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“Experimental and numerical analysis of the acoustics of a manufacturing plant”

TRABAJO FINAL DE GRADO

Autor/a:
Àngela Molina Sancho

Tutor/a:
Marco Carlo Masoero
Joan Martínez Mora

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1. Introduction

1.1. Objetive

This report has the objective of the acoustic condition by developing an analysis, both experimental and numerical, of the reverberation time of a manufacturing plant of the company Fondalmec that is part of the group Endurance.

The project starts with the reverberation time measurement in the factory, followed the extraction of the measurements with the software BZ-5503 and Evaluator 7820. Then the work consists in interpreting the data the sound level meter had compiled and make the pertinent calculation to obtain the T60 of the experimental part of the thesis. After that, it starts the virtual part which is divided in two phases, the first one, is the design of the plant with design software SketchUp and after that run the simulation with acoustic software Odeon 13. And at the end is going to proceed to develop a hypothesis of a possible reduction of the reverberation time and which could be the solutions.

1.2. Presentation of the study object

Fondalmec is a plant of the Endurance Group, located in Lombardore (Piedmont, Italy), focused on automotive market, the core business is the machining and preassembly on aluminium castings, cast iron and forged parts.

Figure 1- Fondalmec Factory

Fondalmec was founded in 1976 as part maker for the industrial vehicle and earth movers' market sector. In 2007, became member of Endurance Group but not completing the 100% the acquisition until 2010 when consequently changed the name into Endurance Fondalmec.

The measurements had been taken place in the new plant of the company, which has a surface of 3,750sqm. In the next figure (Figure 2) is showed the location of the plant in the company with a red rectangle at the bottom of the image.

Figure 2- Company plan

1.3. Introduction to acoustics reverberation

As it is said in the first point of the report the main propose is the acoustical condition of the plant and it is defined as the actions that is need to be done to the sound produced inside the room arrive in perfect condition to the listener determining the acoustic properties which must collect the materials they cover the interior of the room, as well as its placement and installation, to achieve an adequate hearing.

In this point it is impossible to start to speak about reverberation time without speak about Sabine.

Wallace Clement Sabine was an American physicist who formally defined the reverberation time, also named as T60, as the quantity of seconds that is required for the sound's intensity to decrease from the start level the quantity of 60dB.

His equation with all the units are SI is:

$$T = \frac{V}{A} \cdot 0.161s$$

Where

T= the reverberation time

V= the volume of the room

A= the total absorption area

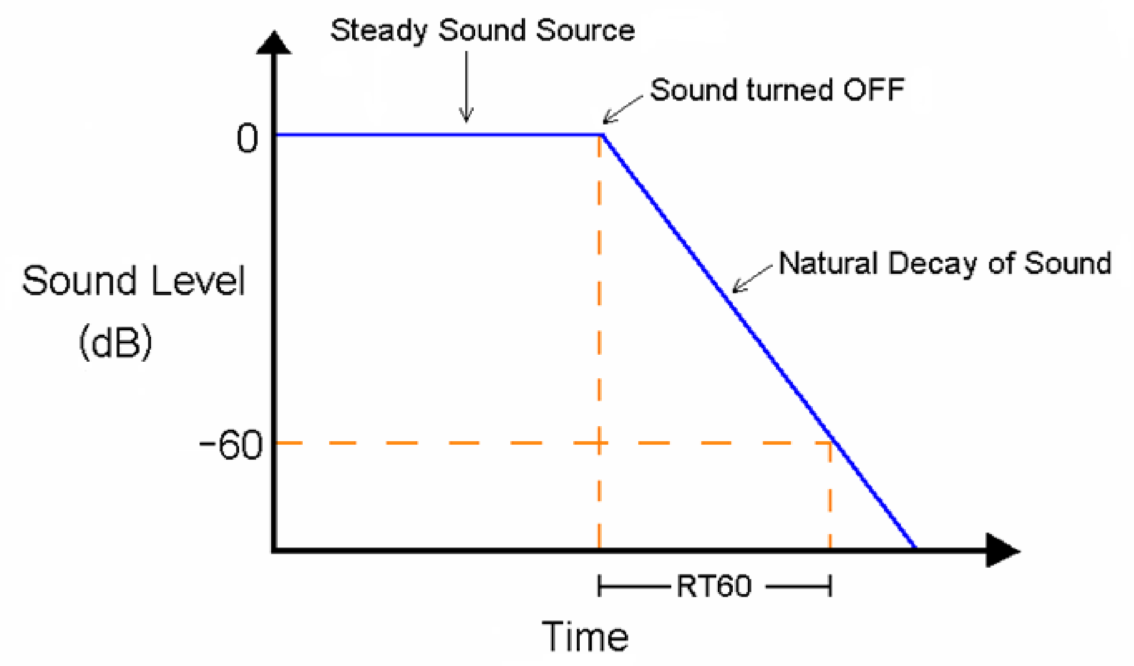

Figure 3-T60 graphical definition

To determinate de reverberation time value it is needed to know the absorption coefficient of any surface in the room. The absorption coefficient, a, is the coefficient without units that provide the amount of sound energy a material can absorb; the value can change with frequency and angle of incidence, and is expressed as a value between 1 (total absorption) and 0 (zero absorption).

2. Instrumentation and experimental setup

2.1. Instrumentation

The instrumentation used to develop the measurements is the following:

- **Sound level meter** 2250 Brüel & Kjäer LIGHT, Type 1
- **Sound calibrator** Brüel & Kjäer (1kHz,94dB), model 4231, type 1
- **Windscreen** spherical UA-1650 90mm spherical windscreen with authomatic detection for the Brüel & Kjæ 2250 Type 1 Sound level meter.
- **Microphone** Brüel & Kjäer Type 4189 pre-polarized of free field ½" with nominal circuit of 50mV/Pa and with dynamic range in weight A between 16.6 and 140dB.
- **Tripod** Gitzo GT1545T
- **Software** BZ 5503
- **Software** Evaluator 7820

2.2. Experimental setup

The first step was to set up the tripod, where later would take place the sound level meter, with a height of 1.5 meters and with a distance of 1 meter of any surface, like it could be walls, doors, machines, etc. (Figure 3). After that, it had to set up the sound level meter, introducing the microphone and the windscreen to be able to screw it into the tripod.

Referring to the sound level meter configuration, it was configured in the mode "Reverberation time" with a sampling interval of 5 milliseconds. It was configured a bandwidth from 63Hz to 10 kHz in step of 1/3 octave band.

Finally it was created a new folder in the memory of the sound level meter to have all the measurements in order.

Figure 4- Location of the sound level meter to carry out measurements

3. Measurements

The next step was to place the sound level meter in a different parts of the factory separated from any close surface, to measure the reverberation time of the noise produced a pistol; this pistol was held by Professor Fabrizio Bronuzzi and located in the enough distance from the sound level meter. There were determinate 8 points around the plant making two measurements for each point, the distribution of the points could be observed in the Appendix 1.

At this point, one the sound level meter is calibrated and the adjustments of the measure instrument were checked, it was preceded to measure the reverberation time obtaining 16 samples of 800 of points and with duration of 5ms each one. Once the measurements were finalized it was proved that everything was alright and it was saved the data.

Figure 5-Measurement of the reverberation time

Once the measurements were done, all the data obtained were dropped into the computer using the software BZ 5503 and after that it was used the software Evaluator 7820 (both of them belong thot ha same company as the sound level meter, Brüel & Kjær).

3.1. Interpretation of measures

As a result of dropping the data from the sound level meter was an Excel sheet with 16000 lines where the values of the 16 samples where. For the simulation with Odeon we only need the data of the average between the values obtained in the two measurements of the eight points, acquiring a total of eight samples, one for each point, named from one to eight. From each sample of 800 points where selected two to proceed to the calculations of the T60, in this case were selected the points 100 and 400 with a frequency range between 63Hz to10kHz.

The first step to calculate de reverberation time of the measurements is providing the difference between the values of the points in the same frequency.

$$Difference\ (dB) = Level\ lower\ point - Level\ higher\ point$$

Sample 1	Reverberation Decay 63Hz
100	81
400	70,79
Dif(dB)	10,21

Table 1- Extract of the values' difference between the points in the same frequency

The next step was calculate the amount of time between points, so if every point take 5 milliseconds the simple equations is the following and the results are represented in the Table 2.

$$Time\ (s) = (Higher\ point - lower\ point) \cdot 5ms$$

Sample 1	Reverberation Decay 63Hz
100	81
400	70,79
Time(ms)	1,5

Table 2- Results of the amount of time between points

After that, the procedure was to calculate the T60 following the next equation and like the previous step the results are shown is the Table 3.

$$T60(s) = \frac{60}{Diff\ (dB)} \cdot Time\ \ (s)$$

Sample 1	Reverberation Decay 63Hz
100	81
400	70,79
T60(s)	8,814887

Table 3- Results of the T60

Finally as the results are in 1/3 octave band and the Odeon software does not read this band it had to be changed to octave band, for that it had to be done an average of the three frequency T60 values included in the each octave band.

Sample 1	Reverberation Decay 63Hz	Reverberation Decay 80Hz
100	81	90,18
400	70,79	69,31
Dif(dB)	10,21	20,87
Time(s)	1,5	1,5
T60(s)	8,814887	4,31241
T60(s)	6,563649	

Table 4- Result of the T60 in octave band

The complete results of the calculation are shown in a table in the Appendix2.

After that as it is said above for the simulation it is only needed eight samples so the next step was to do the average between the two samples of the same point and as a results is obtained the Table 17 of the Appendix 3.

4. Simulation

4.1. Design of the model

In this point, to be able to procced with the simulation is needed to design the model using the software AutoCAD and SketchUp.

As in start was design the plant of the factory with AutoCAD basing it in the plant showed previously in the Figure 2 and it dimensions, obtaining the following result.

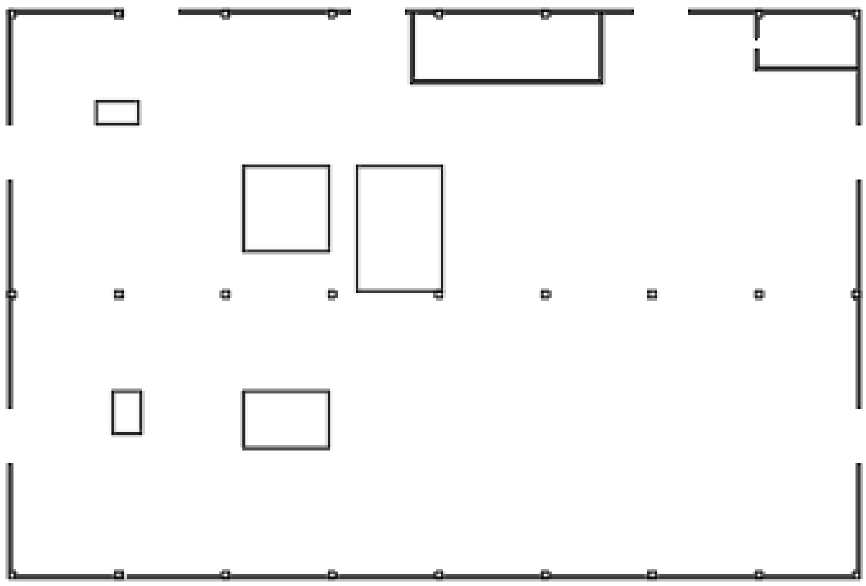

Figure 6- Factory plant in 2D

After that, the plant is imported with SketchUp to proceed to develop the 3D model. In first place, there are build the external walls, letting the spaces that correspond to the doors and pillars. The following step is introducing the pillars, always following the base plant (*Figure 2*) and the dimensions given by the engineer of the factory. Then there are introduced the rooms that it is possible to see in the Figure 18, that represent the offices. Afterwards, as it is possible to observe in the Figure 18, there are build the cubs that simulate the machines of the factory that are the ones that produce the most amount of noise. Next, there are placed the beams covering the entire surface from West to East and the ceiling, which is placed forming a double triangular prism. The last step is to introduce the windows and doors that is possible to see in the Figures 13, 14, 15 and 16 of the Appendix 4.

It have to be sais the parts of the model were divided in layers named as Ceiling, that include the ceiling and the beams, Walls, comprises the walls and the floor, Pillars, Machines, Doors, that contain the industrial doors to access to the plant, Office doors and Windows.

Once the design is ended, the model must be exported with one of the following formats,(.dxf, .3ds) that are the formats that the simulation software con support.

4.2. Simulation

To develop the simulation the software selected is Odeon 13 that is the Room Acoustic Software that helps you make complete studies of room acoustics for any space through simulations and measurements.

4.2.1. Import the model

The first step of the simulation is importing the model and it is important to follow the next steps,

- Select Files > Import from file (dxf, 3ds, cad).
- Specify the input file Fondalmec.3ds.
- Specify the destination file Fondalmec.par.

Once the file names have been specified, the Import 3ds file dialog appears and all the parameters have to be left by default less the drawing unit that must be in meters like in the SketchUp file.

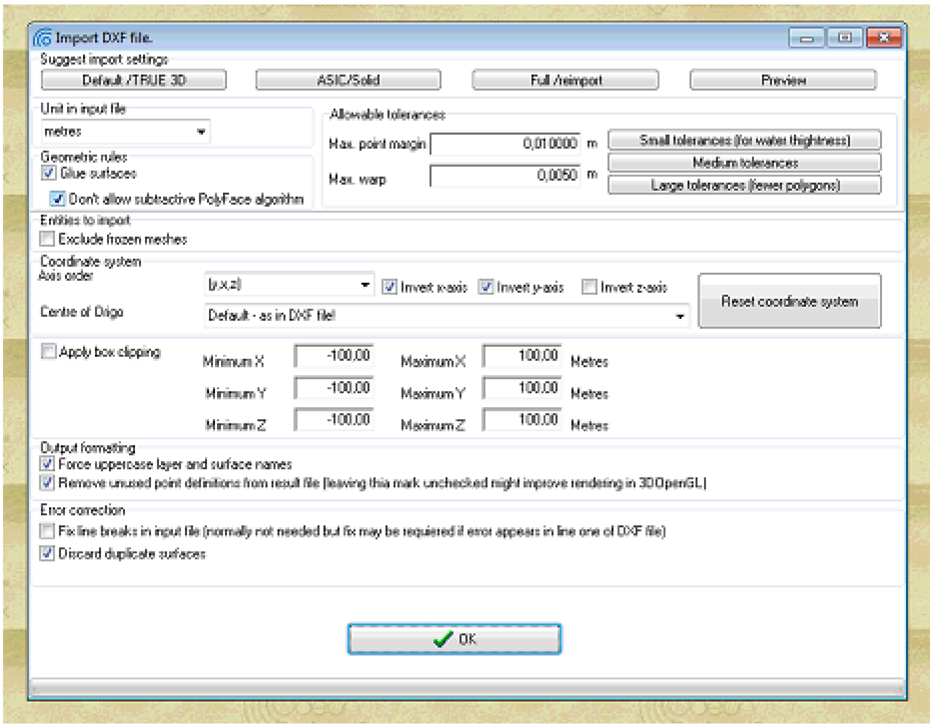

Figure 7- Import file in Odeon

The result of this procedure is the 3D view of the plant as it is possible to observe in the following picture (Figure 8), where all the surfaces are correctly located as in the SkechUp perspectives showed in the Appendix 4.

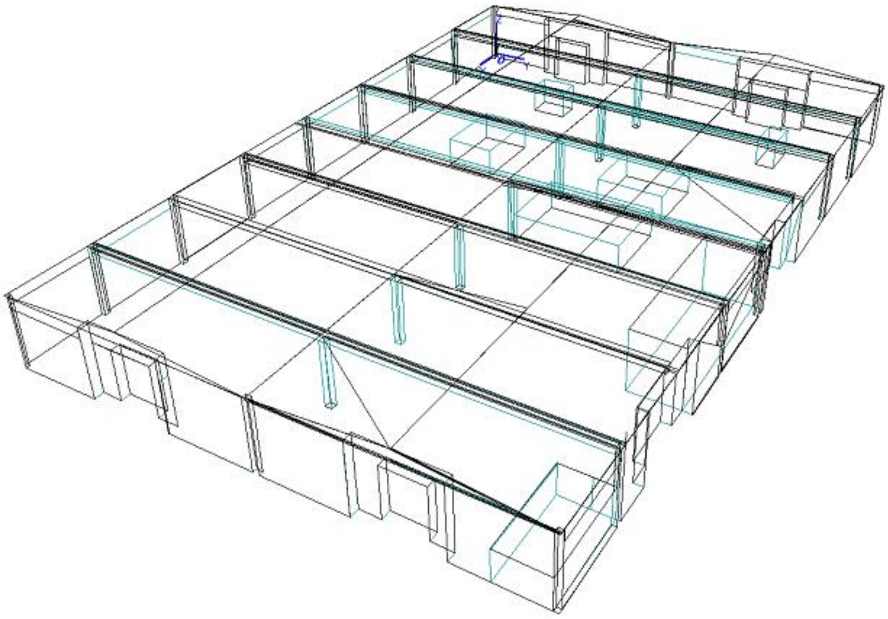

Figure 8- The plant illustrated with Odeon

4.2.2. Materials

The next step is introducing the materials to each surface available in the Material List option. The material list consists in a window with two lists, the surfaces list located in the left of the window, and the material library, in the right part of the window.

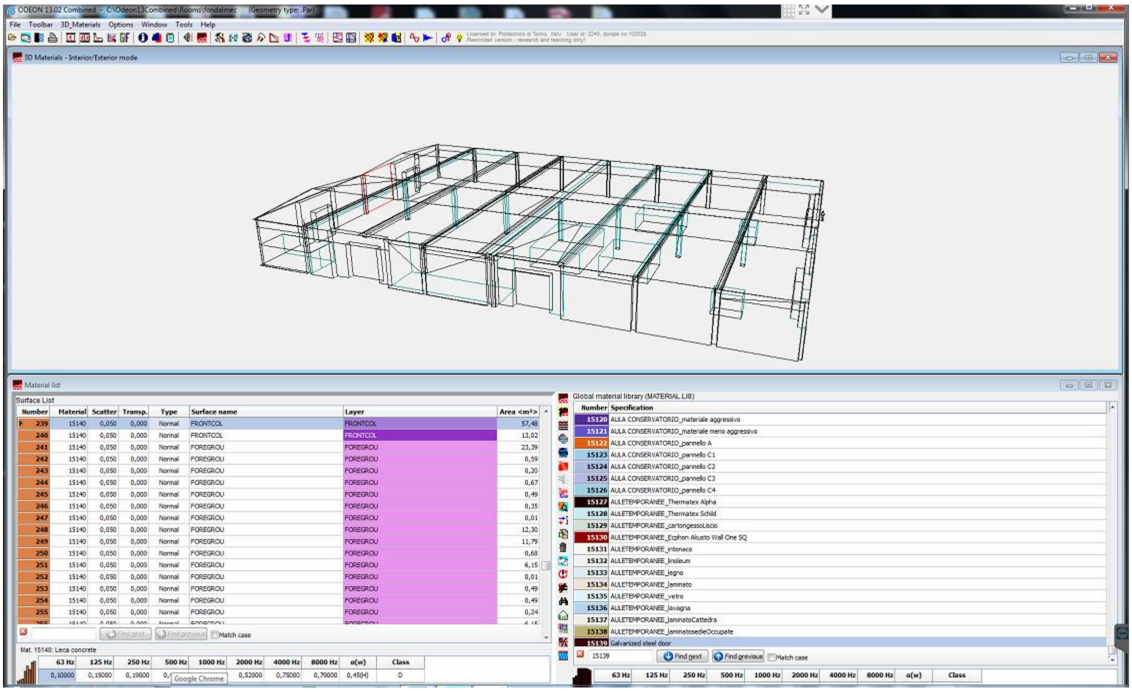

Figure 9- Material list in Odeon

The materials are in order from the number 0 to 15140 and are subdivided in categories, where each material had included the absorption coefficient in the frequency range between 63Hz and 8 kHz in octave band.

- 1-99 Special materials.
- 100-999 Concrete.
- 1000-1999 Brick.
- 2000-2999 Ceramics.
- 3000-3999 Wood.
- 4000-4999 Gypsum.
- 5000-5999 Steel.
- 6000-6999 Vinyl/Plastic/Plexiglas.
- 7000-7999 Carpets.
- 8000-8999 Curtains and blinds.
- 9000-9999 Natural materials (e.g. sand, grass, water…).
- 10000-10999 Doors/Windows/furniture/inventory (e.g. organ pipes, ventilation grills, bookshelves).
- 11000-11999 Audience areas +/- people.
- 12000-12999 Mineral wool.

- 13000-13999 Wood wool and alternative porous absorbers.
- 14000-14999 Slit absorbers/ Micro-perforated absorbers/ miscellaneous.
- 15000-15140 Other materials.

In the next table are exposed the surface selected, the material used for this surface and the absorbent coefficient for each frequency.

Number	Surface	Material	Frequency (Hz)							
			63	125	250	500	1K	2K	4K	8K
102	Floor	Smooth concrete painted	0,01	0,01	0,01	0,01	0,02	0,02	0,02	0,02
5000	Machines	Steel	0.4	0.3	0.25	0.2	0.1	0.1	0.15	0.15
10006	Windows	Glass	0.35	0.35	0.25	0.18	0.12	0.07	0.04	0.04
10007	Office door	Solid Timber wood	0.14	0.14	0.1	0.06	0.08	0.1	0.1	0.1
15139	Industrial doors	Galvanized steel	0,73	0,8	0.99	0,8	0,78	0,8	0,77	0,73
15140	Walls, ceiling and pillars	Fibreboard over airspace on solid wall	0,15	0,22	0,25	0,27	0,35	0,39	0,39	0,4

Table 5-Materials used in the plant

4.2.3. Sources and receivers

As the noise was produced by a pistol, for this model is just needed a single generic source with the same conditions as the ones that where when the measurement took place which means putting the source at the same place as in the measurement and at the same height.

Following that, for the receivers there are needed eight, corresponding with the eight sound level meters which had to be placed at the same space as in the measurement to proceed with the calibration.

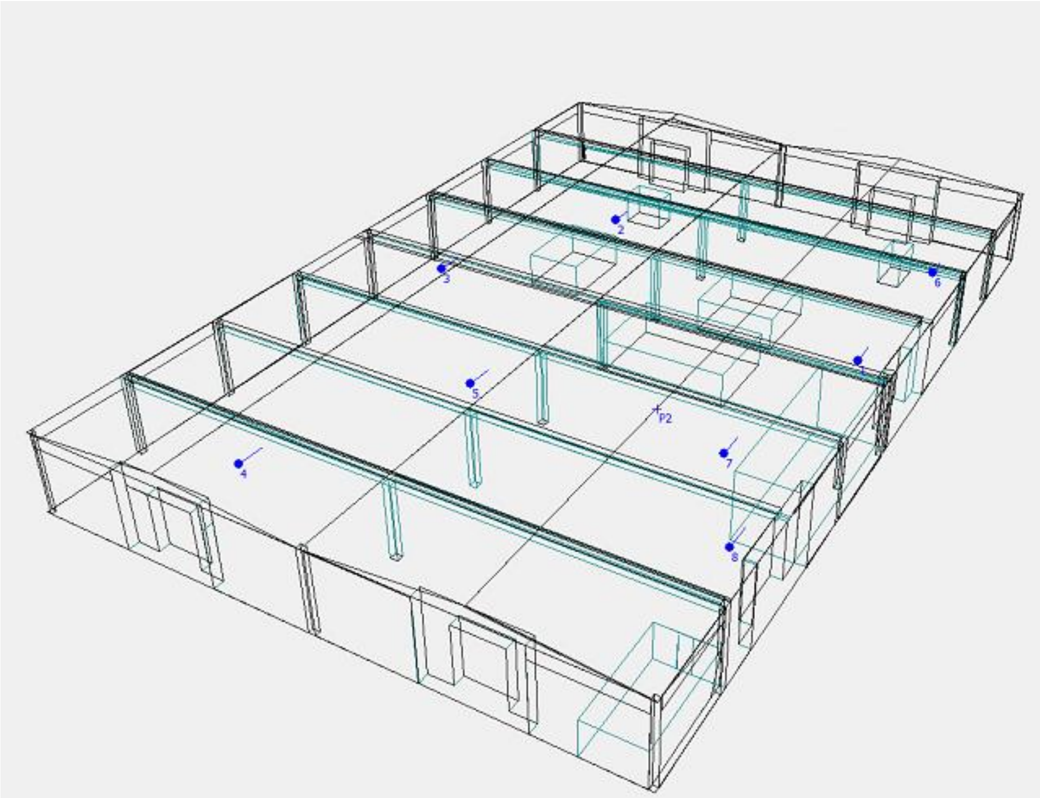

Figure 10- Sources and receivers in Odeon

4.3. Calibration

In this part of the thesis, it is needed to run the simulation to obtain the data of the frequency range in the eight points, for this it is used the option Job List in Odeon.

The first step is active the source in the option Active sources for the selected job located in the left part of the window as it is possible to see in the Figure 11. Then it has to done the same with the receivers in the right part of the window, where with a dropdown option it is possible to select the receivers.

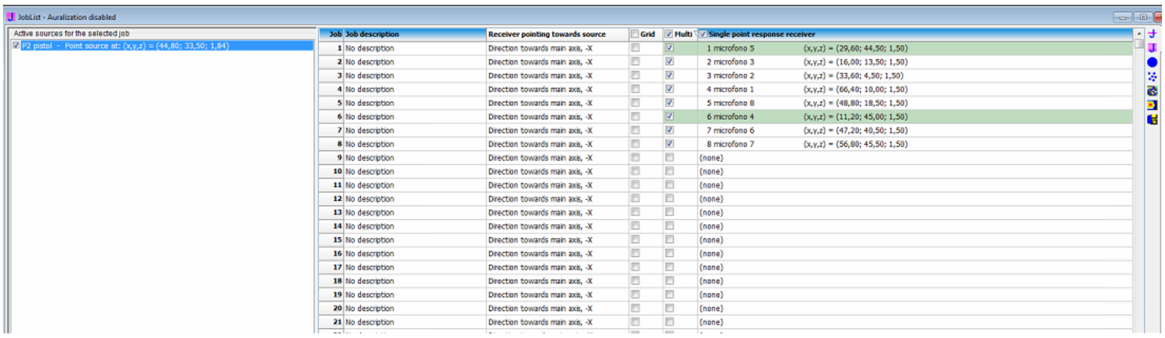

Figure 11-Job List window

Finally the simulation is launched with the option Run All Jobs and it is obtained a window with different calculated parameters for each receiver in this case it is only needed the T30 parameter, which results are the ones showed in the next table (Table 6).

		Frequencies							
		63Hz	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz	8kHz
Sample 1	T (30)	2,9	2,35	2,11	2,04	1,64	1,41	1,2	0,74
	T (60)	5,8	4,7	4,22	4,08	3,28	2,82	2,4	1,48
Sample 2	T (30)	2,98	2,24	2,06	1,98	1,69	1,47	1,16	0,78
	T (60)	5,96	4,48	4,12	3,96	3,38	2,94	2,32	1,56
Sample 3	T (30)	2,88	2,38	2,05	1,92	1,53	1,33	1,1	0,7
	T (60)	5,76	4,76	4,1	3,84	3,06	2,66	2,2	1,4
Sample 4	T (30)	2,92	2,56	2,33	2,2	1,56	1,41	1,22	0,76
	T (60)	5,84	5,12	4,66	4,4	3,12	2,82	2,44	1,52
Sample 5	T (30)	3,24	2,34	2,07	1,96	1,61	1,36	1,12	0,76
	T (60)	6,48	4,68	4,14	3,92	3,22	2,72	2,24	1,52
Sample 6	T (30)	3,08	2,23	1,97	1,88	1,45	1,21	1,01	0,67
	T (60)	6,16	4,46	3,94	3,76	2,9	2,42	2,02	1,34
Sample 7	T (30)	3,35	2,68	2,44	2,21	1,43	1,18	0,87	0,64
	T (60)	6,7	5,36	4,88	4,42	2,86	2,36	1,74	1,28
Sample 8	T (30)	3,06	2,3	2,21	2,11	1,64	1,31	1,1	0,76
	T (60)	6,12	4,6	4,42	4,22	3,28	2,62	2,2	1,52

Table 6- Results of the first simulation

Once the results are obtained the following step is to compare the results of the simulation with the values got in the measurements but first it was need to calculate a margin of a 5% in both ways (higher and lower) as it is showed in the Table 18 of the Appendix 5.

As the results are not inclusive like is possible to see, in a more visual way, in the sheet 3 of the Excel file attached with this document, the next procedure was to modify the absorption coefficient of the materials used until a 10% in both ways (higher or lower) depending of the result desired because the conditions where these materials where measured are not the same as the once in this case. In this case, it is needed more absorption in the lower frequencies (63Hz-500Hz) and less absorption in the higher frequencies (1kHz-8kHz). It was began with the most absorptive material which is the Galvanized steel for the industrial doors, so in the next table (Table 7), there are shown the new absorption coefficients of the material.

Number	Surface	Material	Frequency (Hz)							
			63	125	250	500	1K	2K	4K	8K
15139	Industrial doors	Galvanized steel	0,8	0,88	0,99	0,88	0,702	0,84	0,693	0,657

Table 7- Absorption coefficient with the modification

Once the material coefficients are changed the simulation is launched again and the results obtained are showed in the next table (Table 8).

		Frequencies							
		63Hz	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz	8kHz
Sample 1	T(30)	2,77	2,19	2,02	1,95	1,8	1,55	1,29	0,8
	T (60)	5,54	4,38	4,04	3,9	3,6	3,1	2,58	1,6
Sample 2	T(30)	2,74	2,1	1,98	1,92	1,82	1,61	1,28	0,8
	T (60)	5,48	4,2	3,96	3,84	3,64	3,22	2,56	1,6
Sample 3	T(30)	2,74	2,12	1,88	1,81	1,66	1,46	1,2	0,76
	T (60)	5,48	4,24	3,76	3,62	3,32	2,92	2,4	1,52
Sample 4	T(30)	2,8	2,41	2,17	2,08	1,82	1,49	1,29	0,8
	T (60)	5,6	4,82	4,34	4,16	3,64	2,98	2,58	1,6
Sample 5	T(30)	2,86	2,13	1,92	1,87	1,76	1,49	1,21	0,81
	T (60)	5,72	4,26	3,84	3,74	3,52	2,98	2,42	1,62
Sample 6	T(30)	2,83	2,05	1,82	1,76	1,61	1,35	1,1	0,71
	T (60)	5,66	4,1	3,64	3,52	3,22	2,7	2,2	1,42
Sample 7	T(30)	3,16	2,47	2,14	1,95	1,63	1,35	1,06	0,68
	T (60)	6,32	4,94	4,28	3,9	3,26	2,7	2,12	1,36
Sample 8	T(30)	2,83	2,22	2,09	2,01	1,87	1,53	1,18	0,81
	T (60)	5,66	4,44	4,18	4,02	3,74	3,06	2,36	1,62

Table 8- Results with the first material modified

This result is not completely satisfactory, as it is possible to observe easily in the Excel, nearly all the values are in the ranges but there are some values that are slightly high and in the highest frequencies (4kHz-8kHz) there a several values lightly lower that it is desired, as a solution, this time is going to modify, always at most a 10%, the absorption coefficients of the material used in more quantity, therefore is going to modidy the values of Fibreboard used in the walls, pillars and ceiling, being the results the following (Table 9).

Number	Surface	Material	Frequency (Hz)							
			63	125	250	500	1K	2K	4K	8K
15140	Walls, ceiling and pillars	Fibreboard over airspace on solid wall	0,165	0,242	0,275	0,29	0,315	0,351	0,351	0,36

Table 9- Modification of the absorption coefficient

As a result, it is presented the next table (Table 10) with the results of the simulation developed with the modifications of the absorption coefficient.

		Frequencies							
		63Hz	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz	8kHz
Sample 1	T(30)	2,75	2,18	2,02	1,94	1,8	1,55	1,29	0,8
	T (60)	5,5	4,36	4,04	3,88	3,6	3,1	2,58	1,6
Sample 2	T(30)	2,73	2,1	1,98	1,92	1,82	1,61	1,29	0,8
	T (60)	5,46	4,2	3,96	3,84	3,64	3,22	2,58	1,6
Sample 3	T(30)	2,73	2,11	1,88	1,8	1,66	1,46	1,21	0,77
	T (60)	5,46	4,22	3,76	3,6	3,32	2,92	2,42	1,54
Sample 4	T(30)	2,76	2,4	2,17	2,08	1,83	1,49	1,3	0,8
	T (60)	5,52	4,8	4,34	4,16	3,66	2,98	2,6	1,6
Sample 5	T(30)	2,86	2,13	1,92	1,87	1,76	1,49	1,22	0,82
	T (60)	5,72	4,26	3,84	3,74	3,52	2,98	2,44	1,64
Sample 6	T(30)	2,82	2,03	1,82	1,75	1,62	1,35	1,11	0,71
	T (60)	5,64	4,06	3,64	3,5	3,24	2,7	2,22	1,42
Sample 7	T(30)	3,16	2,48	2,14	1,95	1,63	1,34	1,07	0,97
	T (60)	6,32	4,96	4,28	3,9	3,26	2,68	2,14	1,94
Sample 8	T(30)	2,82	2,23	2,09	2,01	1,87	1,53	1,19	0,81
	T (60)	5,64	4,46	4,18	4,02	3,74	3,06	2,38	1,62

Table 10-Results with the second material modification

Finally, with this last change the results have been achieved and for this reason the calibration is validated.

5. Reduction of the reverberation time

In this last point is going to solve the hypothesis of a possible reduction of the reverberation time, as it is impossible to develop it in the real life because of the economic and time costs. For this reason is going to develop the procedures with the virtual version of the plant through the simulations with Odeon.

As the calibration of the model is done, there are the same conditions as in the Fondalmec plant, so there is going to show three different options for reduce the reverberation time.

5.1. Wood wool slabs

The material that is going to use is 100mm wood wool slabs on 25mm cavity, pre-screened surface facing cavity which has the following absorption coefficients (Table 11).

Number	Surface	Material	Frequency (Hz)							
			63	125	250	500	1K	2K	4K	8K
15141	Ceiling	Wood wool slabs	0,5	0,5	0,75	0,75	0,65	0,7	0,7	0,7

Table 11-Absorption coefficient

The material is distributed all around the ceiling and once the simulation is launched the result table is the following one.

		Frequencies							
		63Hz	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz	8kHz
Sample 1	T(30)	1,93	1,77	1,48	1,4	1,33	1,19	1,04	0,77
	T (60)	3,86	3,54	2,96	2,8	2,66	2,38	2,08	1,54
Sample 2	T(30)	2,02	1,86	1,77	1,71	1,64	1,49	1,14	0,77
	T (60)	4,04	3,72	3,54	3,42	3,28	2,98	2,28	1,54
Sample 3	T(30)	1,71	1,6	1,23	1,12	1,22	1,09	1,03	0,76
	T (60)	3,42	3,2	2,46	2,24	2,44	2,18	2,06	1,52
Sample 4	T(30)	2,27	1,9	1,56	1,68	1,52	1,48	1,3	0,83
	T (60)	4,54	3,8	3,12	3,36	3,04	2,96	2,6	1,66
Sample 5	T(30)	1,95	1,77	1,57	1,47	1,46	1,29	1,09	0,8
	T (60)	3,9	3,54	3,14	2,94	2,92	2,58	2,18	1,6
Sample 6	T(30)	1,71	1,52	1,26	1,23	1,2	1,1	0,94	0,7
	T (60)	3,42	3,04	2,52	2,46	2,4	2,2	1,88	1,4
Sample 7	T(30)	2,35	1,46	1,07	1,04	1,07	0,98	0,85	0,56
	T (60)	4,7	2,92	2,14	2,08	2,14	1,96	1,7	1,12
Sample 8	T(30)	2,19	1,91	1,53	1,4	1,31	1,16	1,04	0,77
	T (60)	4,38	3,82	3,06	2,8	2,62	2,32	2,08	1,54

Table 12- T60 results with me absorption material in the ceiling

The results of the table above (Table 12) in comparison with the results of the calibration of the model (Table 10) show the reverberation time with the absorbent material on the ceiling reduce the T60 in a noticed way in the frequency range between 63Hz and 4kHz and with a lower perception is the 8kHz frequency.

5.2. Sheep wool

In this part of the hypothesis is going to use sheep wool absorbent 100 mm thick from the company Thermafleece and is going to apply it in two different parts of the model, the first one where is going to apply it is in the walls and the second one is in the ceiling like in the simulation. The absorption coefficients of this material are showed in the next table (Table 12).

Number	Surface	Material	Frequency (Hz)							
			63	125	250	500	1K	2K	4K	8K
15142	Walls and ceiling	Sheep wool absorbent	0,47	0,47	0,86	1	0,94	0,96	1	1

Table 13-Absorption coefficient of the sheep wool

5.2.1. Sheep wool on the walls

Once the material is introduced in all the walls of the model it is proceed to run the simulation and compile all the values of the points being the result the following (table 14).

		Frequencies							
		63Hz	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz	8kHz
Sample 1	T(30)	1,95	1,79	1,44	1,36	1,22	1,15	1,02	0,86
	T (60)	3,9	3,58	2,88	2,72	2,44	2,3	2,04	1,72
Sample 2	T(30)	2,04	1,87	1,77	2,17	1,66	1,53	1,14	0,71
	T (60)	4,08	3,74	3,54	4,34	3,32	3,06	2,28	1,42
Sample 3	T(30)	1,75	1,63	1,13	1,26	1,04	1,09	1,03	0,85
	T (60)	3,5	3,26	2,26	2,52	2,08	2,18	2,06	1,7
Sample 4	T(30)	2,33	2,02	1,67	4,43	1,89	1,68	3,52	0,93
	T (60)	4,66	4,04	3,34	8,86	3,78	3,36	7,04	1,86
Sample 5	T(30)	1,97	1,79	1,54	1,49	1,43	1,27	1,16	0,79
	T (60)	3,94	3,58	3,08	2,98	2,86	2,54	2,32	1,58
Sample 6	T(30)	1,75	1,54	1,28	1,26	1,22	1,14	0,91	0,7
	T (60)	3,5	3,08	2,56	2,52	2,44	2,28	1,82	1,4
Sample 7	T(30)	2,39	1,54	1,05	1,01	1,01	0,96	0,78	0,58
	T (60)	4,78	3,08	2,1	2,02	2,02	1,92	1,56	1,16
Sample 8	T(30)	2,21	1,94	1,49	1,4	1,22	1,17	1,06	0,77
	T (60)	4,42	3,88	2,98	2,8	2,44	2,34	2,12	1,54

Table 14- T60 of the sheep wool on the walls

The values obtained with this material in this emplacement show that the reverberation time is reduced slightly in all frequency range but there are some inconsistencies as for example the values of the sample 4 in the frequencies 500Hz and 4kHz are significantly high comparing it with any of the results of any of the simulations done before.

5.2.2. Sheep wool on the ceiling

The material is allocated on the ceiling surface it is launched the simulation obtaining the results showed in the table (Table 15).

		Frequencies							
		63Hz	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz	8kHz
Sample 1	T(30)	2,36	1,96	1,25	1,01	1,01	0,89	0,77	0,51
	T (60)	4,72	3,92	2,5	2,02	2,02	1,78	1,54	1,02
Sample 2	T(30)	2,25	1,85	1,38	1,18	1,11	0,93	0,77	0,54
	T (60)	4,5	3,7	2,76	2,36	2,22	1,86	1,54	1,08
Sample 3	T(30)	2,25	1,68	1,32	1,32	1,29	1,13	0,95	0,8
	T (60)	4,5	3,36	2,64	2,64	2,58	2,26	1,9	1,6
Sample 4	T(30)	2,24	1,71	1,15	1,11	1,04	0,84	0,84	0,55
	T (60)	4,48	3,42	2,3	2,22	2,08	1,68	1,68	1,1
Sample 5	T(30)	2,12	1,72	1,15	1,05	1,01	0,9	0,78	0,48
	T (60)	4,24	3,44	2,3	2,1	2,02	1,8	1,56	0,96
Sample 6	T(30)	2,09	1,68	1,24	1,13	1,03	0,88	0,76	0,55
	T (60)	4,18	3,36	2,48	2,26	2,06	1,76	1,52	1,1
Sample 7	T(30)	2,42	1,73	1,18	0,95	0,94	0,86	0,78	0,52
	T (60)	4,84	3,46	2,36	1,9	1,88	1,72	1,56	1,04
Sample 8	T(30)	2,19	1,83	1,43	1,3	1,11	0,98	0,94	0,73
	T (60)	4,38	3,66	2,86	2,6	2,22	1,96	1,88	1,46

Table 15- T60 of the sheep wool on the ceiling

This material emplaced on the ceiling produces a remarkable reduction of the reverberation time in an equitably way between the frequency range.

6. Conclusion

As there is not a normative or any law in reference to the acceptable reverberation time in a manufacturing plant there is not a guide to decide which is the best option of the three simulated in the previous point.

The hypothesis raised was to reduce the reverberation time it is going to discard the option of the sheep wool on the walls because the reduction was very light and there was that two values oddly high.

Finally between the two simulation developed focused on the ceiling the diminution of the values in the sheep wool simulation is very equitable but as the reverberation time in the lower frequencies is quite higher than the high frequencies and the reduction in the high frequencies in both cases is small the best option would be use the wool wood on the ceiling to reduce fundamentally the reverberation time in the lower frequencies.

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Appendix

1. Appendix 1: Distribution of the sound level meters in the plant.

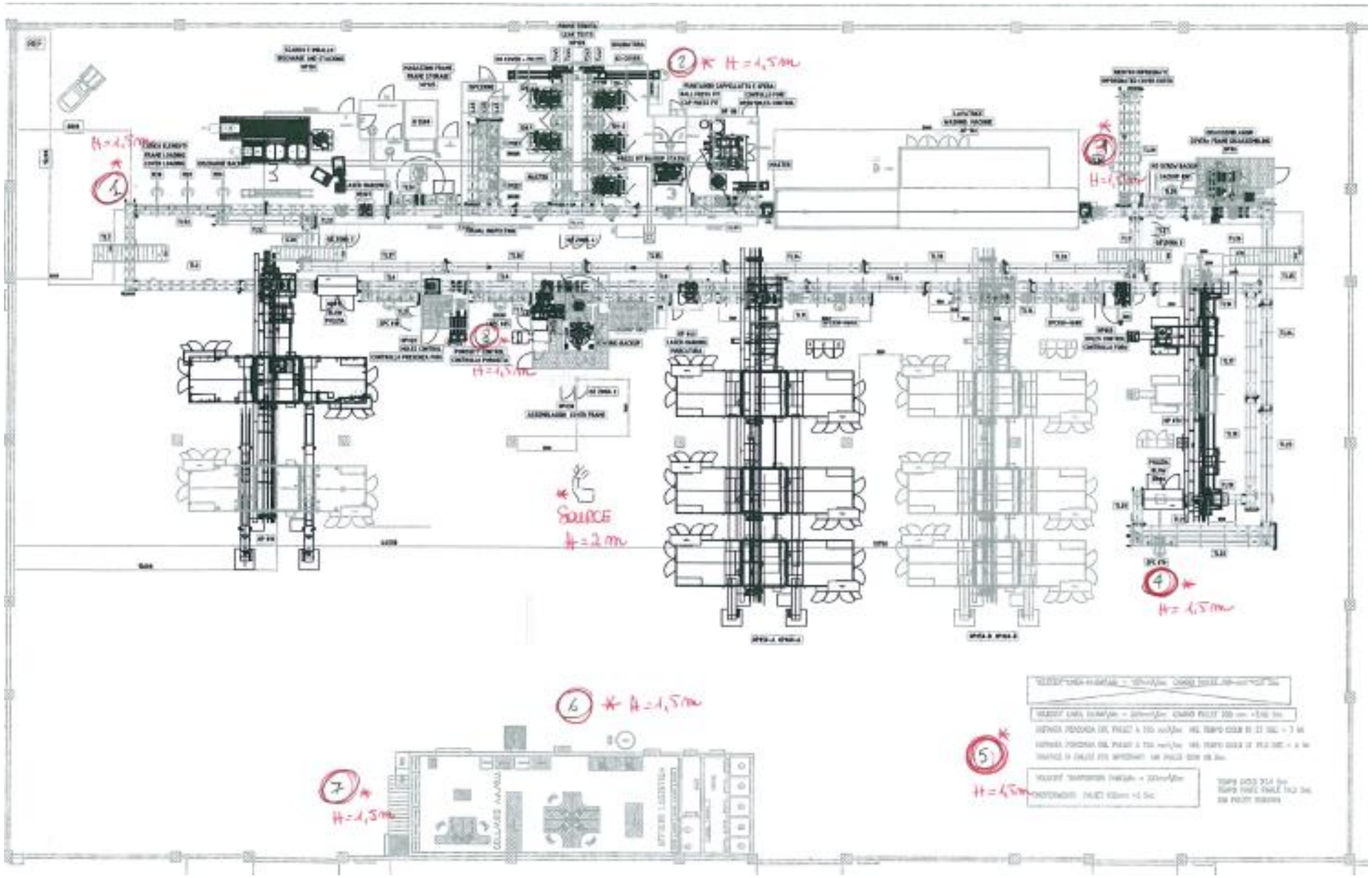

Figure 12-Dsitribution of the sound level meters in the plant

2. Appendix 2: Measurements table

S1	50Hz	63Hz	80Hz	100Hz	125Hz	160Hz	200Hz	250Hz	315Hz	400Hz	500Hz	630Hz	800Hz	1kHz	1.25 kHz	1.6k Hz	2kHz	2.5k Hz	3.15 kHz	4kHz	5kHz	6.3k Hz	8kHz	10kHz
100	88,46	88,29	90,18	92,97	95,85	99,59	100,26	96,38	97,29	98,52	96,27	95,36	95,89	97,76	99,78	97,03	100,63	97,22	98,46	96,19	95,4	93,24	92,32	91,38
400	85,5	70,79	69,31	71,41	74,42	76,97	76,42	71,95	75,29	72,74	72,28	73,94	74,93	71,12	72,19	72,73	69,28	67,19	64,31	62,26	58,99	42,31	40,18	39,35
Dif (dB)	2,96	17,5	20,87	21,56	21,43	22,62	23,84	24,43	22	25,78	23,99	21,42	20,96	26,64	27,59	24,3	31,35	30,03	34,15	33,93	36,41	50,93	52,14	52,03
T ms	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
T60 (s)	30,40541	5,142857	4,31241	4,174397	4,19972	3,97878	3,775168	3,683995	4,090909	3,491078	3,751563	4,201681	4,293893	3,378378	3,262051	3,703704	2,870813	2,997003	2,635432	2,65252	2,471848	1,767131	1,726122	1,729771
		4,727634			4,117632			3,850024			3,814774			3,644774			3,190507			2,5866			1,741008	
S 2																								
100	87,77	84,47	89,59	96,33	99,86	100,67	100,53	96,22	97,8	98,03	98,94	97,45	98,25	95,84	97,36	97,21	99,64	97,87	96,32	96,4	95,71	94,72	93,24	90,56
400	85,31	82,71	75,03	76,33	78,56	81,24	81,56	78,03	72,51	75,53	75,4	73,86	72,88	73,63	71,19	71,94	68,09	69,21	64,26	62,77	57,51	43,83	40,22	38,9
Dif(dB)	2,46	1,76	14,56	20	21,3	19,43	18,97	18,19	25,29	22,5	23,54	23,59	25,37	22,21	26,17	25,27	31,55	28,66	32,06	33,63	38,2	50,89	53,02	51,66
T ms	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
T60 (s)	36,58537	51,13636	6,181319	4,5	4,225352	4,632012	4,744333	4,947774	3,558719	4	3,82328	3,815176	3,547497	4,052229	3,439052	3,561535	2,852615	3,140265	2,807236	2,676182	2,356021	1,76852	1,697473	1,74216
		6,181319			4,452455			4,416942			3,879485			3,679593			3,184805			2,613146			1,736051	

S 3																								
100	97,37	53,12	92,93	94,63	98,11	100,79	99,54	96,69	96,81	97,75	95,78	95,79	98,1	96,93	97,93	98,64	97,55	97,99	97,57	96,81	96,77	94,96	93,24	92,7
400	92,13	52,64	75,4	72,95	75,72	75,75	76,79	75,59	75,08	73,07	73,42	77,14	72,12	73,19	74,35	72,7	70,3	70,31	67,8	64,88	61,69	41,41	40,7	38,07
Dif dB	5,24	0,48	17,53	21,68	22,39	25,04	22,75	21,1	21,73	24,68	22,36	18,65	25,98	23,74	23,58	25,94	27,25	27,68	29,77	31,93	35,08	53,55	52,54	54,63
T ms	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
T60 (s)	17,17557	187,5	5,134056	4,151292	4,019652	3,594249	3,956044	4,265403	4,14174	3,646677	4,025045	4,825737	3,464203	3,79107	3,816794	3,469545	3,302752	3,251445	3,023178	2,818666	2,565564	1,680672	1,712981	1,647446
		5,134056			3,921731			4,121062			4,16582			3,690689			3,341247			2,802469			1,680366	
S 4																								
100	91,39	86,54	85,32	89,79	87,57	103,69	101,89	92,63	93,62	98,64	97,33	95,93	95,3	95,32	97,96	96,75	96,84	95,91	95,49	94,36	95,51	95	94,37	92,56
400	91,39	67,89	70,46	63,63	71,73	79,68	76,86	73,57	72,2	70,43	73,16	72,51	72,41	70,56	70,29	70,54	68,88	67,96	63,42	57,66	55,83	42,07	39,52	38,02
Tms	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
Dif(dB)	0	18,65	14,86	26,16	15,84	24,01	25,03	19,06	21,42	28,21	24,17	23,42	22,89	24,76	27,67	26,21	27,96	27,95	32,07	36,7	39,68	52,93	54,85	54,54
T60 (s)	0	4,825737	6,056528	3,440367	5,681818	3,748438	3,595685	4,721931	4,201681	3,190358	3,723624	3,842869	3,931848	3,634895	3,25262	3,433804	3,218884	3,220036	2,806361	2,452316	2,268145	1,700359	1,640839	1,650165
		5,441132			4,290208			4,173099			3,585617			3,606454			3,290908			2,508941			1,663788	

S 5																								
100	89,09	78,63	87,33	91,49	94,47	97,35	99,03	93,63	94,81	97,86	97,24	96,69	97,2	96,88	96,36	96,45	96,56	97,75	95,75	96,84	95,5	94,95	93,75	92,97
400	86,71	65,3	68,81	70,63	69,24	78,6	76,85	74,02	74,33	72,45	71,36	71,63	70,65	71,93	70,59	68,06	67,29	65,54	63,33	60,79	58,13	41,49	39,3	39,07
T ms	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
Dif (dB)	2,38	13,33	18,52	20,86	25,23	18,75	22,18	19,61	20,48	25,41	25,88	25,06	26,55	24,95	25,77	28,39	29,27	32,21	32,42	36,05	37,37	53,46	54,45	53,9
T60 (s)	37,815	6,75168	4,8596	4,3144	3,567	4,8	4,0571	4,589	4,3945	3,5419	3,4775	3,5913	3,3898	3,6072	3,4924	3,17013	3,0748	2,7941	2,7760	2,4965	2,4083	1,6835	1,6528	1,6697
		5,80565			4,22722			4,34724			3,53696			3,49649			3,01303			2,56031			1,66871	
S 6																								
100	88,6	80,45	89,24	93,88	95,5	98,67	102,37	99,38	98,54	97,75	97,26	97,41	98,01	97,72	96,7	96,24	97,05	96,14	98,24	96,88	95,35	93,58	92,85	91,47
400	86,37	65,99	71,67	71,75	72,82	73,82	73,2	73,49	73,67	75,5	71,83	72,8	70,78	71,87	72,02	70,06	67,43	64,77	62,39	58,36	55,12	40,07	39,21	38,24
Time in ms	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
Dif(dB)	2,23	14,46	17,57	22,13	22,68	24,85	29,17	25,89	24,87	22,25	25,43	24,61	27,23	25,85	24,68	26,18	29,62	31,37	35,85	38,52	40,23	53,51	53,64	53,23
T60 (s)	40,3587	6,224066	5,122368	4,066878	3,968254	3,62173	3,085362	3,476246	3,618818	4,044944	3,539127	3,65705	3,305178	3,481625	3,646677	3,437739	3,038488	2,868983	2,51046	2,336449	2,237136	1,681929	1,677852	1,690776
		5,673217			3,885621			3,393475			3,74704			3,477827			3,11507			2,361348			1,683519	

S 7																								
100	92,41	87,84	89,27	85,33	96,92	100,74	102,64	94,17	96,41	95,63	96,22	95	95,12	95,82	95,84	97,42	96,77	98,47	95,86	97,59	95,26	95,76	94,85	93,66
400	91,79	72,91	69,59	70,57	73,33	76,28	76,3	75,14	74,42	71,86	72,42	73,79	71,5	72,45	71,78	69,79	68,66	65,36	64,78	60,04	56,57	41,67	39,27	38,27
Dif (dB)	0,62	14,93	19,68	14,76	23,59	24,46	26,34	19,03	21,99	23,77	23,8	21,21	23,62	23,37	24,06	27,63	28,11	33,11	31,08	37,55	38,69	54,09	55,58	55,39
T ms	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
T60 (s)	145,1613	6,028131	4,573171	6,097561	3,815176	3,679477	3,416856	4,729375	4,092769	3,786285	3,781513	4,243281	3,81033	3,851091	3,740648	3,257329	3,201708	2,718212	2,895753	2,396804	2,326182	1,663894	1,619288	1,624842
		5,300651			4,530738			4,079667			3,937026			3,80069			3,059083			2,53958			1,636008	
S 8																								
100	80,57	81,21	86,12	91,06	96,37	98,18	102,93	94,41	94,3	95,86	94,16	96,05	97,75	98,27	96,25	97,3	98,28	97,52	96,45	94,78	93,98	94,78	93,37	90,93
400	63,32	65,48	68,11	76,34	74,07	77,64	78,07	74,25	74,86	73,29	72,11	73,86	72,51	73,35	72,35	70,13	67,72	66,75	65,56	61,7	55,72	42,44	38,12	36,21
Dif (dB)	17,25	15,73	18,01	14,72	22,3	20,54	24,86	20,16	19,44	22,57	22,05	22,19	25,24	24,92	23,9	27,17	30,56	30,77	30,89	33,08	38,26	52,34	55,25	54,72
Time in ms	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
T60 (s)	5,217391	5,721551	4,997224	6,11413	4,035874	4,381694	3,620274	4,464286	4,62963	3,987594	4,081633	4,055881	3,565769	3,611557	3,76569	3,312477	2,945026	2,924927	2,913564	2,720677	2,352326	1,719526	1,628959	1,644737
		5,312055			4,8439			4,238063			4,041703			3,647672			3,06081			2,662189			1,664407	

S 9																								
100	80,78	80,54	87,8	88,66	90,25	94,18	94,7	90,16	91,79	90,22	93,05	93,73	92,93	96,89	94,86	94,18	92,36	93,53	91,77	92,59	91,14	91,57	90,21	89,14
400	79,52	72,85	62,91	69,77	70,36	72,52	70,21	69,51	70,22	68,7	68,87	70,76	68,45	70,57	69,29	67,97	67,46	65,88	58,08	55,25	52,2	43,66	39,3	35,02
T ms	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
Dif (dB)	1,26	7,69	24,89	18,89	19,89	21,66	24,49	20,65	21,57	21,52	24,18	22,97	24,48	26,32	25,57	26,21	24,9	27,65	33,69	37,34	38,94	47,91	50,91	54,12
T60 (s)	71,42857	11,70351	3,61591	4,764426	4,524887	4,155125	3,674969	4,358354	4,172462	4,182156	3,722084	3,918154	3,676471	3,419453	3,51975	3,433804	3,614458	3,254973	2,671416	2,410284	2,311248	1,878522	1,767826	1,662971
		7,659711			4,481479			4,068595			3,940798			3,538558			3,434412			2,464316			1,769773	
S 10																								
100	77,9	80,22	87,27	89,63	90,85	97,24	95,07	92,2	93,27	94,87	93,19	92,62	94,8	95,3	93,7	97,67	95,84	96,86	94,92	93,87	89,64	91,66	90,07	89,9
400	70,65	62,1	63,1	69,41	72,36	74,42	71,99	71,51	70,02	70,37	71,31	70,39	70,44	70,64	68,65	65,3	64,3	61,49	59,54	57,61	54,76	44,67	37,21	35,16
Dif (dB)	7,25	18,12	24,17	20,22	18,49	22,82	23,08	20,69	23,25	24,5	21,88	22,23	24,36	24,66	25,05	32,37	31,54	35,37	35,38	36,26	34,88	46,99	52,86	54,74
Time in ms	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
T60 (s)	12,41379	4,966887	3,723624	4,451039	4,867496	3,943909	3,89948	4,349928	3,870968	3,673469	4,113346	4,048583	3,694581	3,649635	3,592814	2,780352	2,853519	2,544529	2,54381	2,482074	2,580275	1,915301	1,702611	1,644136
		4,345256			4,420814			4,040125			3,945133			3,645677			2,726134			2,535386			1,754016	

S11																								
100	90,3	79,27	89,15	96,9	99,13	98,35	100,52	97,72	96,15	96,69	96,86	94,12	96,14	98,11	97,79	101,31	101,41	100,71	97,78	97,19	95,91	94,88	93,74	90,23
400	89,65	66,12	62,83	73,83	77,26	77,49	76,07	76,46	74,12	73,55	71,25	71,05	72,4	70,5	70,01	70,14	69,39	65,39	60,31	58,33	56,24	45,98	42,27	32,52
Time in ms	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
Dif (dB)	0,65	13,15	26,32	23,07	21,87	20,86	24,45	21,26	22,03	23,14	25,61	23,07	23,74	27,61	27,78	31,17	32,02	35,32	37,47	38,86	39,67	48,9	51,47	57,71
T60 (s)	138,461	6,84410	3,41945	3,901	4,11522	4,31447	3,68098	4,23330	4,08533	3,88936	3,51425	3,90117	3,79107	3,2596	3,23974	2,887	2,81074	2,54813	2,40192	2,31600	2,26871	1,84049	1,74859	1,55952
		5,13178			4,11029			3,99987			3,76826			3,43016			2,74875			2,32888			1,71620	
S 12																								
100	47,48	80,69	92,4	96,62	98,9	100,96	101,7	100,79	98,32	97,54	97,31	96,63	97,96	95,97	99,65	98,55	97,89	97,33	96,96	95,7	96,72	94,68	93,75	91,89
400	51,56	69,99	72,28	76,27	77,57	79,44	73,19	77,24	75,35	73,63	71,05	72,29	72,29	71,26	70,25	69,27	66,1	65,29	60,09	58,38	56,19	45,68	43,17	33,49
Dif(dB)	-4,08	10,7	20,12	20,35	21,33	21,52	28,51	23,55	22,97	23,91	26,26	24,34	25,67	24,71	29,4	29,28	31,79	32,04	36,87	37,32	40,53	49	50,58	58,4
Time in ms	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
T60 (s)	22,058	8,41121	4,4731	4,4226	4,21940	4,1821	3,1567	3,82165	3,9181	3,7641	3,42726	3,6976	3,5060	3,64225	3,061224	3,073	2,831079	2,808989	2,441009	2,411576	2,220577	1,836735	1,779359	1,541096
		6,442188			4,274723			3,632199			3,629666			3,403171			2,904613			2,357721			1,719063	

S 13																								
100	82,16	74,22	86,24	88,19	89,86	95,69	95,16	94,37	96,32	94,04	93,28	94,49	96,71	97,38	93,76	95,33	96,27	97,1	96,73	95,96	95,84	94,7	87,45	83,7
400	82,07	64,22	67,96	71,76	72,23	77,76	73,02	72,07	72,85	72,12	71,75	71,75	70,28	70,19	68,39	63,32	65,72	64,4	59,14	57,28	55,26	51,4	44,26	36,28
Dif (dB)	0,09	10	18,28	16,43	17,63	17,93	22,14	22,3	23,47	21,92	21,53	22,74	26,43	27,19	25,37	32,01	30,55	32,7	37,59	38,68	40,58	43,3	43,19	47,42
Time in ms	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
T60 (s)	1000	9	4,92344	5,47775	5,10495	5,01952	4,06501	4,03584	3,83463	4,10589	4,18024	3,95774	3,40521	3,31004	3,54747	2,8111	2,94599	2,75224	2,39424	2,32678	2,21784	2,07852	2,08381	1,89793
		6,96170			5,20074			3,97853			4,08127			3,42092			2,83663			2,31296			2,02009	
S 14																								
100	77,18	77,73	84,67	89,49	90,4	95,36	94,84	93,74	92,54	93,21	93,18	95,7	96,89	97,06	95,39	96,67	97,47	96,99	97,57	96,76	95,91	96,47	86,97	79,72
400	70,73	65,42	64,32	70,86	72,13	78,93	76,6	74,99	72,75	71,81	70,69	71,11	70,77	70,28	69,67	66,25	63,12	61,16	59,25	58,19	55,42	52,21	46,38	34,11
Dif (dB)	6,45	12,31	20,35	18,63	18,27	16,43	18,24	18,75	19,79	21,4	22,49	24,59	26,12	26,78	25,72	30,42	34,35	35,83	38,32	38,57	40,49	44,26	40,59	45,61
Time in ms	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
T60 (s)	13,95349	7,311129	4,422604	4,830918	4,926108	5,477785	4,934211	4,8	4,547751	4,205607	4,001779	3,660024	3,445636	3,360717	3,499222	2,95858	2,620087	2,511862	2,348643	2,33342	2,222771	2,033439	2,217295	1,973251
		5,866867			5,07827			4,760654			3,955803			3,435192			2,696843			2,301611			2,074662	

S15																								
100	78,63	79,77	86,94	93,33	97,87	99,68	98,46	97,04	96,87	95	97,6	95,09	96,23	95,85	96,31	96,19	96,22	93,49	95,88	95,07	93,86	92,45	91,77	89,73
400	70,71	65,15	68,53	75,88	77,39	78,29	79,38	75,27	75,14	74,08	72,71	71,26	70,21	71,97	70,13	70,55	69,78	67,37	66,65	58,29	54,11	45,42	40,23	37,05
Dif (dB)	7,92	14,62	18,41	17,45	20,48	21,39	19,08	21,77	21,73	20,92	24,89	23,83	26,02	23,88	26,18	25,64	26,44	26,12	29,23	36,78	39,75	47,03	51,54	52,68
Time in ms	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
T60 (s)	11,36364	6,155951	4,888647	5,157593	4,394531	4,207574	4,716981	4,13413	4,14174	4,302103	3,61591	3,776752	3,458878	3,768844	3,437739	3,51014	3,403933	3,445636	3,079028	2,446982	2,264151	1,913672	1,746217	1,708428
		5,522299			4,586566			4,33095			3,898255			3,555154			3,453236			2,59672			1,789439	
S 16																								
100	76	82,55	85,67	89,96	98,16	100,82	98,44	95,9	96,89	96,81	95,49	96,13	97,05	95,85	96,38	96,85	95,99	94,63	97,85	96,31	95,68	95,97	89,97	88,67
400	61,58	66,37	70,66	75,78	76,32	75,59	74,6	72,76	73,56	72,13	71,63	72,52	71,25	70,85	71,78	66,52	63,31	62,08	60,25	58,85	58,62	45,02	39	36,06
Dif (dB)	14,42	16,18	15,01	14,18	21,84	25,23	23,84	23,14	23,33	24,68	23,86	23,61	25,8	25	24,6	30,33	32,68	32,55	37,6	37,46	37,06	50,95	50,97	52,61
Time in ms	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
T60 (s)	6,241331	5,562423	5,996003	6,346968	4,120879	3,567182	3,775168	3,889369	3,857694	3,646677	3,772003	3,811944	3,488372	3,6	3,658537	2,967359	2,753978	2,764977	2,393617	2,402563	2,428494	1,766438	1,765745	1,710701
		6,118667			4,678343			3,840744			3,743542			3,582303			2,828771			2,408225			1,747628	

Table 16- Measurements results

3. Appendix 3: Average of the measurements table

	Frequencies							
Sample	63	125	250	500	1K	2K	4K	8K
1	4,72	4,11	3,85	3,81	3,64	3,19	2,58	1,74
2	6,18	4,45	4,41	3,87	3,67	3,18	2,61	1,73
AVERAGE	5,45	4,28	4,13	3,84	3,655	3,185	2,595	1,735
3	5,13	3,92	4,12	4,1	3,59	3,34	2,8	1,68
4	5,44	4,29	4,17	3,58	3,6	3,29	2,5	1,66
AVERAGE	5,285	4,105	4,145	3,84	3,595	3,315	2,65	1,67
5	5,18	4,22	4,34	3,53	3,49	3,01	2,56	1,66
6	5,67	3,88	3,39	3,74	3,47	3,11	2,36	1,68
AVERAGE	5,425	4,05	3,865	3,635	3,48	3,06	2,46	1,67
7	5,3	4,53	4,07	3,93	3,8	3,05	2,53	1,68
8	5,31	4,84	4,23	4,04	3,64	3,06	2,66	1,64
AVERAGE	5,305	4,685	4,15	3,985	3,72	3,055	2,595	1,66
9	7,65	4,48	4,06	3,94	3,53	3,43	2,46	1,76
10	4,34	4,42	4,04	3,91	3,64	2,72	2,53	1,75
AVERAGE	5,995	4,45	4,05	3,925	3,585	3,075	2,495	1,755
11	5,13	4,11	3,99	3,76	3,43	2,74	2,32	1,71
12	6,44	4,27	3,63	3,62	3,4	2,9	2,35	1,71
AVERAGE	5,785	4,19	3,81	3,69	3,415	2,82	2,335	1,71
13	6,96	5,2	3,97	4,08	3,42	2,83	2,31	2,02
14	5,86	5,07	4,76	3,95	3,43	2,69	2,3	2,07
AVERAGE	6,41	5,135	4,365	4,015	3,425	2,76	2,305	2,045
15	5,52	4,58	4,33	3,89	3,55	3,45	2,59	1,78
16	6,11	4,67	3,84	3,74	3,58	2,82	2,4	1,74
AVERAGE	5,815	4,625	4,085	3,815	3,565	3,135	2,495	1,76

Table 17- Average of the T60 of the measurements

4. Appendix 4: Perspectives of the plant with Sketch Up

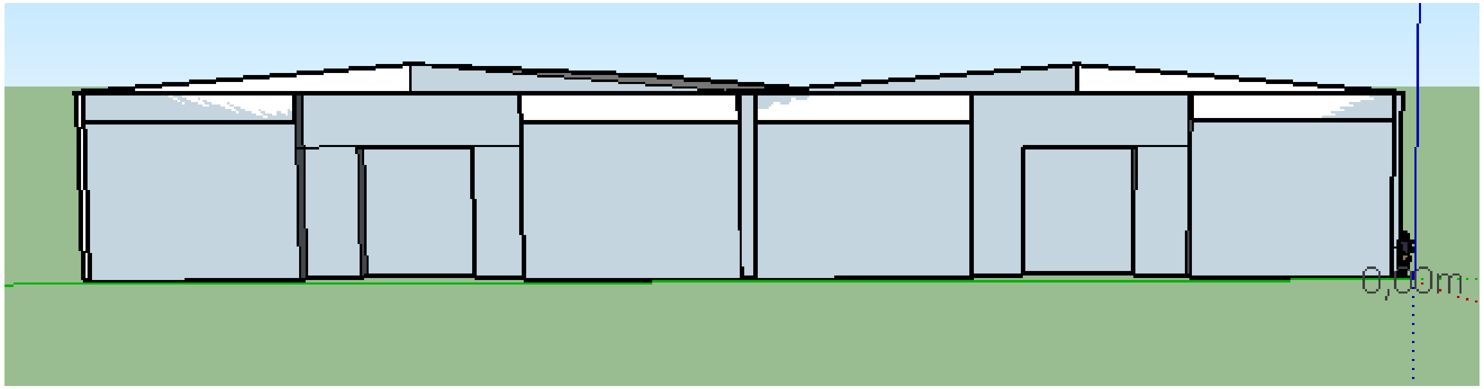

Figure 13- Front view of the plant

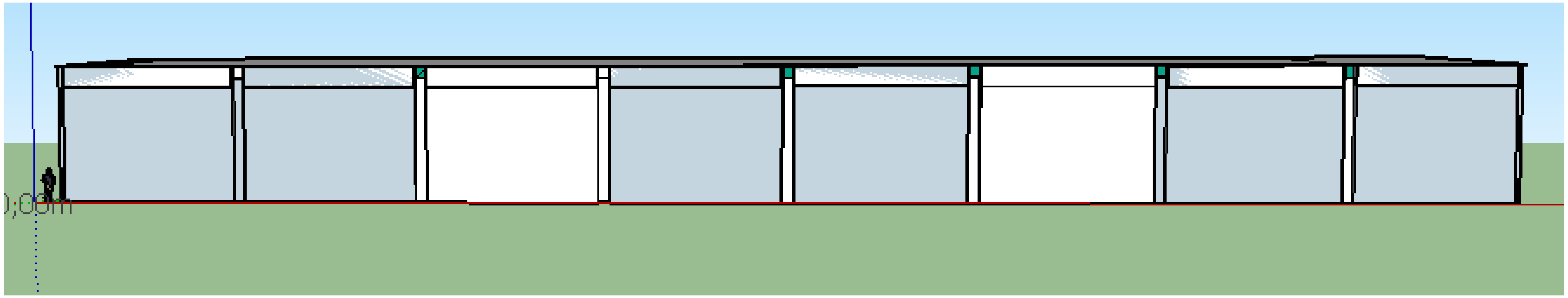

Figure 14- Right side of the plant

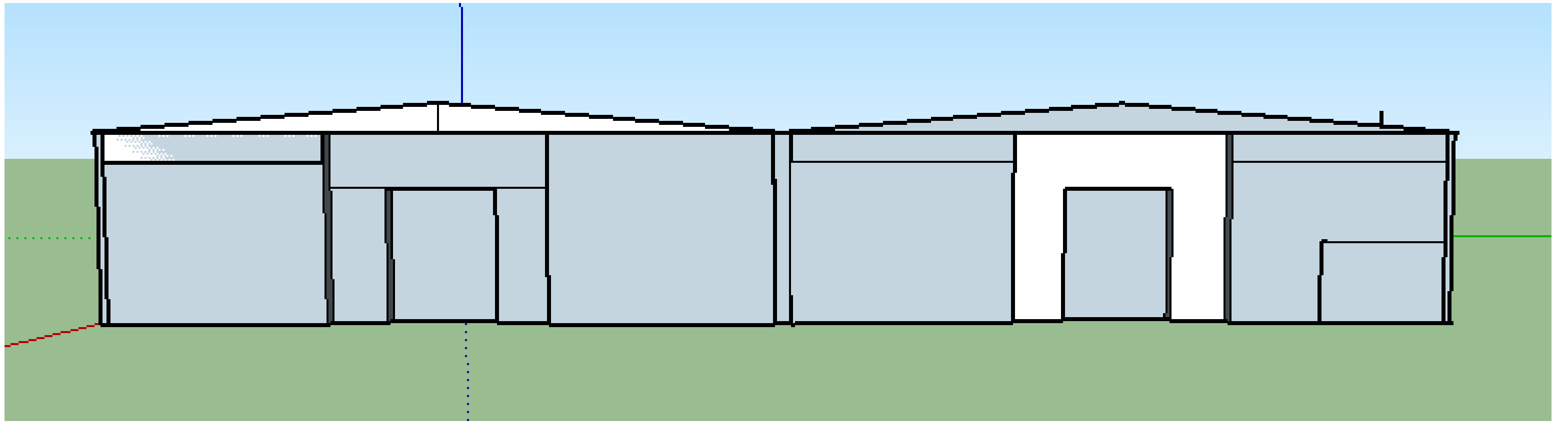

Figure 15- Back view of the plant

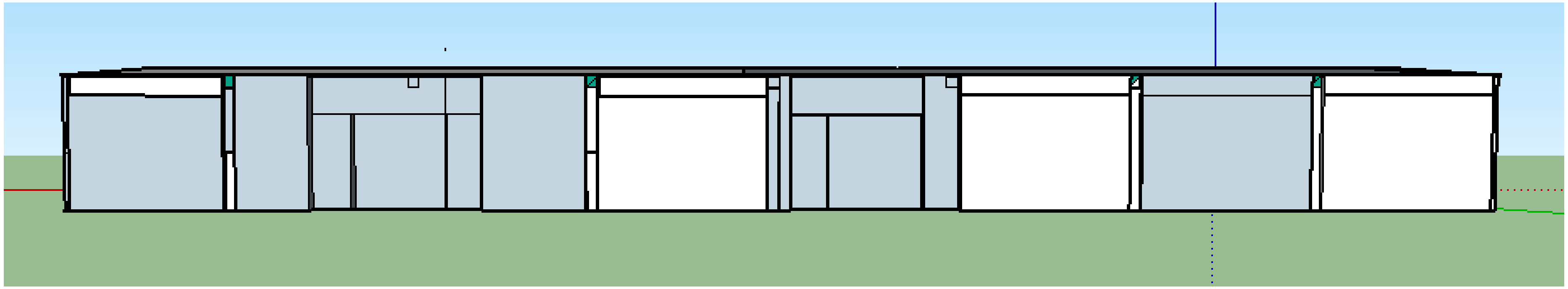

Figure 16- Left side of the plant

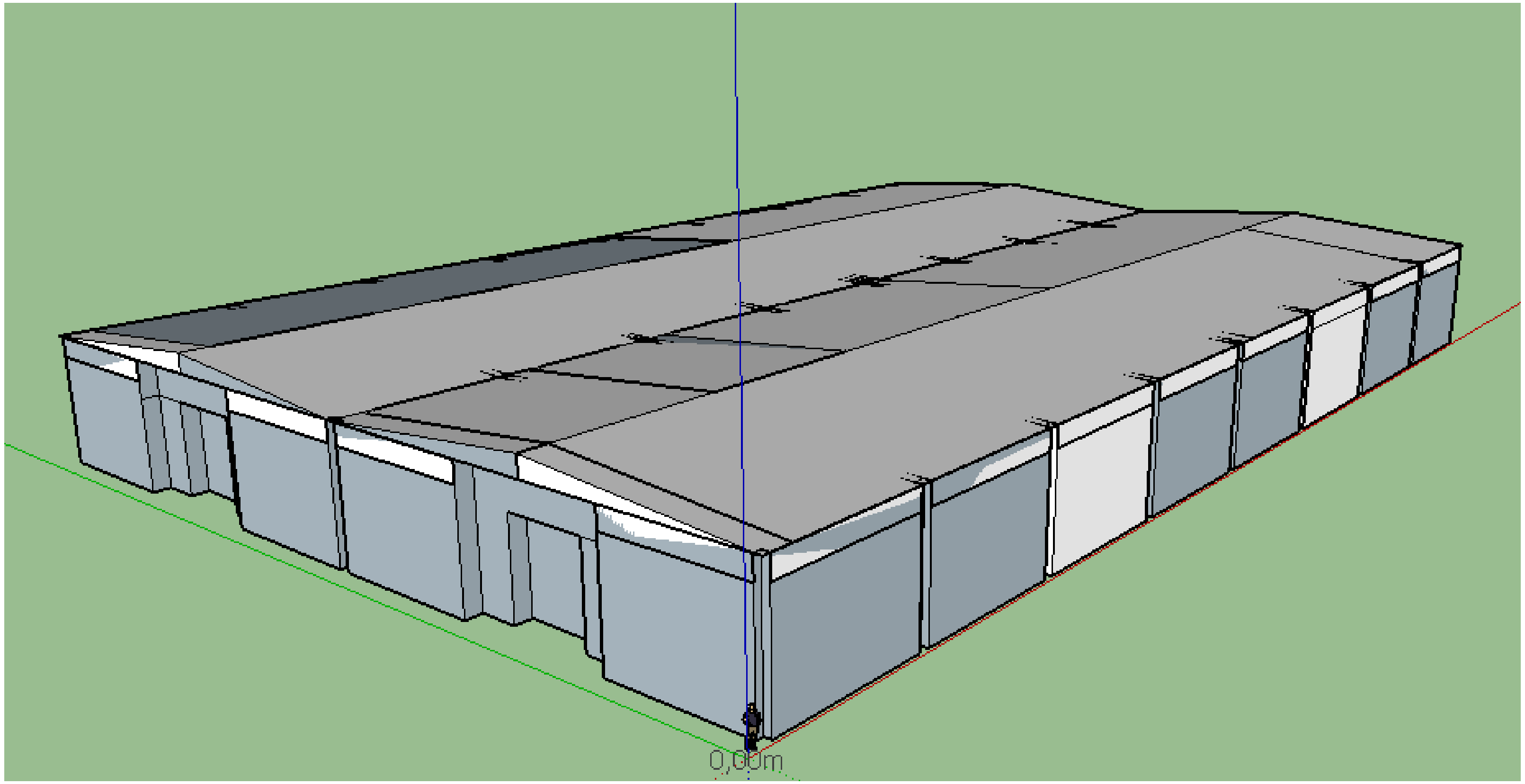

Figure 17- Perspective of the ceiling of the plant

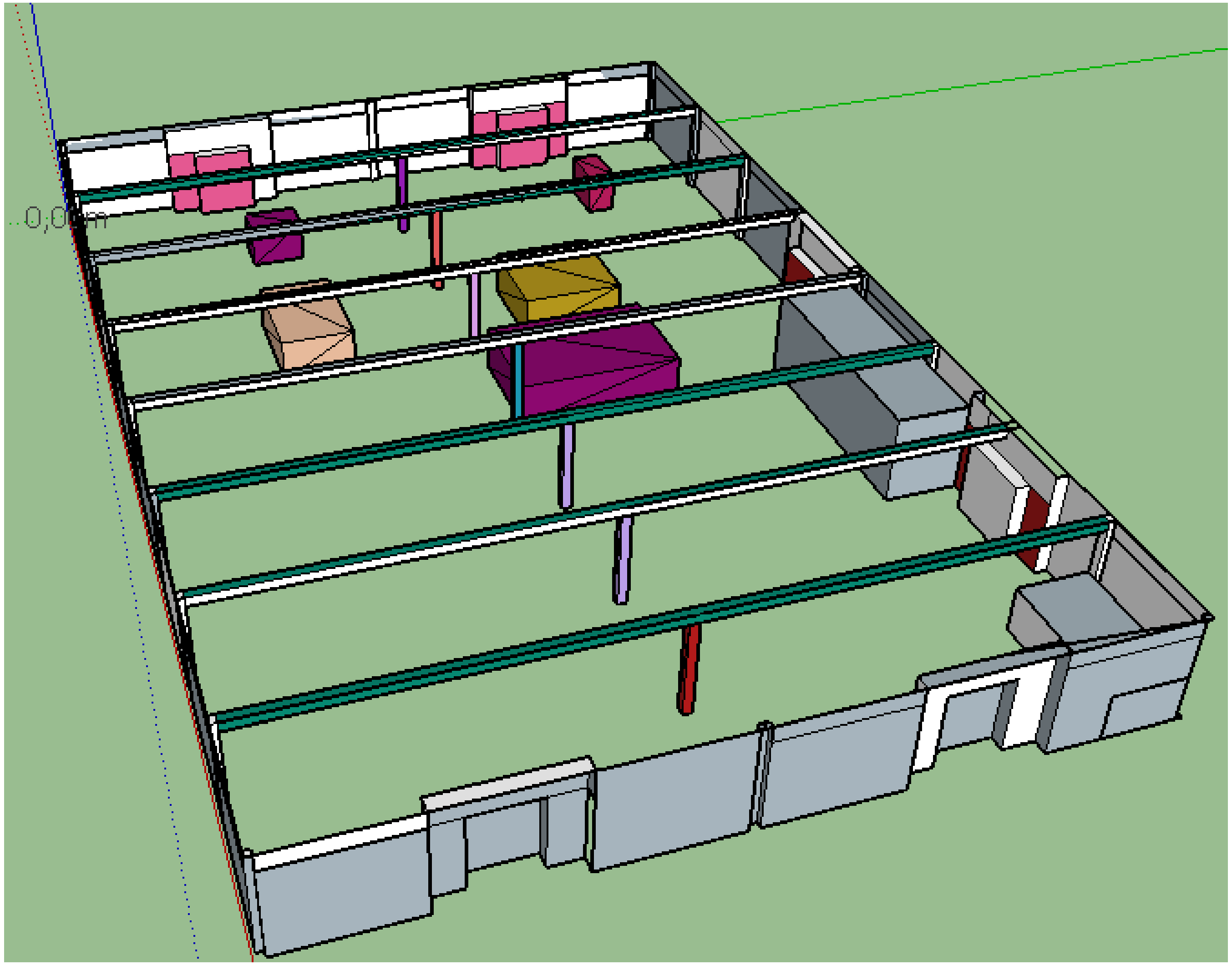

Figure 18-Perspective of the interior of the plant

5. Appendix 5: Variation of the 5% in the values obtained in the average of the measurement data

Sample	-5,00%	63Hz	5,00%	-5,00%	125Hz	5,00%	-5,00%	250Hz	5,00%	-5,00%	500Hz	5,00%
1	5,1775	5,45	5,7225	4,066	4,28	4,494	3,9235	4,13	4,3365	3,648	3,84	4,032
2	5,02075	5,285	5,54925	3,89975	4,105	4,31025	3,93775	4,145	4,35225	3,648	3,84	4,032
3	5,15375	5,425	5,69625	3,8475	4,05	4,2525	3,67175	3,865	4,05825	3,45325	3,635	3,81675
4	5,03975	5,305	5,57025	4,45075	4,685	4,91925	3,9425	4,15	4,3575	3,78575	3,985	4,18425
5	5,69525	5,995	6,29475	4,2275	4,45	4,6725	3,8475	4,05	4,2525	3,72875	3,925	4,12125
6	5,49575	5,785	6,07425	3,9805	4,19	4,3995	3,6195	3,81	4,0005	3,5055	3,69	3,8745
7	6,0895	6,41	6,7305	4,87825	5,135	5,39175	4,14675	4,365	4,58325	3,81425	4,015	4,21575
8	5,52425	5,815	6,10575	4,39375	4,625	4,85625	3,88075	4,085	4,28925	3,62425	3,815	4,00575

Sample	-5,00%	1kHz	5,00%	-5,00%	2kHz	5,00%	-5,00%	4kHz	5,00%	-5,00%	8kHz	5,00%
1	3,47225	3,655	3,83775	3,02575	3,185	3,34425	2,46525	2,595	2,72475	1,64825	1,735	1,82175
2	3,41525	3,595	3,77475	3,14925	3,315	3,48075	2,5175	2,65	2,7825	1,5865	1,67	1,7535
3	3,306	3,48	3,654	2,907	3,06	3,213	2,337	2,46	2,583	1,5865	1,67	1,7535
4	3,534	3,72	3,906	2,90225	3,055	3,20775	2,46525	2,595	2,72475	1,577	1,66	1,743
5	3,40575	3,585	3,76425	2,92125	3,075	3,22875	2,37025	2,495	2,61975	1,66725	1,755	1,84275
6	3,24425	3,415	3,58575	2,679	2,82	2,961	2,21825	2,335	2,45175	1,6245	1,71	1,7955
7	3,25375	3,425	3,59625	2,622	2,76	2,898	2,18975	2,305	2,42025	1,94275	2,045	2,14725
8	3,38675	3,565	3,74325	2,97825	3,135	3,29175	2,37025	2,495	2,61975	1,672	1,76	1,848

Table 18- Variation of the 5% in the T60 of the measurements