is a relationship between those answers and the acoustic measured data.

Table 10 shows a set of proposed ideal conditions' values and the percentage of gyms found in compliance with those limits.

A multicriteria *Acoustics Gym Index* (AGI) was defined that allows to classify and compare the rooms according with their acoustics behavior.

It is concluded that the tested high school gyms do not present a reasonable environment to the practice of regular and healthy physical activity and the professional teaching of PE classes.

Table 10 - Proposal for Ideal conditions values and summary of results found in the 68 room tested.

Parameters	Ideal conditions	Percentage of rooms tested not fulfilling the ideal conditions
L_{Aeq}_PE (during PE classes)	≤ 80 dB	47%
L_{Aeq}_BN (background noise, no activity)	≤ 40 dB	56%
RT 500/1k/2k Hz (s)	≤ 1.5 s	100%
RASTI	≥ 0.45	96%

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