INTELLIGIBILITY MEASUREMENT OF AN EMERGENCY P.A SYSTEM.

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Abstract – *This paper describes the intelligibility measurement procedure of a high school Public Address system; the main theoretical concepts are defined and explained, and the measurement performed is described. This is an important evaluation to quantify if a message in an emergency situation could be clearly understood or if some adjustments need to be done in the system in order to have a better intelligibility thru this loudspeaker group. This could define some live-death situation in an unexpected episode, so it is important that the STI values are as high as possible to ensure everyone's reaction in an emergency, so some recommendations can be obtained in the conclusions of this measurement.*

1. INTRODUCTION

Nowadays, Public Address systems (P.A. systems) are more and more common. They are used to transmit information (news, advertisement) or to help with evacuation of buildings in case of emergency. In the last case, the good efficiency of the system can be a vital matter, as too slow reactions can lead to severe injuries or deaths. The good efficiency of such systems corresponds to the intelligibility of the speech messages. The importance of creating good P.A. systems led to the development of a whole new field of investigation. A broad range of methods and indicators appeared, latter certified by standards like the IEC 60268-16 [0]. Nonetheless, the field is still opened to new evolutions, and no method wins unanimous support. Speech Transmission Index (STI) and its variations, Clarity of speech (C_{50}), Speech Intelligibility Index (SII) or Percentage Articulation Loss of Consonants (%ALCons), all these indicators are used, according to the countries.

Historically, Houtgast and Steeneken made a lot to create and improve the STI [1]. However, this technique isn't still flawless in particular conditions, as stated by Mapp [2]. The fifth version of the IEC 60268-16, expected for 2018, should take this into consideration. One of the main factors allowing to reach a satisfying speech intelligibility is the Sound to Noise Ratio (SNR). For example, D'Antonio discusses the configuration of classrooms and suggests passive solutions. A very interesting fact he emphasizes is the necessity of including early reflections to get an optimum intelligibility [3]. The influence of the listeners hearing capacities should also be considered. Srinivasan et al. studied the influence of the early and late reflections on young or old subjects, arriving to the conclusion that the late reflections are especially molesting the oldest subjects [4]. Utami et al. studied the speech intelligibility in open offices, and interestingly, showed that the office configuration could bring an excess of intelligibility, which occurs as a distraction for the workers [5]. It is to say that, in specific cases, the best intelligibility is not always the best solution. Despite the huge number of papers and the awareness of the importance of understanding such concerns, Argentinean authorities have not, so far, precised requirements about intelligibility of P.A. systems [6].

This work presents a set of intelligibility measurement in the ORT high school of Buenos Aires. The performance of the P.A. system is evaluated, mapping a corridor equipped with seven loudspeakers and the adjacent rooms.

2. THEORETICAL BACKGROUND

2.1. HEARING AND SPEECH INTELLIGIBILITY

According to the Cambridge Dictionary, a speech is intelligible if it is "clear enough to be understood" [7]. It means that the formulation of the message, its transmission and its hearing between two persons are good enough to exchange information. Therefore, evaluating speech intelligibility means checking the efficiency of each of the components and their compatibility. A P.A. system will provide satisfactory intelligibility if these conditions are fulfilled. But this evaluation requires to clarify first a few fundamentals: how is the speech made? And how do we hear and process the information to understand it?

To produce a sound, the following steps are followed instinctively: compression of the diaphragm to expel the air from the lungs, vibration of the vocal folds when the airflow passes through the larynx, filtration by the oral and nasal cavities, and radiation by the lips. The sound thus emitted is ranging from 100 to 8000 Hz. The octave band spectrum of a typical speech is showed in Figure 1. Most of the speech signal is located in low frequencies, it partly corresponds to the vibration of the vocal folds.

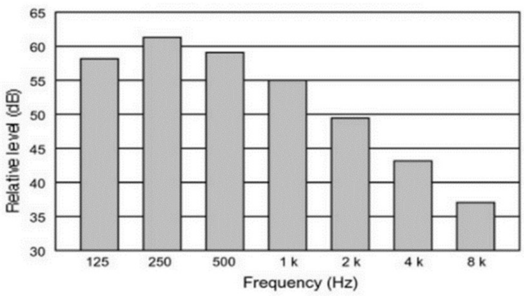

Figure 1: Octave band spectrum of typical speech, from [8].

Nonetheless, the contribution of each octave band to the intelligibility of the speech does not follow the same distribution. As Figure 2 shows, the intelligibility is mainly provided by the 1, 2 and 4 kHz bands.

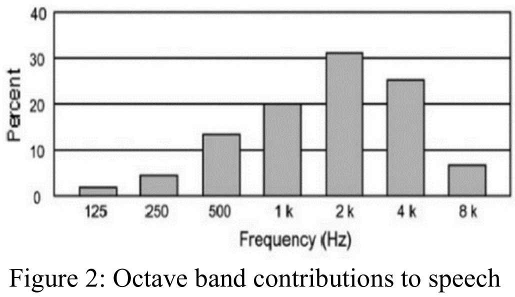

Figure 2: Octave band contributions to speech intelligibility.

The low frequency components are mostly due to the vowels, and their predominance can be explained by the duration of the vowels (about 100 ms), longer than the duration of the consonants (about 65 ms) [8]. As Beranek showed, the intelligibility is mostly carried by the consonants [9]. Therefore, it is essential to make sure that the consonants are not affected by the PA system or room acoustics.

2.2. INTELLIGIBILITY PARAMETERS

Different methods have been developed in order to evaluate the speech intelligibility: Articulation Index (AI), SII, C_{50}, and statistical methods such as rhyme tests. Nowadays, one of the most commonly used indexes is the STI, based on the modulation transmission. As the STI calculation was necessitating important computational resources, different indexes derived from the STI appeared: STITEL, STIPA, RASTI. Another well-established intelligibility index is the %ALCons, based on the loss of consonants articulation. The STI and indexes derived from it, as well as the %ALCons will be presented, as they are all used in this study.

2.2.1. STI

The STI is the Speech Transmission Index. It consists of a value, between 0 and 1, quantifying the degree of degradation of speech intelligibility by a transmission channel. The STI quantifies losses due to reverberation, background noise and echoes. The principle on which the STI is based is that speech information can be linked to a sound modulation. A loss of this modulation results in a decrease of the intelligibility. The STI was developed by Houtgast and Steeneken in 1973, adapting the Modulation Transfer Function (MTF) from optics to acoustics [10].

A total of 14 modulation frequencies F_m are considered, as shown by Table 1.

Seven interest frequencies F_0, corresponding to the central frequencies of the seven octaves between 125 and 8000 Hz are modulated with each of the modulation frequencies. The 98 values obtained are sorted in a modulation reduction matrix. Each value is calculated using the MTF as:

$$m(f_m, f_0) = \frac{1}{\sqrt{1+\left(\frac{2\pi f_m T_{60}(f_0)}{13.8}\right)^2}} \frac{1}{1+10^{\frac{-SNR(f_0)}{10}}} \quad (1)$$

In this study, the reverberation time will be measured as T_{20}. m values are between 0 and 1: 0 indicates an absence of modulation and 1 indicates a modulation perfectly transmitted. Thus, the intelligibility of all the modulation frequencies at all interest frequencies are contained in the modulation reduction matrix m. The apparent signal to noise

Table 1: Modulation frequencies f_m.

Modulation Frequencies f_m (Hz)													
0.63	0.8	1	1.25	1.6	2	2.5	3.15	4	5	6.3	8	10	12.5

ratio can be obtained then by:

$$SNR_{app}(f_m, f_0) = 10log\left(\frac{m(f_m,f_0)}{1-m(f_m,f_0)}\right) \quad (2)$$

And normalized to Transmission Index (TI) value between 0 and 1:

$$TI(f_m, f_0) = \frac{SNR_{app}(f_m,f_0)+15}{30} \quad (3)$$

Seven values of modulation transfer index (MTI) are obtained by averaging the 14 values of TI for each octave band:

$$MTI(f_0) = \frac{1}{14}\sum_{f_m=1}^{14} TI(f_m, f_0) \quad (4)$$

Eventually, the STI is calculated as an average of the seven octave bands:

$$STI = \sum_{n=1}^{7} \alpha_n MTI_n - \sum_{n=1}^{6} \beta_n \sqrt{MTI_n \times MTI_{n+1}}$$

Weighting factors α_n and β_n, displayed in Table 2, are applied to correct respectively the octaves importance in intelligibility and redundancy of adjacent frequency bands.

Table 2: Weighting values α and β for STI calculation.

f_0	Male		Female	
	α	β	α	β
125	0.085	0.085	-	-
250	0.127	0.078	0.117	0.099
500	0.23	0.065	0.223	0.066
1000	0.233	0.011	0.216	0.062
2000	0.309	0.047	0.328	0.25
4000	0.224	0.095	0.25	0.076
8000	0.173	-	0.194	-

2.2.2. STITEL

The STITEL, STI for telecommunications Systems, is a simplified version of the STI. It removes the non-correlated modulations, reducing the number of values from 98 to 7. As a consequence, it is not efficient to analyse the non-linear distortions. Other limitations make it useful only in precise cases. There is one modulation frequency for each interest frequency, as shown in Table 3:

Table 3: STITEL interest frequencies and modulation frequencies.

f_0 (Hz)	f_m (Hz)
125	1.12
250	11.33
500	0.71
100	2.83
2000	6.97
4000	1.78
8000	4.53

2.2.3. STIPA

The STIPA, STI for public address systems, is a simplified version of the STI that reduces the number of values from 98 to 12. The two modulation frequencies used for each octave band, presented in Table 4, are tested simultaneously. It should not be used in the cases of impulsive background noise and strong non-linearities.

Table 4: STIPA interest frequencies and modulation frequencies.

f_0 (Hz)	f_m (Hz)	
125-250	5.00	1.00
500	3.15	0.63
100	10.0	2.00
2000	6.25	1.25
4000	4.00	0.80
8000	12.5	2.50

2.2.4. RASTI

The RASTI, which means Room Acoustic STI, is another index derived from the STI. It was the first effectively used to measure in the mid 1980's. The RASTI method only uses two interest frequencies: 500 and 2000 Hz. Four modulation frequencies are used with the first interest frequency, and five with the second one, as presented in Table 5.

Table 5: RASTI interest frequencies and modulation frequencies.

f_0 (Hz)	f_m (Hz)				
500	1.00	2.00	4.00	8.00	-
2000	0.7	1.4	2.8	5.6	11.2

2.2.5. %ALCons

The %ALCons is the percentage articulation loss of consonants. Created by Peutz in 1971, it is very used in the United States [11]. The smaller it is, the better is the intelligibility. The %ALCons is calculated as:

$$\%ALCons = 0.652\left(\frac{r_{LH}}{r_H}\right)RT \tag{6}$$

where r_{LH} is the distance between the listener and the speaker, and r_H is the reverberation radius. In the case of directional speakers r_H is the critical distance.

The %ALCons can be related to the STI. Thus, Farrel Bekker has determined an empirical relation between the two [12]:

$$\%ALCons = 170.5405e^{-5.419STI} \tag{7}$$

In this work, the %ALCons will be calculated using this relation.

2.3. INTELLIGIBILITY STANDARD: IEC 60268-16

The IEC 60268-16 is probably the more precise standard about STI. The Speech Transmission Index and its derived versions are detailed and analysed.

The standard explains two methods of measurement. The first one is a direct method. It is based on the measurement thru the use of modulated signals. The indirect method uses impulse responses, with the generation of MLS sequences or logsine sweeps, and requires post-processing. The use of the indirect method is more developed; however, one should be aware that it cannot treat non-linear distortions (wind, clipping, etc). In some conditions the use of the direct method will therefore be necessary.

The standard also gives indications to help judging the results obtained. Table 6 provides the rating of the speech intelligibility according to the STI.

Table 6: Rating of speech intelligibility and STI.

Rating	STI
Bad	0 - 0.3
Poor	0.3 - 0.45
Fair	0.45 - 0.6
Good	0.6 - 0.75
Excellent	0.75 - 1

3. MEASUREMENT

3.1. LOCATION

The analysed system is placed in a circulation corridor of ORT High School, one of the biggest and most important private institutes in Buenos Aires city. They offer initial education, high school and tertiary level. It has two headquarters, one in Almagro neighbourhood and another in Nuñez that include the three educational institutes and the administration of the association (ORT Argentina). Both locations are composed by 2 buildings each with approximately 5 floors and a wide covered surface that takes in around 4000 teenage students every day during high school schedule during morning and afternoon.

The analysed system is located in the third floor of 'Libertador' building located in Av. Libertador 6796, Nuñez, City of Buenos Aires, Argentina. There are classrooms dedicated to the high school classes of the mass media production specialisation, a TV studio, broadcasting studios, a video edition laboratory, administrative and educational offices. The P.A. system is distributed in 7 loudspeakers, which have coverage above the circulation corridor; it is important to keep in mind that in each break between lessons, about 500 teenagers chat and play loudly in this place, generating a high-level background noise.

Figure 3 shows the measured corridor viewing the classrooms and Figure 4 shows the corridor facing the TV and broadcast studios.

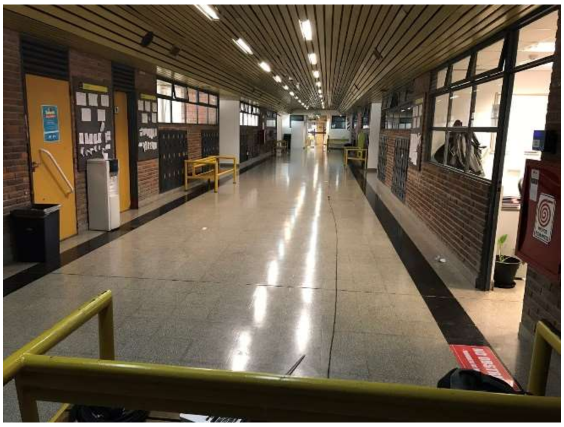

Figure 3: Circulation corridor facing classrooms, bathrooms and offices.

Figure 4: Corridor facing TV and broadcast studios.

The measurement was performed between 5:30 PM and 7:00 PM, which was the assigned time that could be used, so the measurement was taken in unoccupied conditions. During this time, the high school lessons have ended, and at 7:00 PM the tertiary-level lessons begin. Despite this, the administration staff still works and other activities are in progress, so the measurement level had to be controlled in order to avoid annoyance (the test signals are not the most pleasant music). The background noise was recorded during a class-break around 11 AM to represent the real noise, which is not at the time of the measurement. This is of great influence in the results, but still represents the real situation, because the reproduction level of the system remained unchanged.

The corridor is 40 meters long, 4.5 wide and 4 tall, with a total volume of 720 m^3. The floor is made with tiles, the ceiling has a wooden covering and the walls are made of viewable brick. Each classroom has high windows to the main corridor and a wooden door with a little glass window. There are also built-in lockers in the walls for the students. Figure 5 shows a messy classroom with the measurement microphone positioned.

Figure 5: Messy classroom with measurement microphone.

Possible noise sources are: teenagers shouting, music from cell phones and noise from a very crowded avenue: Libertador Avenue. It has a big transit flow during daytime and the school is located in a crowded area very close to the River Plate (Athletic club) soccer stadium as can be seen in Figure 6.

Figure 6: Measurement microphone and River Plate's stadium in the background.

3.2. P.A. SYSTEM

As mentioned before, the P.A. System is based on 7 speakers distributed as shown in Figure 7. This distribution is used for the high-school break ring, some important announcements and emergency messages if needed. It has 2 active inputs: the broadcast shows produced by the students (used sporadically) and the automatic ring system, which runs every day.

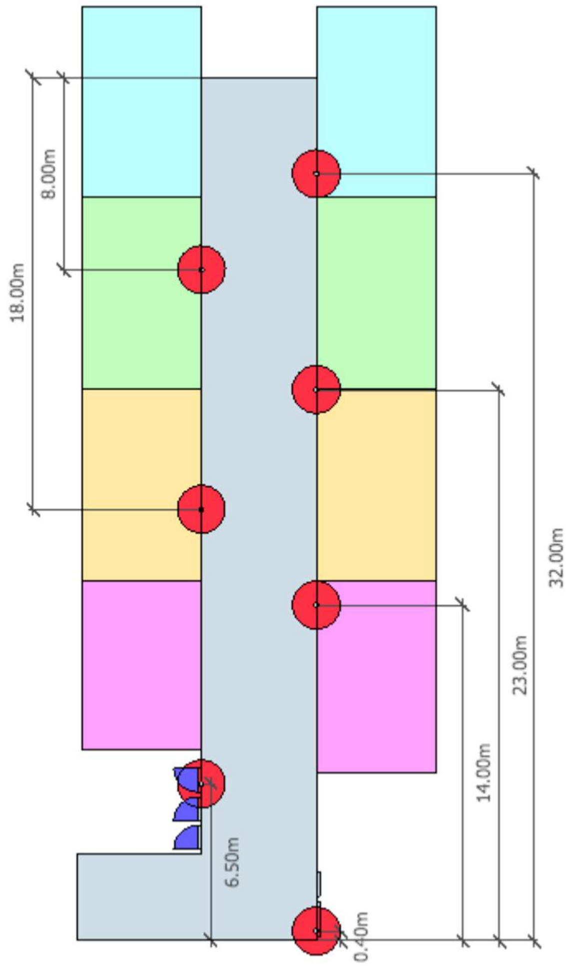

Figure 7: Loudspeaker locations. Cyan, pink,

yellow and green indicate the classrooms and the blue doors are the bathroom's entrance. Red circles show the loudspeakers.

The shown speakers are set into the ceiling/wall structure, so its brand and model are unknown, as well as its connection, impedance and other system characteristics. Figure 8 shows one of the speakers.

Figure 8: One built-in loudspeaker.

The administration rack of this system is located inside one of the broadcast studios, locked to avoid vandalization or manipulation from non-experts. The reproduced signal is administrated by a Gemini MM-01 mixing console, as shown in Figure 9, which is amplified by one channel of an SKP Max 300X power system shown in Figure 10 (other amplifiers are used in other distributed P.A. systems). The main signal distribution is based on a 100 V electrical line as can be appreciated in Figure 11.

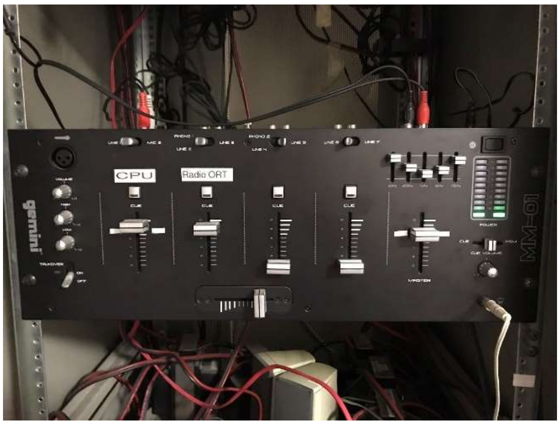

Figure 9: Gemini MM-01 in location.

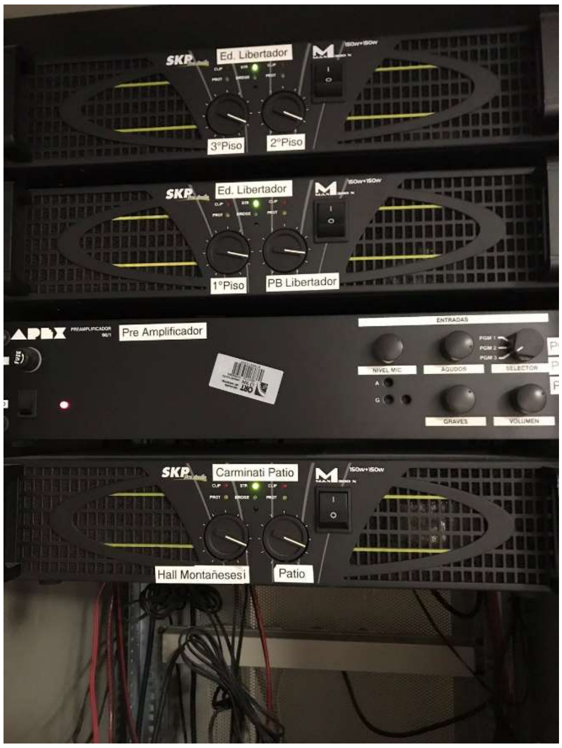

Figure 10: SKP Max 300X with the analysed and other distributions.

Figure 11: Electrical transformers and sloppy cabling.

The test signals were reproduced by an iPad connected to the mixing console and the other P.A. systems connected to this distribution were turned off (i.e. second floor and playground).

The main measurement points were chosen in front of each loudspeaker, while all of them were reproducing the signal. The microphone distances were based on requirements on ISO 3382 [13] because of the lack of information in the applied standard. Extra measurements were performed on distant positions where there appeared to be a lack of coverage of the system, inside the bathroom and inside two unoccupied classrooms. Those are described properly in Figure 12.

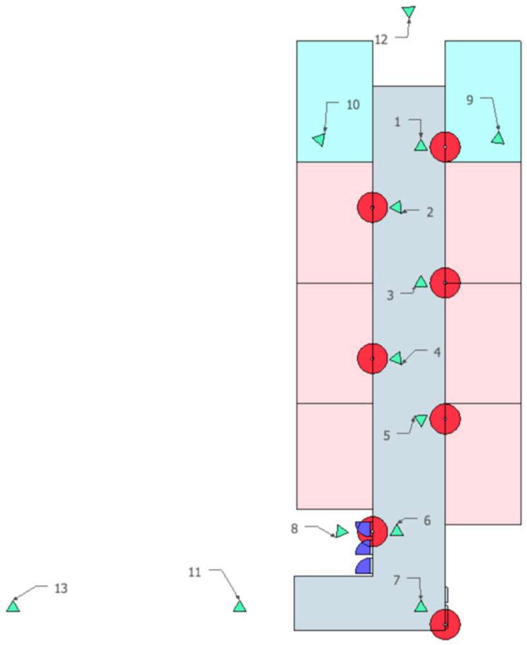

Figure 12: Corridor with measurement points. The cyan classrooms are the analysed and the green triangles show the measurement points.

Point 12 is in the middle point between the lateral walls at 10 m from the point 1. Points 11 and 13 are on the same axis as point 7 at a distance of 11 and 31 m respectively. Point 8 is on point 6's axis, but 2 m inside the men's bathroom.

3.3. MEASUREMENT EQUIPMENT

The measurement was performed with the group's personal equipment, because there was no chance of renting the equipment provided by the university. Two stations were connected separately: reproduction and recording.

For the reproduction, two test signals were synthesized and then loaded to an iPad Air 2 (S.N. DMPT1AV8HG5D) connected to the mixing console. The signals were generated in Audacity software, consisting in a gaussian pink noise of 30 s of duration and a logarithmic sine sweep from 80 to 18000 Hz, also of 30 s of duration.

The recording equipment consisted of:

- Macbook pro Early 2010 (S.N. WQ024SWUATM). Included Adobe Audition DAW.
- Presonus iTwo sound card (S.N. AB5C16090489).
- Audix TR40A measurement microphone (S.N. 5010139-97).
- Microphone cable (Rapco with Switchcraft and Neutrik connectors) and microphone stand.

4. RESULTS AND ANALYSIS

The sound pressure levels (SPL) corresponding to the background noise of the room under study, the signal reproduced by the P.A, and the signal to noise ratio between both are analysed. Figure 13 shows the curves along with their standard deviation for each octave band.

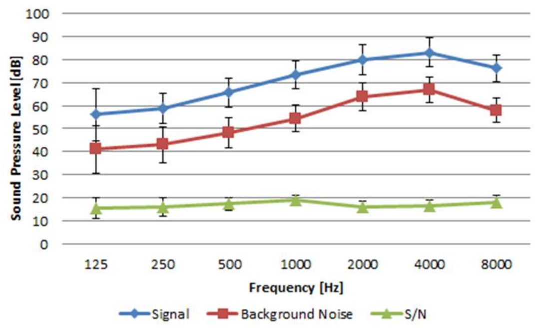

Figure 13: Signal and background noise comparison.

It is important to note that the highest levels of deviation are due to the distance between the measurement points. In Table 1A, Table 2A and Table 3A (shown in annex section) the values for each measurement point are observed.

The reverberation time (T_{20}) of the enclosure is calculated with Aurora Software in Audacity (2.0.5 version) and the results are presented in Figure 14.

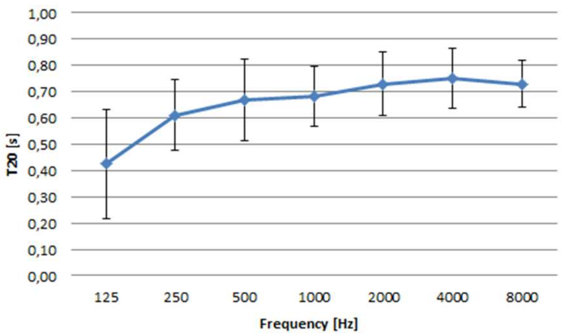

Figure 14: Reverberation Time (T_{20}).

Here it is also important to note that the deviations are large due to the different measurement positions. The values of T_{20} for each particular point are shown in Table 4A of the annex section._The reverberation time is an important acoustic parameter to take into account when studying the intelligibility of the speech (STI), since increasing the reverberation time decreases the STI value due to the temporary masking that occurs.

Female and Male STI are calculated by an indirect method. It is based on impulse response measurement (by logarithmic sine sweeps) and its subsequent processing with software. It is important to note that the indirect method cannot be used if there are nonlinearities in the system, such as wind, clipping or compressors/expanders. These conditions are checked and bypassed during the measurement. Figure 15 shows the similarity between Female and Male STI for all the measurement positions. In Table 5A (show in annex section) shows the STI complete values for each position.

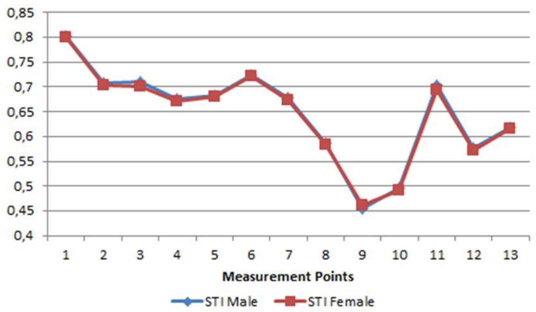

Figure 15: Female STI and Male STI for all the measurement positions.

Then it is decided to define the average STI between both which is presented in the Figure 16.

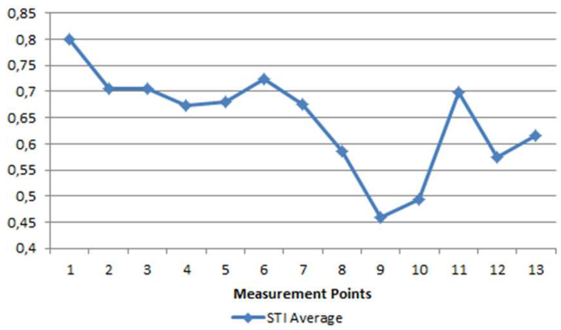

Figure 16: STI Average between Female and Male for all the measurement positions.

It is observed that at the points where the STI is lower, are furthest positions from the P.A. system. The positions of lowest values are point 9 and 10, both located inside classrooms. These are the points where more STI is necessary since they are the places where students spend more time, and it is more likely that in a communication situation, most of the students will be in that place. Point 12 is located 10 meters away from point 1, in the middle of the corridor. This point represents the furthest point to the main corridor and thus, from the speakers; that might be the reason of low level of STI. Then another low-level measurement position is point 8, located inside the men's bathroom. This point is not so far from the loudspeakers but having a door in the middle (and an increase of the background noise) significantly reduces the STI. In addition, one of the highest T_{20} values of the whole analysed room is registered in the bathroom. This contributes to the decline of the STI value. Another point of low STI is point 13, which is located 31 meters from the nearest speaker. It is an important distance, but because of its visual connection with the system, there is no such a large decrease in the STI value.

The RaSTI, STItel and STIpa parameters are also calculated. In Figure 17 those values are presented together with the STI Average, and it is observed that there are no great variations among the position. The conclusions that are obtained for the STI Average previously, might be also applied for these three parameters.

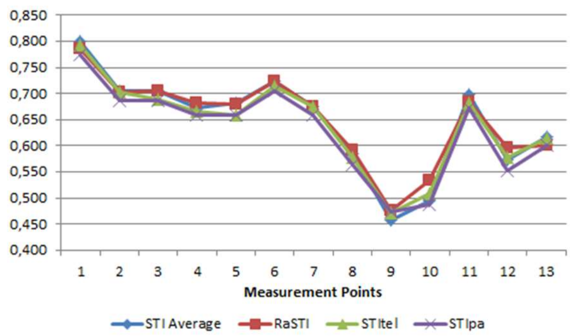

Figure 17: STI Average, RaSTI, STItel and STIpa comparison for all the measurement positions.

Table 6A (shown in annex) shows all the RaSTI, STItel and STIpa values for each position. In Figure 18 the global values of STI Average, RaSTI, STItel and STIpa with their respective deviations are presented.

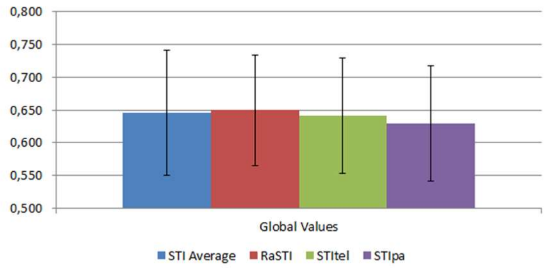

Figure 18: STI Global values with deviations values.

Considering the rating criteria from IEC 60268-16 can be considered that the overall value of STI (0.646) is "Good". The STI global values are shown in Table 7.

Table 7: STI Global Values.

	STI Average	RaSTI	STItel	STIpa
Global STI	0,646	0,649	0,641	0,629
σ	0,096	0,085	0,088	0,088

It is important to note that the STI values for the points on the corridor and the closest to the speakers (points 1 to 7) are all above 0.7 and close to 0.75, which would indicate an STI value located between "Good" and "Excellent" according to the criterion presented by IEC 60268-16; as they are averaged with the values located more far away from the speakers (points from 8 to 13) the global STI value drops to 0.646. This value is more representative since most of the time the students are in the places represented by points 8 to 13.

Also, the parameters %ALcons Female and %Alcons Male are also obtained. These values are obtained with the equation (7) proposed by Bekker, as explained in section 2.5.

Figure 19 shows the similarity between %ALcons Female and %ALcons Male for all the measurement positions. In Table 7A (shown in annex), all the %ALcons values for each position are shown.

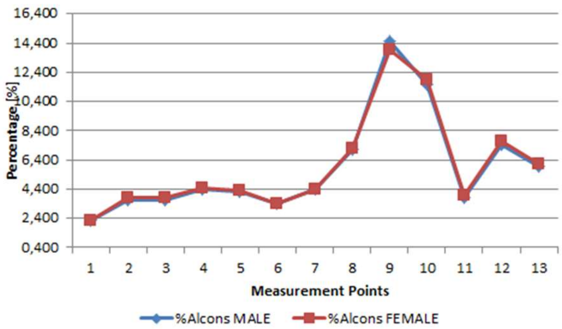

Figure 19: %ALcons Average between Female and Male for all the measurement positions.

Then it is decided to define the average %ALcons between both and is presented in the Figure 20.

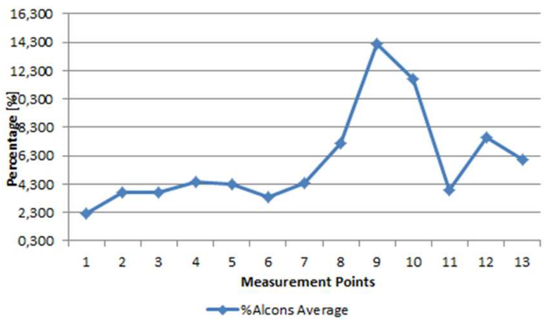

Figure 20: %ALcons Average between female and male for all the measurement positions.

It is observed that the positions where the %ALcons is greater, meaning higher percentage of loss of consonants, are those that are furthest from the P.A. system. The points of worst value are point 9 and point 10, both located inside classrooms. These are the points where less %ALcons is necessary since they are the places where students spend more time, and it is more likely that if it is necessary to transmit an emergency message through the PA system, most of the students will be in that place. Then follows point 8, located inside the men's bathroom; this point is not so far from the loudspeakers but having a door in the middle significantly increase the %ALcons. Point 12 is located 10 meters from point 1, in the middle of the corridor. This represents the position of the main corridor furthest from the speakers, which is why its high level of %ALcons is understandable. Another point of low STI is point 13, which is located 31 meters from the nearest speaker. It is a great distance, but because of having direct visual connection, there is no such large increase in the %ALcons.

In Figure 21, the global values of %ALcons Average, %ALcons Female and %ALcons Male with their respective deviations are presented.

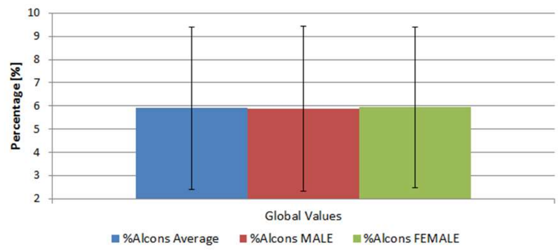

Figure 21: %ALcons Average, Male and Female global values with deviations.

It is important to note that the %ALcons values for the points on the corridor and closest to the speakers (points 1 to 7 and point 11) are all below 4.3%, which would indicate a good %ALcons value, but as they are averaged with the values located more far away from the speakers (points from 8 to 13) the global %ALcons value grows up to 6%. This value is more representative since most of the time the students are in the places represented by points 8 to 13. The points from 8 to 13 take %ALcons value between 7% and 14%. Table 8 shows the %ALcons global values.

Table 8: %ALcons Global Values.

	%Alcons Average	%Alcons MALE	%Alcons FEMALE
Global %Alcons	5,866	5,941	5,904
σ [%]	3,554	3,466	3,509

It is also interesting to analyse the relationship between the parameters STI and %ALcons. In Figure 22 both normalized values are shown, referenced to the maximum value they take respectively.

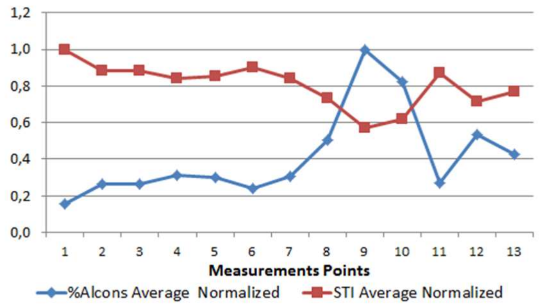

Figure 22: %ALcons and STI comparison, both normalized.

It can be seen by increasing the percentage of loss of consonants (% ALcons) decreases the STI and vice-versa. This is consistent with the proper definition of each parameter, and demonstrates dependence between both, as well as a faithful description of the same phenomenon addressed with different parameters.

5. CONCLUSIONS

The overall result of STI (0.646) and % ALcons (5.86%) correspond to a good intelligibility according to the IEC 60268-16. The specific values of intelligibility on the main hall where the loudspeakers are located are very good, but it should be considered that most of the time the people who frequent the building are inside the classrooms, where the results of intelligibility are simply good.

Taking into account that the P.A system would be used, among other announcements, for emergency messages, such as evacuation of the building or similar, it is important to be aware of the need to improve global intelligibility. One way would be to reduce background noise, although it is clearly difficult as the study site is a school full of children. On the other hand, you could place more speakers, especially in the interior of the classrooms. This would help considerably to increase the STI and decrease the% ALcons. In short, the intelligibility would be improved in the busiest sectors of the building, the classrooms.

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7. ANNEX

Table 1A : Signal Sound Pressure Level.

	Signal Sound Pressure Level [dBZ]						
Measurements Points	Frequency [Hz]						
	125	250	500	1000	2000	4000	8000
1	54,17	50,40	57,56	66,07	72,33	76,51	70,45
2	56,30	52,99	59,89	68,99	74,54	77,79	70,80
3	55,10	53,73	60,62	68,44	74,25	77,15	70,32
4	56,99	55,80	62,27	70,78	76,85	78,35	72,94
5	53,11	54,10	61,48	67,82	73,49	77,55	71,34
6	53,39	53,83	59,62	67,90	73,68	77,04	69,77
7	59,52	55,91	61,42	69,40	75,60	78,44	72,56
8	71,14	69,79	74,70	80,94	88,55	91,12	84,07
9	40,46	66,79	74,37	83,31	89,25	92,31	84,22
10	69,10	67,12	72,02	78,38	86,56	89,56	81,55
11	30,00	59,12	68,91	76,41	82,81	87,25	79,67
12	66,69	66,42	74,27	81,11	86,76	89,11	82,71
13	64,36	61,55	67,42	76,73	84,77	90,15	81,09
Global [dBZ]	56,18	59,04	65,73	73,56	79,96	83,25	76,27
σ [dBZ]	11,31	6,54	6,41	6,06	6,53	6,54	5,91

Table 2A : Background Noise Sound Pressure Level.

	Background Noise Sound Pressure Level [dBZ]						
Measurements Points	Frequency [Hz]						
	125	250	500	1000	2000	4000	8000
1	37,11	37,27	42,09	48,27	57,29	60,69	51,12
2	40,13	41,87	41,89	50,79	60,93	62,99	54,65
3	41,23	30,99	42,43	48,31	58,29	59,91	52,94
4	40,67	36,24	44,83	49,93	58,73	63,87	55,17
5	41,99	39,50	45,23	50,33	58,27	62,44	55,06
6	43,09	38,93	44,58	50,67	60,12	63,63	55,33
7	36,07	40,58	44,29	53,17	61,76	64,22	54,91
8	56,79	52,03	62,93	62,16	71,19	72,95	66,21
9	34,85	58,17	57,76	65,75	76,85	75,89	68,61
10	48,52	49,90	55,11	61,23	71,13	75,82	65,87
11	14,38	37,60	48,09	53,27	64,14	67,70	57,50
12	51,37	53,18	52,11	59,18	68,22	70,86	59,83
13	45,98	42,86	46,49	55,48	63,95	67,91	57,51
Global [dBZ]	40,94	43,01	48,29	54,50	63,91	66,84	58,05
σ [dBZ]	10,12	7,91	6,67	5,78	6,15	5,51	5,50

Table 3A :Signal to Background Noise Ratio.

	Signal to Background Noise Ratio [dBZ]						
Measurements Points	Frequency [Hz]						
	125	250	500	1000	2000	4000	8000
1	17,06	13,14	15,47	17,81	15,04	15,82	19,33
2	16,18	11,13	18,00	18,21	13,60	14,80	16,14
3	13,87	22,74	18,19	20,13	15,96	17,23	17,39
4	16,32	19,56	17,44	20,85	18,12	14,48	17,77
5	11,12	14,60	16,26	17,49	15,23	15,11	16,28
6	10,31	14,90	15,04	17,23	13,57	13,41	14,44
7	23,45	15,33	17,13	16,24	13,84	14,23	17,65
8	14,36	17,76	11,77	18,78	17,36	18,17	17,86
9	5,61	8,62	16,61	17,56	12,40	16,42	15,61
10	20,59	17,22	16,91	17,15	15,43	13,75	15,68
11	15,62	21,52	20,82	23,15	18,66	19,55	22,17
12	15,33	13,24	22,16	21,92	18,54	18,25	22,88
13	18,38	18,70	20,92	21,25	20,82	22,24	23,57
Global [dBZ]	15,24	16,03	17,44	19,06	16,04	16,42	18,21
σ [dBZ]	4,55	4,06	2,75	2,16	2,49	2,59	2,95

Table 4A: Reverberation Time (T20).

Measurements Points	Reverberation Time T20 [s]						
	Frequency [Hz]						
	125	250	500	1000	2000	4000	8000
1	0,49	0,57	0,62	0,60	0,66	0,69	0,69
2	0,31	0,51	0,60	0,62	0,61	0,64	0,68
3	0,60	0,54	0,66	0,67	0,67	0,70	0,67
4	0,40	0,55	0,55	0,65	0,69	0,66	0,69
5	0,38	0,58	0,46	0,59	0,63	0,66	0,64
6	0,22	0,45	0,44	0,51	0,56	0,60	0,57
7	0,24	0,52	0,57	0,53	0,59	0,63	0,68
8	0,52	0,74	0,67	0,74	0,80	0,84	0,80
9	0,24	0,84	0,90	0,73	0,81	0,88	0,83
10	0,59	0,81	0,86	0,83	0,89	0,84	0,82
11	0,06	0,67	0,66	0,75	0,80	0,83	0,76
12	0,75	0,42	0,87	0,86	0,88	0,86	0,85
13	0,72	0,74	0,83	0,82	0,91	0,92	0,82
Global T20 [s]	0,42	0,61	0,67	0,68	0,73	0,75	0,73
σ [s]	0,21	0,14	0,15	0,12	0,12	0,11	0,09

Table 5A : STI Values for each measurement positions.

Measurements Points	STI Male	STI Female	STI Average
1	0,802	0,799	0,801
2	0,708	0,703	0,706
3	0,710	0,701	0,706
4	0,676	0,671	0,674
5	0,682	0,680	0,681
6	0,724	0,722	0,723
7	0,677	0,674	0,676
8	0,586	0,584	0,585
9	0,455	0,462	0,459
10	0,497	0,492	0,495
11	0,703	0,694	0,699
12	0,577	0,571	0,574
13	0,618	0,615	0,617
Global STI	0,647	0,644	0,646
σ	0,097	0,095	0,096

Table 6A: RaSTI, STItel and STItel values for each measurement positions.

Measurements Points	RaSTI	STItel	STIpa
1	0,787	0,793	0,774
2	0,703	0,704	0,687
3	0,706	0,689	0,686
4	0,682	0,666	0,659
5	0,680	0,658	0,659
6	0,724	0,715	0,706
7	0,675	0,675	0,660
8	0,592	0,578	0,565
9	0,476	0,472	0,473
10	0,535	0,509	0,488
11	0,684	0,682	0,673
12	0,597	0,577	0,553
13	0,602	0,614	0,600
Global STI	0,649	0,641	0,629
σ	0,085	0,088	0,088

Table 7A: %ALcons Male, %ALcons Female and %ALcons Average values for each measurement positions.

Measurements Points	%Alcons MALE	%Alcons FEMALE	%Alcons Average
1	2,210	2,246	2,228
2	3,678	3,779	3,728
3	3,638	3,820	3,729
4	4,374	4,494	4,434
5	4,234	4,280	4,257
6	3,372	3,409	3,391
7	4,351	4,422	4,386
8	7,124	7,201	7,163
9	14,488	13,949	14,218
10	11,539	11,856	11,697
11	3,779	3,968	3,873
12	7,480	7,727	7,603
13	5,990	6,088	6,039
Global %Alcons	5,866	5,941	5,904
σ [%]	3,554	3,466	3,509

8. PREGUNTAS

1. ¿Analizando los resultados obtenidos, hay riesgos de no entender los mensajes de emergencia?

Los puntos ubicados en las aulas tienen un STI que no supera 0.5. Hay que tener en cuenta que las mediciones fueron realizadas a una hora con muy poca actividad. Por lo tanto, el STI daría valores inferiores durante los periodos de actividad. En esos puntos, el nivel de ruido generado por las actividades de clase influirá mucho sobre la inteligibilidad del mensaje, que ya es solamente regular en condiciones optímales. En esos puntos, hay riesgos de no entender los mensajes de emergencia. Igualmente, los ruidos generados por la utilización del baño van a generar perturbaciones de la inteligibilidad que no fueron tomados en cuenta por las mediciones. El STI de 0.585 no es crítico, pero se podría no entender los mensajes de emergencias en algunas condiciones.

2. Enumere las potenciales causas que producen baja inteligibilidad en un diseño cualquiera.

La información importante dentro de una señal de voz (para el habla inglesa) está principalmente en las consonantes, y en las bandas de octava de 1, 2 y 4 kHz. Por lo tanto, hay que asegurarse primero de que estas bandas podrán ser percibidas por los oyentes. Hay fuentes que provocan baja de la inteligibilidad de la palabra en cada uno de los elementos involucrados en la reproducción del mensaje: grabación del mensaje de emergencia, emisión por los altoparlantes, difusión en el lugar, recepción por el oyente. Los parámetros importantes a la hora de la grabación son: la precisión del habla y la velocidad, pronunciación y el ruido de fondo. Respecto al altoparlante, se debe tomar en cuenta: su ancho de banda, respuesta en frecuencia (especialmente en las bandas de 1 a 4 kHz), distorsión, directividad y el nivel sonoro generado. El sistema de parlantes está colocado en una sala. Por lo tanto, las características acústicas de la sala van a influir mucho, y especialmente: sus dimensiones (geometría) y la posición de los parlantes (ausencia de zonas muertas) y de los oyentes, las reflexiones principales. Se pueden medir el tiempo de reverberación, la relación entre sonido directo y sonido reflejado (D/R), la presencia de echo (echo speech) que todos son parámetros importantes al momento de juzgar la inteligibilidad en el lugar. También se debe tomar en cuenta los usuarios del lugar: el hecho de que el castellano sea su lengua nativa o no, la presencia de personas con pérdidas de oído, pueden cambiar lo que será considerado como buena inteligibilidad.

Producirán baja inteligibilidad malas combinaciones de estos parámetros. Por lo tanto, es importantísimo ser consciente de la influencia de los mismos para diseñar de manera adecuada la instalación del sistema.

3. En el caso analizado, ¿cuáles son los motivos por los que se presenta baja inteligibilidad en algunos puntos?

Hay cuatro puntos en los cuales el STI está por debajo de 0.6, es decir que la inteligibilidad no puede ser considerada como buena: son los puntos 8, 9, 10 y 12. Lo que esos puntos tienen en común es que no están en el pasillo sino en salas contiguas. El punto 8, ubicado en el baño, no está lejos del parlante más próximo. Sin embargo, la puerta cerrada genera una baja del nivel sonoro. Además, presenta un alto nivel de reverberación. Durante el día, es un lugar con gente pasando y ruidos de agua produciendo altos niveles sonoros. Los puntos 9 y 10 están ubicados en dos aulas. La baja de inteligibilidad está probablemente debida al aislamiento por las paredes de cada aula. Sería interesante medirlo, y especialmente ver si las bandas de 1, 2 y 4 kHz son muy aisladas. El punto 12 está ubicado en el pasillo, pero una distancia de 10 m del parlante más próximo. También hay que destacar los parlantes están colocados en el techo. Por lo tanto, el sonido llega al punto 12 después de varias reflexiones. Por cierto, el TR medido es el más alto con el del baño. El número de reflexiones, que probablemente no llegan al mismo tiempo según los trayectos, así que la atenuación por la distancia, deben de ser los factores que más bajan la inteligibilidad en ese punto.