INTELLIGIBILITY MEASUREMENT OF AN EMERGENCY P.A. SYSTEM

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Abstract - *The aim of the present paper is to obtain intelligibility parameters of an emergency P.A system in order to determine whether there is a risk of understanding the message or not. STI and ALcons% parameters of a beer pub are measured following UNE-EN 60268-16 standard. Results are then analyzed considering background noise and reverberation time influence. It was found that STI was high except when noisy machinery was turned on. Also, correlation between STI, C50 and RT20 was observed.*

1. INTRODUCTION

The concept of speech intelligibility is relevant to several fields, including acoustic phonetics, auditory phonetics, audiology science and audiometry testing. Since speech is the most vital mean of communication, speech intelligibility is crucial for situations where the message is considered of substance, for instance, for public buildings emergency evacuation protocols.

Public address systems in building complexes have to inform people about escape directions in case of an emergency. Such public buildings include airports, railway stations, shopping centers, concert halls, etc. However if such announcements are misunderstood due to poor system quality, tragic consequences may result. Therefore, it is essential to design, install and verify sound reinforcement systems properly for intelligibility. In addition, a variety of other applications such as legal and medical applications may require intelligibility verification.

There are several factors that may affect speech intelligibility, for example: high levels of background noise or high reverberation time values, commonly present in churches. Room characteristics like this can deteriorate the message that is being transmitted to the point where it is not understandable any more.

Speech Intelligibility may not be a problem if the message can be repeated until the receiver understands it. However, there are various daily situations where a high speech intelligibility is prefered. From a classroom where is essential that students understand what the professor is teaching; to a supermarket, where product information advertising through P.A systems is meaningful for business. The need of objectively quantifying speech intelligibility becomes evident.

In 1971, Tammo Houtgast and Herman Steeneken [1] proposed that the quality of speech intelligibility could be determined by an objective parameter known as STI (speech transmission index). Since then, other parameters (such as Alcons, STIPA, RASTi, etc) were developed and are used nowadays to determine the speech intelligibility of a location of interest.

The purpose of the present report is to measure and determine STI and ALcons% parameters in a beer pub named Holzen Hops, located in Buenos Aires, Argentina; by applying the impulse response method specified in ISO UNE-EN 60268-16. A total of 12 STI and 4 background noise measurements are carried out.

The structure of this paper will be as follows: in the first part, a brief summary of basic concepts are introduced; then methodology and procedures are explained; later, results are analyzed and discussed; and finally, conclusions are presented.

2. CONCEPTS AND TERMS

2.1 Intelligibility

In speech communication, intelligibility is a measure of how comprehensible is a message transmission system. Speech intelligibility is negatively impacted by background noise and excessive reverberation. The relationship between signal to noise levels is crucial: speech transmission is often compromised for S/N ratio lower than 12 dB, according to Robinson and Casali [2].

2.2 Articulation Loss of Consonants (ALcons%)

The articulation loss of consonants in speech (Alcons) is determined by intelligibility tests as shown in equation (1)

$$\%AL_{cons} = 100\% - WER \tag{1}$$

Where WER is the word error rate during a dictation of words. According to Peutz [3], ALCons% can be calculated from the equation (2) :

$$\%AL_{cons} = \frac{200\, r^2\, {T_{60}}^2\, (1+N)}{V\, Q M} + K \tag{2}$$

Where r is the distance from the loudspeaker to the farthest listener, RT60 is the reverberation time in seconds, V is the volume of the room in cubic meters, Q is the directivity ratio, N the number of sources radiating equal SPL, and M is a constant usually chosen as 1. K is a correction factor of 2% for a good listener. When D2 is greater than 3.16 times the critical distance, equation (3) can be used.

$$\%AL_{cons} = 9\, R\, T_{60} \tag{3}$$

From these equations, it can be noticed that intelligibility depends heavily on reverberation time and distance to loudspeaker.

Also SNR is important when this parameter is lower than 25 dB as seen in Figure 1, taking into account Peutz considerations and having a SNR measurement, optimal reverberation time can be calculated for a good intelligibility [3].

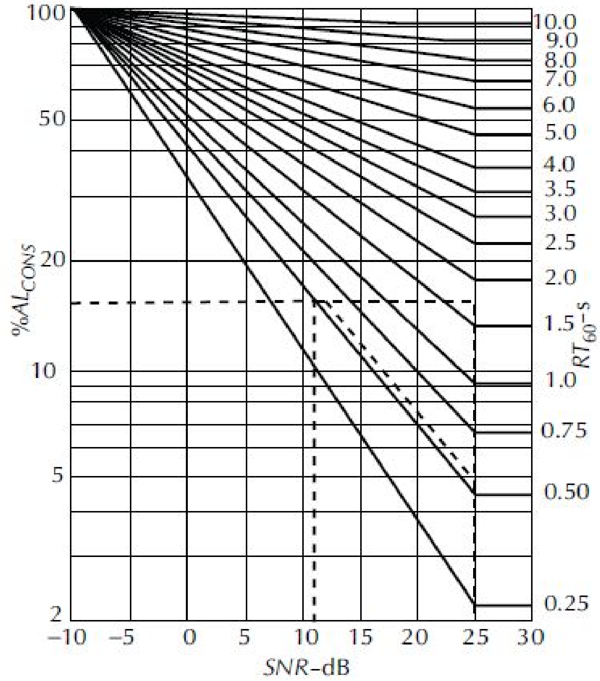

Figure 1: Effect of SNR in %ALcons.

Peutz states that when %ALcons is lower than 10%, speech intelligibility is very good, and an %ALcons of between 10% and 15% is sign of a good intelligibility only for certain messages, listeners and talkers. Effect of distance to loudspeaker is shown in Figure 2.

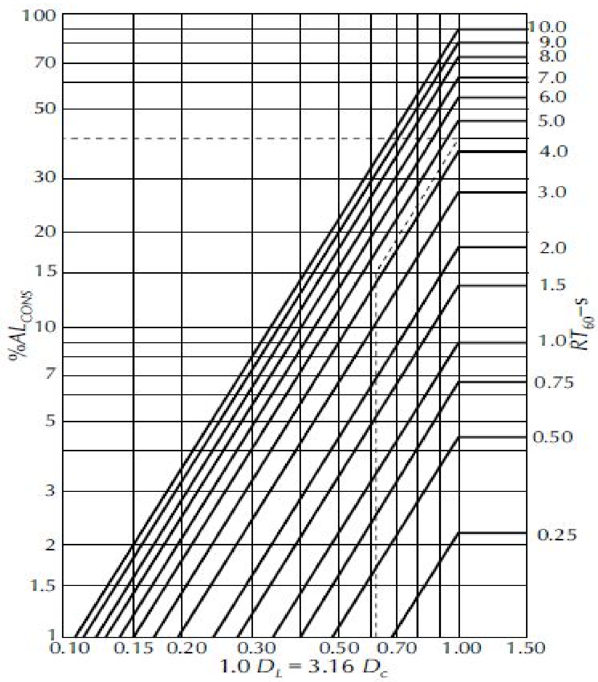

Figure 2: Effect of distance to loudspeaker and critical distance in %ALcons. [3]

2.3 Speech Transmission Index (STI)

Speech Transmission Index (STI) is an objective parameter for evaluating intelligibility based on the modulation transfer function (MTF). Modulation transfer function is measured by exciting the room with a well defined envelope input signal and observing the envelope of the output system. Considering the input signal of equation (4).

$$I(t) = I_{IND}\ (\ 1 + cos\ 2\pi\ F\ \ t\ ) \qquad (4)$$

Where F denotes the modulation frequency, the output of equation (5) is measured.

$$I_0(t) = I_{OUT}\ (1 + \ m\ cos\ 2\ \pi\ F\ \ t\ ) \qquad (5)$$

Where m is the modulation depth or index and takes a value between 0 and 1 reflecting the loss of modulation caused by the system and transmission path.

Reverberation decreases m as can be seen in equation (6) and Figure 3.

$$m_R(F\,) = \frac{1}{\sqrt{1+(\frac{2\,\pi\,F\,T}{13.8})^{\,2}}} \qquad (6)$$

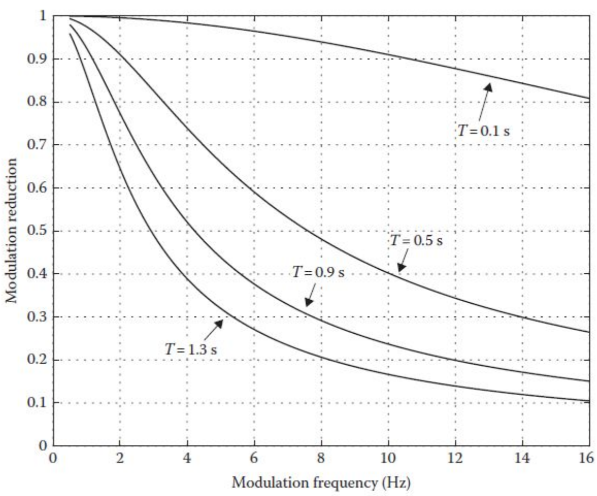

Figure 3: Modulation reduction as function of modulation frequency and reverberation times.

Also, SNR and m can be related through equation (7).

$$SNR_{dB} = 10\ log_{10}\ (\frac{m_N}{1-m_N}) \qquad (7)$$

This way, effect of noise on modulation index can be calculated, and effect of reverberation can be interpreted as a noise contamination.

Kuttruff [4] explains that moving as much radiated sound energy as possible to early reflections, or early receiver pickup, increases STI. Later arrival of sound is smeared with prevailing reverberation.

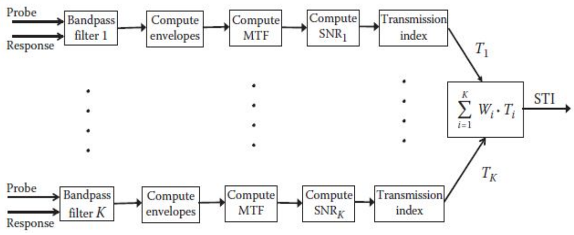

Figure 4: Flow diagram of STI calculation.

Steps for computing STI are shown in Figure 4. First, the probe signal is filtered in octaves (125 Hz - 8 KHz) and envelopes are computed using 14 modulation frequencies determined in [5]. Differences in modulation index across each envelope are computed obtaining MTF for each envelope and band. From MTF using Equation 7, SNR is computed and by taking the mean of SNRs and normalizing to 1, Transmission index is computed. STI is obtained weighting each band transmission index. Different weights are specified for male and female voices.

A Table is given courtesy of Farrel Becker, showing relationships between %ALcons, STI and intelligibility quality, are shown in Figure 5. Also formulas are derived from approximating table results.

	STI	$\%AL_{CONS}$		STI	$\%AL_{CONS}$
	0.20	57.7		0.60	6.6
	0.22	51.8		0.62	5.9
BAD	0.24	46.5	GOOD	0.64	5.3
	0.26	41.7		0.66	4.8
	0.28	37.4		0.68	4.3
	0.30	33.6		0.70	3.8
	0.32	30.1		0.72	3.4
	0.34	27.0		0.74	3.1
POOR	0.36	24.2		0.76	2.8
	0.38	21.8		0.78	2.5
	0.40	19.5		0.80	2.2
	0.42	17.5		0.82	2.0
	0.44	15.7		0.84	1.8
	0.46	14.1		0.86	1.6
	0.48	12.7	EXCELLENT	0.88	1.4
	0.50	11.4		0.90	1.3
FAIR	0.52	10.2		0.92	1.2
	0.54	9.1		0.94	1.0
	0.56	8.2		0.96	0.9
	0.58	7.4		0.98	0.8
				1.00	0.0

Figure 5: Subjective Valuation of STI & Alcons%

Numerous formulas correlating STI and ALCons% exist but there are limitations as they are based on English language tests, but they serve as a good approximation. Equation (8) and equation (9) are some of the formulas which correlate STI and ALcons% parameters.

$$\%AL_{cons} = 170.5405\ e^{-5.419\ STI} \quad (8)$$

$$STI = 0.9482 - 0.1845\ ln\ (\%AL_{cons}) \quad (9)$$

Previous studies of STI over PA emergency systems can be found in [6] where intelligibility in a new canadian subway line was tested. An STI value higher than 0.45 was desired as higher values were difficult to reach because of the high reverberation time of 1.5 seconds in the subway. Different distances to microphone were used in order to test the influence of acoustics and PA system quality in a separated way. STI values ranging from 0.42 to 0.63 were obtained. Another study is performed in [7] where STI in a road tunnel is evaluated and also simulated by generating a synthetic IR with ray-tracing method.

3. CHOSEN FACILITY

3.1 Location and Activity

The chosen location, in this case, is a beer pub named “Holzen Hops” on Av. Maipú 3886, located in Olivos, Buenos Aires, Argentina.

Even though the pub is open everyday from 1:00 pm to 1:00 am; its highest demand occurs on thursdays, fridays and saturdays, peaking at 9:00 pm, information provided by Google’s machine learning algorithm “Popular Times” [8]. According to information provided by the establishment owner, the pub has the capacity of hosting up to 200 people. However, since there is no sitting place available, the pub allows people to remain inside the establishment standing up. According to the owner, the most crowded day was during a decisive football match between Argentina and Ecuador for the last World Cup classification, where the pub hosted approximately 250 people.

The pub has three distinct sections where customers are allowed to sit: inside the building, outside on the street, and outside in the backyard. However, the street section has no PA system. The pub dimensions are 9 m wide, 25 m long and it has a ceiling 3.5 m high. Its volume inside is estimated to be over 350 m^3. Even though a sense of volume cannot be calculated for the outside sector since it is open, the surface area of the backyard is 85.4 m^2. The pub blueprints, frontal section and 3D model made based on in-situ measurements are shown in Figures 6-8.

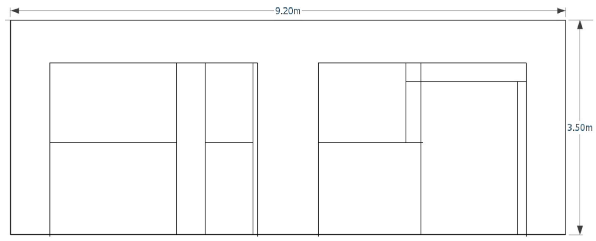

Figure 6: Holzen Hops, Frontal Section

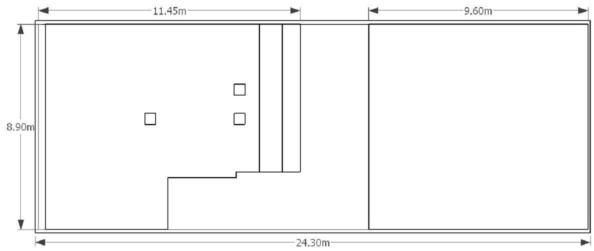

Figure 7: Holzen Hops, Blueprint

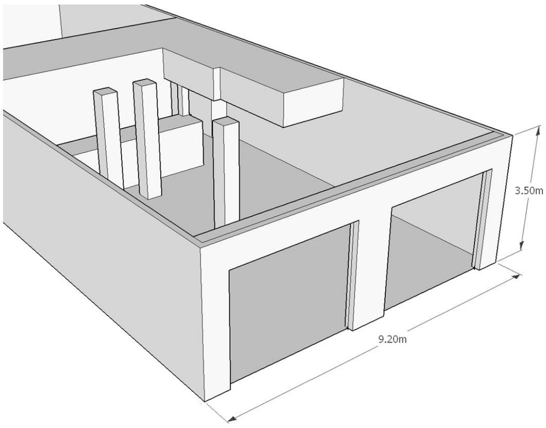

Figure 8: Holzen Hops, 3D Model

This particular location was chosen because of two main reasons: in the first place, the pub can host a great amount of people in a regular working night, when the noise generated by the customers, the music and the avenue elevated traffic noise could empurish the message being transmitted by the PA system. This can represent a serious problem in an emergency situation where an evacuation protocol is to be reproduced through the PA system and must be understood in every establishment location. On the other hand, the main use of the PA system is to inform the customers when their order is ready. The customer is called by their name and they must go to fetch their order. The owner explains that often customers cannot distinguish their names, which leads to unnecessary delays.

3.2 Installed PA System

Holzen Hops has an installed array of centrally power amplified speakers that the pub uses mainly to call customers, scattered around the multiple sectors of the building, waiting to receive their order.

The speaker array is a LD LDSAT62AG2, 6.5’’ PA System [9]. A unit is shown in Figure 9.

Figure 9: PA System, Model LDSAT62AG2

The speaker is a 50 W_{RMS} , active system, with an 6.5’’ (165mm) woofer and a 1’’ (25mm) tweeter, with a claimed frequency response that ranges from 55 Hz to 20 kHz, reaching maximum sound pressure level of 108 dB. Its cabinet is built from MDF, providing an horizontal and vertical dispersion 60°. Each unit is 200 mm wide, 320 mm high and 200 mm deep, weighting 5.25 Kg.

The pub uses a SKP 58XLR [10] dynamic cardioid microphone. Its frequency response is claimed to be from 60 Hz to 16 KHz. Its specifications show a sensibility of -77 dB with an uncertainty of 3 dB.

A picture of the microphone is shown in Figure 10.Information regarding the PA speakers used in the backyard as well as the amplifier model, is unknown.

Figure 10: Pub’s PA Microphone, SKP 58XLR

The PA system consists of six speakers, four of which are LDs indoors and two unknown exterior speakers outdoors.

Figures 11-14 show pictures of the PA installed in the pub.

Figure 11: PA System, Holzen Hops.
Inside left side.

Figure 12: PA System, Holzen Hops.
Inside right side.

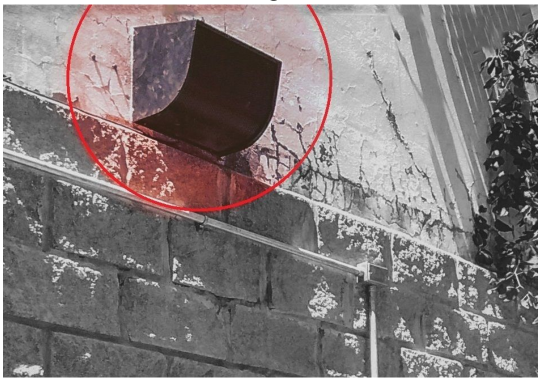

Figure 13: PA System, Holzen Hops
Outside left side.

Figure 14: PA System, Holzen Hops
Outside right side.

4. METHOD

4.1. Standards

In order to obtain intelligibility parameters, the ISO UNE-EN 60268-16 [11], method was used. This part of the standard contemplates four methods for the evaluation of the quality of speech transmision regarding the intelligibility of the spoken word. This methods are:

- STI
- STITEL
- STIPA
- RASTI.

In this report, only the first method is used, which can be useful for comparing the speech intelligibility in several locations inside a room and also to determine the effect that its acoustical characteristics can have over the intelligibility.

The determination of the speech quality is related with the reduction of the modulation signal (m_1) that simulates the speech of a real person. There are three possible methods to obtain the STI values according to the standard:

- Exciting the room through a microphone input
- Electrically injecting a signal through the microphone input
- Applying MLS analisis equipment

The first method is used in this report. It is based on the frequency spectrum of the spoken word. Speech can be separated in individual phonemes, each with a unique frequency spectrum. Distortion of the signal as a consequence of possible reverberation or background noise can affect this spectral components thus distorionign the message. By comparing the spectrum envelope of the signal obtained directly for the announcer and from the transmission channel determines the fluctuation losses of the transmission channel.

Before any STI measurements are performed, the standard states that the signal level reaching the microphone should be the same than those sound pressure levels generated in a normal speech. For this purpose, following the standard indications the speaker level must be adjusted until a global 62 dBA level is achieved at the microphone at 1 mt from the speaker.

4.2. Measurement Set-up

For the measurement the following equipment was necessary:

- KRK Rokit 6 G2 Active Monitor
- Behringer ECM8000 Microphones (2)
- Focusrite Scarlett 18i6 audio interface
- M-audio Fast Track 8 audio interface
- Sony Vaio E Series Notebook
- Asus X541U Notebook
- XLR, RCA, USB, AC cables extensions

The connection diagram between all the equipment is shown in Figure 15.

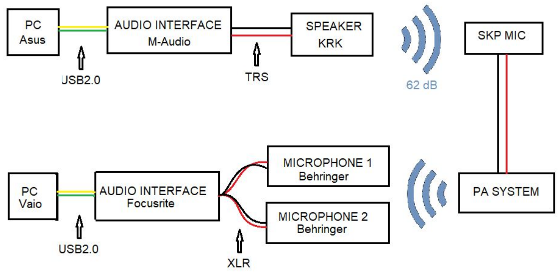

Figure 15: Equipment connection diagram

4.3. Measurement procedure

4.3.1 Background Noise Measurement

As it was stated before, the background noise of a certain room can reduce the spectral differences between the phonemes, thus diminishing the STI values. So the background noise of the room is very important in order to calculate correctly this parameter. In order to obtain representative measurement of the background noise considering different noise levels scenarios throughout the day, measurements were performed with customers on a saturday at 9:00 pm (peak of activity), and the very next day at 11:00 am without customers, when the pub was closed to public. Two microphone positions inside the building (C1 and A1 from Figure 16) and two outside (D1 and E1 from Figure 17) were set during the measurements. Background noise was recorded in the lapse of one minute for each

4.3.2 STI Measurement

The method implemented for measuring STI is described in ISO 60268 section 4.6.1, which establish that the measurements shall be performed by exciting the room through a microphone input.

In order to calibrate the speaker to 62 dBA, a pink noise signal was applied to the input, and a microphone recorded the output level through an already calibrated system (94 dB SPL). The SPL is obtained by post-processing the recorder signal through a custom design sonometer in the Matlab platform, previously validated. This procedure was repeated until the desired level was achieved.

Once all the aforementioned conditions were satisfied the measurements can be performed. In the first place, the KRK Rokit was positioned in the bar counter where the microphone is located, at 20 cm distance. In order to correctly characterize the room, six measurement positions were chosen inside and outside as shown in Figure 16 and 17. This measurement positions not only intend to register the direct radiation of the PA system in each location, but also to register the ambience of the room. Positions with subindex 1 (A1, B1, C1, etc) represent the positions that were under direct radiation of the PA system, while positions with subindex 2 represent the opposite situation. The positions that share the same letter are those that were performed simultaneously as there were available only two microphones, so in order to obtain all the desired positions, a total of six measurements were needed.

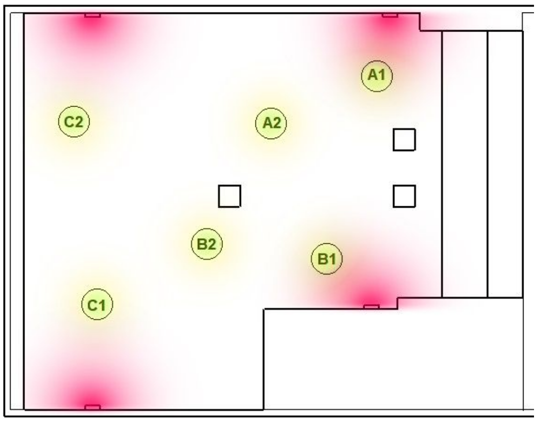

Figure 16: Microphone Positions, inside.

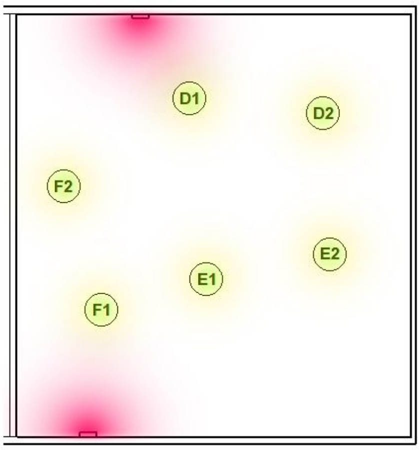

Figure 17: Microphone Positions, outside.

The excitation signal used was a log sine-sweep (LSS) with a duration of 30 seconds, 8 seconds of silence and a frequency range from 80 Hz to 16000 Hz in order to obtain a valid measurement in the frequency bands of interest.

4.5 Postprocessing

4.5.1 Noise Processing

Background noise recordings and microphone calibrations signals are processed with a digital sound meter app developed in the Matlab environment for previous works. Results are exported into an excel file, where sound pressure levels from the different sectors of the pub are calculated in third octave bands. Calculations can be found in the annexed folder.

4.5.2 Spectrum Computations

To characterize the spectrum response of the PA system, a sine sweep measurement of the SKP microphone can be used to generate a frequency response curve using the "*plot spectrum*" function in Audacity, and later plotting the results in Matlab. However, the resulting curve will be associated to the whole system. In order to obtain the spectrum of the microphone independently, it is necessary to compensate its magnitude with the spectrum of the sound source, measured with a flat frequency response reference microphone. The difference between both curves will result in the frequency response of the mic under test.

4.5.3 RT20 & C50 Computations

Reverberation Time and Clarity parameters are obtained by convolving the recorded sine sweeps (y[n]) with its inverse filter (x^{-1}[n]), in order to generate an impulse response (h[n]). The last signal is processed using Aurora's "Acoustical Parameters" module, which estimates T20 and C50 values per octave band for each measurement. Finally, this data is exported into an excel file where averages are calculated.

4.5.4 STI Computations

STI values were computed with Angelo Farina's software Aurora's Speech Transmission Index evaluator [12] hosted in Audacity 2.0.5. Four audio files are requested for calculations: 1) a calibration signal of 94 dB. 2) room's background noise. 3) a test signal (pink noise recorded at 1 meter from loudspeaker at 62 dBA as requested in ISO UNE-EN 60268-16. 4) the room impulse response. From audios 2 and 3 the software calculates the SNR, and with audio 4, it calculates the MTF.

STI was calculated at each position using the corresponding background noise and calibration file. *STIMale*, *STIFemale*, RaSTI among other parameters are calculated by the software. Each measured STI was calculated with and without noise correction in order to be able to separate background noise from room acoustics effects producing loss of intelligibility.

Colormaps of STI, T20 and C50 values along Holzen Hops were computed in Matlab by linearly extrapolating the scattered measured data in a rectangular grid of 14 x 17 for indoors and 14x13 for outdoors with the *ScatteredInterpolant()* function. After obtaining the extrapolated surface, *GriddedInterpolant()* function was used to refine the grid with cubic splines and a smooth surface was obtained. *Contourf()* was used to compute the filled contour plot. To avoid asymptotic behaviours, values at the borders were fixed with nearest measured value.

5. RESULTS & DISCUSSION

5.1 Background Noise Results

After post processing the background noise files, four different curves can be generated combining measurements from the inside, the outside; with customers and without customers. Curves are shown in Figure 18.

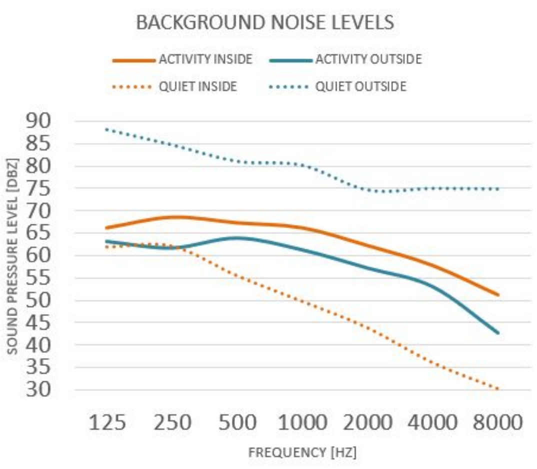

Figure 18: Background noise levels

It is observed that the lowest sound pressure level registered correspond to the measurement inside, without customers, which is logical as the place is quiet and isolated from traffic. The maximum values registered correspond to the measurement outside, because there was a loud AC compressor turned on while there were no customers. As the AC units were turned off when people arrived, background noise levels outside sharply decreased. Whereas, levels inside increased significantly due to customers interaction.

5.2 PA Frequency Response Results

The SKP microphone used by the pub does not present a datasheet with an accurate frequency response curve. Therefore it is obtained as the difference between its measurement and the sound source spectrum, as shown in Figure 19.

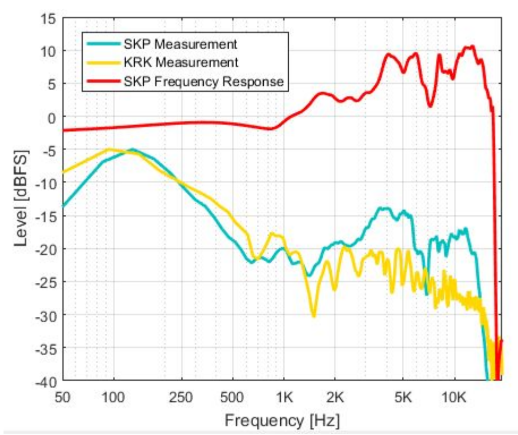

Figure 19: SKP Microphone Frequency Response

As it can be observed, the frequency response of the SKP microphone is very different when applying the source difference correction. Originally, low frequencies were boosted, however, by analysing the KRK spectrum for the same microphone position (35 cm from the acoustical center) it is observed that this boost is attributed to the uneven frequency response of the sound source used. The corrected spectrum shows a flat frequency response for low and mid range, with boosted high frequencies over 4 KHz.

Since six measurements were done considering six PA speakers, it is possible to generate a frequency response for each measurement using the direct recording, shown in Figure 20. Differences in magnitude will be associated with distance to source disparity.

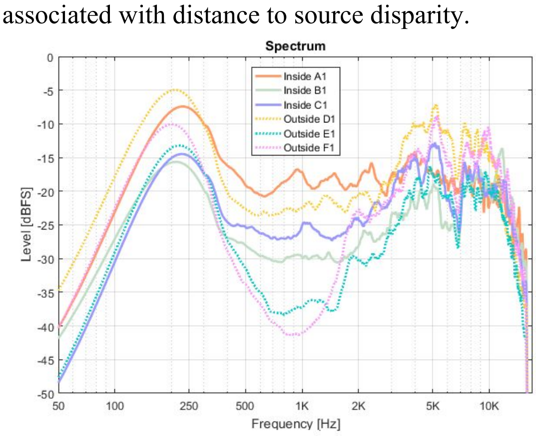

Figure 20: Spectrum of measured IR.

It can be observed that all measurements present a considerable boost at 150 Hz, which is again linked to the source uneven response at low frequencies. Source curve correction was not applied in this case, displaying raw measurements for each direct microphone position.

Spectrum analysis of measurements outside (E and F) show a significant notch at 1 kHz, whereas the others do not; this may be due to the existence of two diverse PA speaker models used outside and inside.

5.3 T20 & C50 Results

Values obtained for T20 analysis are shown in Figure 21.

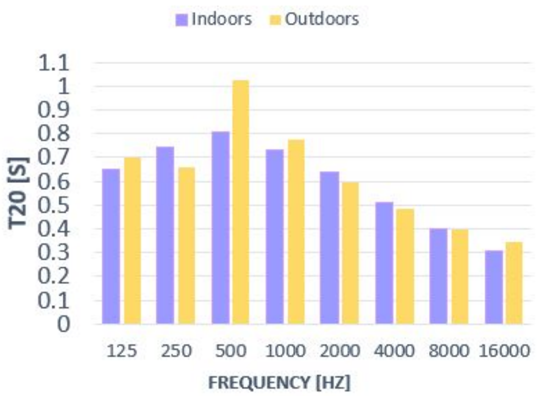

Figure 21: T20, Indoors vs Outdoors

No significant differences in reverberation time measurements are found between the outside and inside, but clarity is noticeably higher outside possibly due to the highly reflecting walls which provide strong early reflections.

Mean T20 inside is 0,55 seconds and outside 0,52 seconds. According to equation 3, if these reverberation times are multiplied by 9, predicted ALcons% are 4,68% outside and 4,95% inside. Calculated mean ALcons% values with Farrel Becker equations are 3,7% and 4,64% respectively. Both of predicted ALcons% are good and provide a good intelligibility of the PA system. If equation 2 is used, taking a distance of 4.5 meters, N = 4 and Q = 4, ALCons% for indoors is 4,37% without using K correction. As no volume is enclosed outdoors, the equation 2 cannot be used.

Values obtained for C50 analysis are shown in Figure 22. According to [4], early reflections enhance intelligibility. C50 shows the ratio of early energy to late energy in the impulse response. A higher C50 value means a higher early energy level. As it can be seen in Figure 22, C50 is higher outdoors for almost all frequency bands correlating with the higher STI measured values.

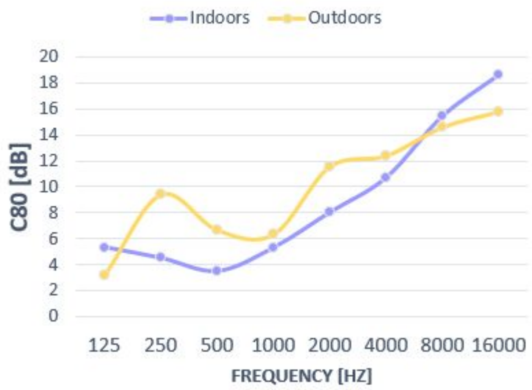

Figure 22: Clarity, Indoors vs Outdoors

5.4 STI & ALcons Results

Obtained STIs and their mean are shown in Table 1.

Table 1: STI and %ALCons Male and Female results for interior and exterior conditions.

Position	STI Male	STI Female	%ALCons Male	%ALCons Female
A-1	0,691	0,695	4,033	3,946
A-2	0,649	0,654	5,063	4,928
B-1	0,658	0,663	4,822	4,693
B-2	0,658	0,662	4,822	4,719
C-1	0,668	0,675	4,568	4,398
C-2	0,668	0,674	4,568	4,422
D-1	0,651	0,656	5,009	4,875
D-2	0,66	0,667	4,770	4,593
E-1	0,724	0,735	3,372	3,177
E-2	0,739	0,75	3,109	2,929
F-1	0,739	0,752	3,109	2,898
F-2	0,754	0,766	2,866	2,686
Mean Inside	0,665	0,671	4,646	4,518
Mean Outside	0,711	0,721	3,706	3,526
Std Inside	0,013	0,013	0,323	0,314
Std Outside	0,040	0,043	0,852	0,870

Mean values in the exterior are higher than in the interior, so intelligibility is slightly better outside. This happens also without noise correction so differences in background noise at exterior and interior are not the causes of differences in STI. A higher deviation is observed in outside measurements. Probably due to a systematic error or a change in measurement conditions, STI results at D1 and D2 are considerably lower than the other 4 measurements. If these outlier measurements are discarded, the mean STI outside is higher reaching 0,739 (male) and 0,75 (female).

Inspection of Figure 23 shows a dip in the 500 Hz and 1 kHz bands of MTI. This can be due to the frequency response of the system which exhibits a significant notch at 1 kHz specially at measurements performed outside.

Figure 23. Measured MTI Mean

Considering the use of alternative background noise, where the AC compressor was turned on, different STI and Alcons% values will be obtained, as shown in Table 2.

Table 2: STI and %ALCons Male and Female results for exterior conditions with HVAC noise.

Posición	STI Male	STI Female	%ALCons Male	%ALCons Female
D-1	0,199	0,248	58,009	44,481
D-2	0,259	0,316	41,907	30,771
E-1	0,216	0,272	52,903	39,056
E-2	0,287	0,353	36,007	25,180
F-1	0,225	0,282	50,385	36,996
F-2	0,290	0,356	35,427	24,774
Mean	0,246	0,305	45,773	33,543
Std	0,035	0,041	8,556	7,263

STI measurements with HVAC noise give poor intelligibility results as SNR is very low. Modulation depth is highly decreased and %ALCons is of 45% for male voice and 33% for female voice. This subtle difference can be explained by inspection of Figure 24 where it can be seen that modulation is 0 for low frequency bands. As female voice has its spectrum more concentrated in higher frequency bands, differences in STI are slightly favorable for female voices.

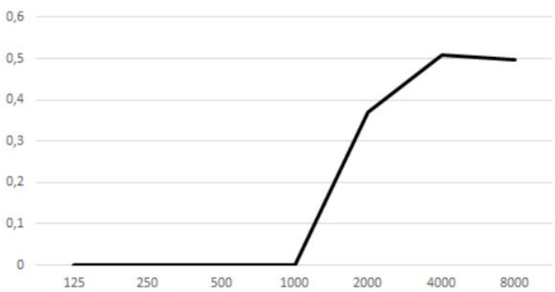

Figure 24. Mean MTI under HVAC Noise, outdoors

5.5 Spatial distribution of STI

Various parameter measurements are mapped to microphone locations through an specially developed matlab code. Results for STI mappings are shown in Figure 25 and 26; C50 mappings are shown in Figure 27 and 28; and finally T20 mappings are shown in Figure 29 and 30.

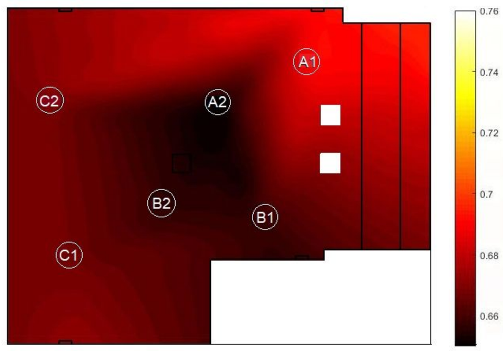

Figure 25: STI Male Contour Plot, indoors

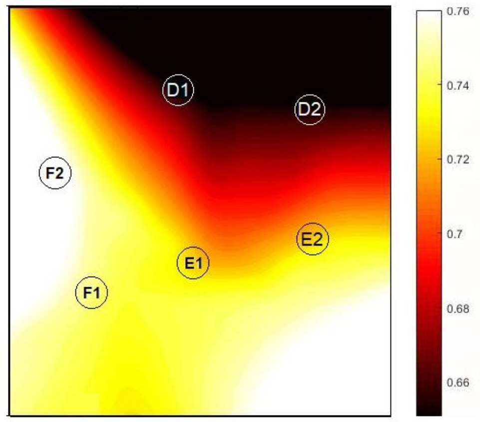

Figure 26: STI Male Contour Plot, outdoors

From Figure 25, it can be seen that the zone with less intelligibility is located in the middle of the bar, which corresponds to the farthest place to loudspeakers. This causes the direct to reverberant ratio to be lower than near the PA System. A2 measurement position exhibits the largest T20 and the lowest C50 as seen in Figures 27-28.

From contour maps, a correlation between T20, C50 and STI can be observed: a higher C50 and lower T20 increases STI and %ALCons. Highest intelligibility outdoors is observed near the loudspeakers, specially the one at the upper right corner (A1 position). Anyway, variations in STI indoors are within the 3.8% of the mean value and uncertainty taking 95% of confidence and assuming normal distribution of measurements is 0.026.

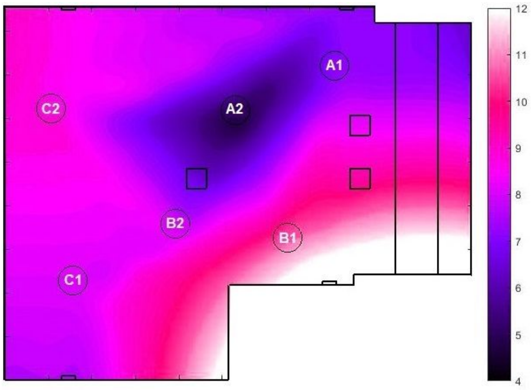

Figure 27. C50 Contour Plot, indoors

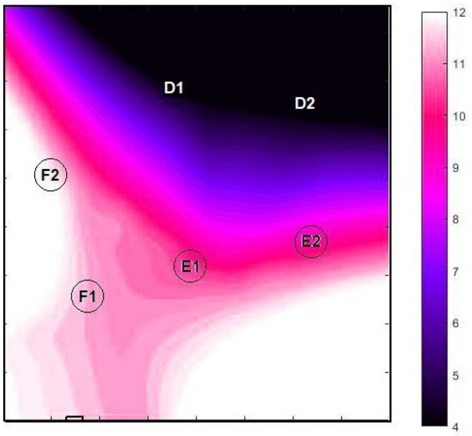

Figure 28. C50 Contour Plot, outdoors.

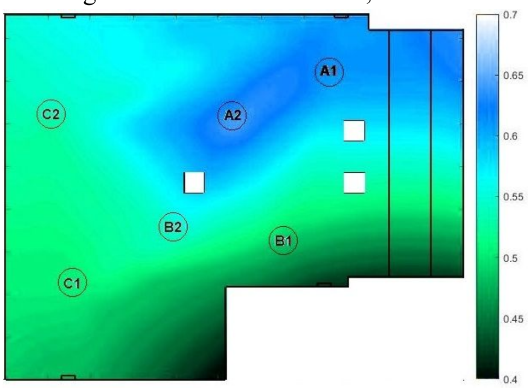

Figure 29. T20 Contour Plot, indoors

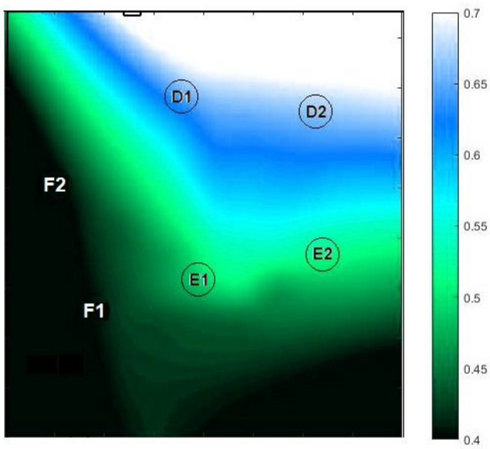

Figure 30. T20 Contour Plot, outdoors

Outdoors a big difference in STI, RT20, and C50 is observed between positions D1 and D2, and the other ones. This can be caused by the closeness to the compressor (which was placed on the upper wall), or by a measurement error (for example an unnoticed change in measurement conditions).

6. CONCLUSIONS

The measured facility has an overall good intelligibility as STI values are higher than 0.64 for all measured positions. Outdoors STI is slightly higher during normal conditions, but when outside machinery is turned on, noise level increases noticeably resulting in a poor STI measure. This indicates the need of insulating HVAC noise to improve intelligibility in this condition and avoid tragedies in an emergency case. Changing PA systems also could improve intelligibility, as current system has a dip at 1 kHz band. During the study it was found a correlation between reverberation times, C50 and STI measurements. Higher levels of C50 and lower reverberation times correlate with an increase in STI.

7. REFERENCES

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