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Research Report 2

Noise measurements in boiler plants

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Contents

1. Introduction

The report 2 of the thesis entitled "Noise measurements in boiler plants" presents a synthesis of experimental researches on the influence of constructive and functional parameters of boiler plants on the noise level and acoustic comfort in buildings.

Research has been carried out with the help of a large number of people, including university professors, doctoral students, automatists, stoker, directors and others, who have been working in the years 2017-2018. At the moment this thesis is underway, with a certain delay due to the implications and problems that appear in an experimental thesis:

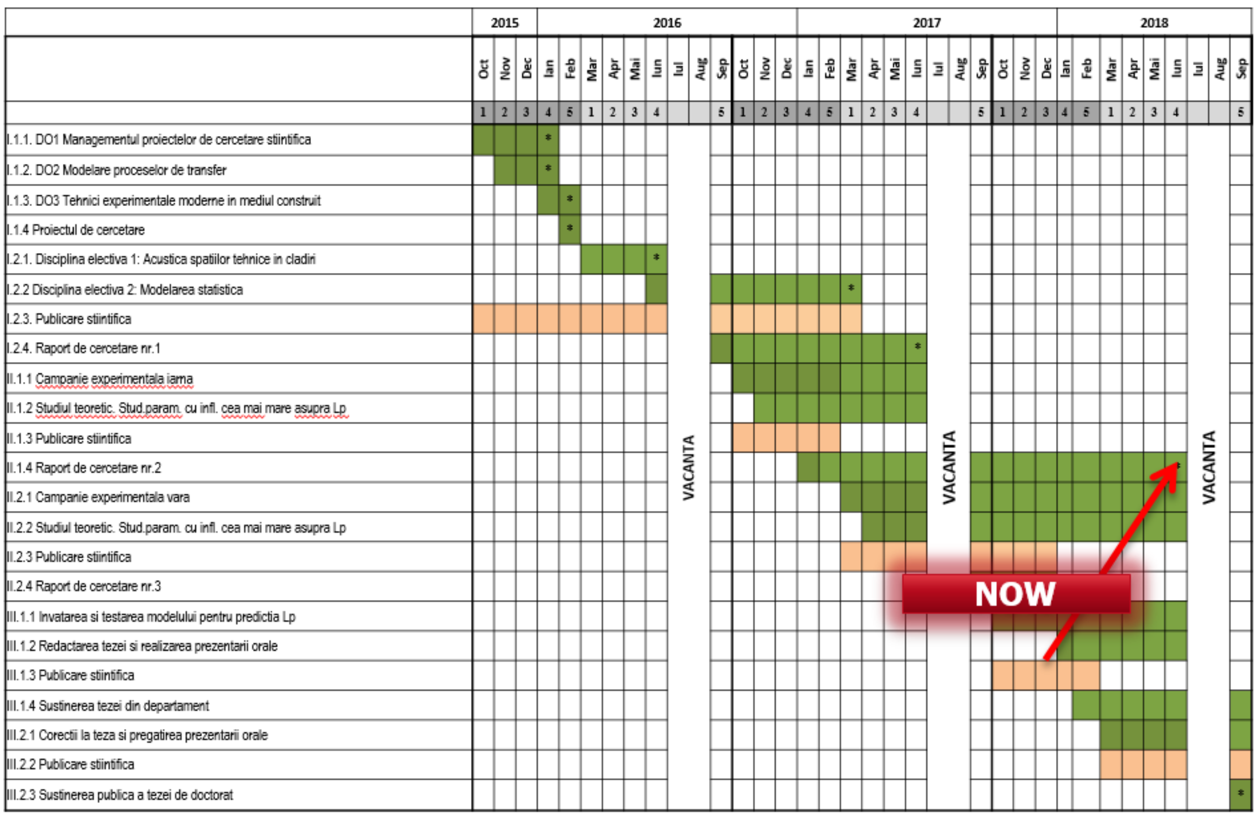


Fig.1 The Doctorate Thesis calendar of activity

This report presents the influence of parameters such as the temperature and pressure of the gas on the thermal power, three boiler plants in Ploiesti, Brasov and Bucharest, and a brief comparison of the results obtained from the measurements with the models in the literature.

2. The influence of pressure and temperature of the gas on the thermal power

The importance of this chapter is due to the isochoric process of the gas, a thermodynamic process during which the volume of the closed system undergoing such a process remains constant.

The ideal gas law, also called the general gas equation, is the equation of state of a hypothetical ideal gas. It is a good approximation of the behavior of methane gas under many conditions.

The gas low is:

$$\frac{p \cdot V}{T} = ct, \qquad (1)$$

where *ct* is a constant that is directly proportional to the amount of gas, n (Avogadro's law). The proportionality factor is the universal gas constant, *R*, i.e. *ct* = n*R*.

There are two situations of gas law:

- Normal conditions, when $p_o(bar)=p_{atm}$ and $T_o=273{,}15^oC$
- Real conditions. $p(bar)=p_{atm}+p_g$ and $T(^oC)=T_o+t_g$,

This change of the gas can introduce large changes in the performance of a burner, but we do not know how great the influence of the variance of these two paramas in real situations is on our phenomenon (noise level prediction). So we want to estimate this influence. This is what we propose in this chapter, to highlight how big is the influence of p and t on the thermal power and further on the noise level from boiler plants.

The thermal power of the boiler plant is measured at the gas meter, so the thermal output at the branch level, not the useful thermal power (what goes out of the boiler). This termal power depends on the normal state of the gas (normal pressure and normal temperature), lower calorific value and not the actual gas conditions.

$$\Phi_{burner} = B \cdot H_{i\,comb} = \frac{V_{1min}^{N}}{60[s]} \cdot H_i, \qquad (2)$$

where $\Phi_{burner}[kW]$- real thermal power for 60 seconds, $H_i\ [kj/m^3_N] = 35372$ - lower calorific value of gas for normal conditions, V_{1min}^{N} [m^3]– the volume of gas for normal conditions measured in one minute and $B\ [m^3_N/s]$ - gas consumption for 1 minute.

The volume of gas for normal conditions is determined on the basis state relationship (1), depending on the real gas conditions p_{real}, T_{real} and normal gas conditions, p_{atm}, T= 273,15^{o}C and the actual gas volume based on the gas meter measurements.

$$\left(\frac{p \cdot V}{T}\right)_{normal\ conditions} = \left(\frac{p \cdot V}{T}\right)_{real\ conditions}, \quad (3)$$

$$\frac{p_o \cdot V_0}{T_0} = \frac{p_{real} \cdot V_{real}}{T_{real}}, \quad (4)$$

$$\frac{p_{atm} \cdot V_{1min}^N}{T_0} = \frac{p_{real} \cdot V_{1min}}{T_{real}}, \quad (5)$$

$$\frac{p_{atm} \cdot V_{1min}^N}{273.15} = \frac{(p_g + p_{atm}) \cdot V_{1min}}{273.15 + t_g}, \quad (6)$$

$$V_{1min}^N = V_{1min} \cdot \frac{p_g + p_{atm}}{p_{atm}} \cdot \frac{273.15}{273.15 + t_g} \quad (7)$$

where p_{real} *[bar]* - real gas pressure, T_{real} *[K]*- real gas temperature, p_{atm} *[bar]* - atmospheric pressure, *To= 273,15 [°C],* V^N_{1min} [m^3] – the volume of gas measured in one minute and the actual gas volume based on the gas meter measurements, *B [m^3/s]* - gas consumption for 1 minute, p_g*[bar]*- methane gas pressure, t_g *[°C]* - methane gas temperature.

The actual volume of gas consumed in one minute is determined based on the gas meter readings at the beginning and at the end of this minute.

$$V_{1min} = I_F - I_I \quad (8)$$

where I_F *[m^3]* – final index read from gas meter and I_F *[m^3]* – initial index read from gas meter

The time considered as optimal for these experiments was 1 minute. During this time, the boiler must operate linearly, without interruption or without being in a state of initialization.

The V^N_{1min} from equation (7) is introduced in equation (2) in order to obtain the calculation formula for the thermal power as a function of the gas index :

$$\Phi_{burner} = \frac{V_{1min} \cdot \frac{p_g + p_{atm}}{p_{atm}} \cdot \frac{273.15}{273.15 + t_g}}{60} \cdot H_{i\ comb} \quad (9)$$

From the previous relationship (7) result the equation we used to calculate the thermal power produced by the burner in the experiments performed.

$$\Phi_{burner} = \frac{(I_{1min} - I_{0min}) \cdot \frac{p_g + p_{atm}}{p_{atm}} \cdot \frac{273.15}{273.15 + t_g}}{60} \cdot 35372 \quad (10)$$

Considering that the pressure and temperature for methane gas provided by the energy distributor do not vary greatly, the density obtained has insignificant variations.

Using equation (10), thermal power was calculated for V_{1min}=1 [m^3], temperatures between 5-15 [°C] and pressures of 20-40 [mbar] for the usual conditions of methane gas.

Table 1 Thermal power Φ_{burner}(kW) for different gas temperatures and pressures

		Temp, tg, [°C]										
		5	6	7	8	9	10	11	12	13	14	15
Gas pres., p_g, [mbar]	20	1892	1885	1878	1872	1865	1859	1852	1846	1839	1833	1826
	25	1883	1876	1869	1863	1856	1849	1843	1837	1830	1824	1817
	30	1874	1867	1860	1854	1847	1840	1834	1828	1821	1815	1809
	35	1865	1858	1851	1845	1838	1832	1825	1819	1812	1806	1800
	40	1856	1849	1842	1836	1829	1823	1816	1810	1804	1797	1791

From the above table it is observed that for these variations of temperature and pressure, the thermal power is poorly influenced, therefore, when the gas parameters cannot be identified, we can use as default value p_g=30 [mbar] t_g=10 [°C]

In the following table we will calculate the LA [dBA] – global A-weighted acoustic pressure level, depending on the thermal power with prediction model of Hamayon [1996], to highlight the influence of pressure and temperature on the LAeq produced by the burner.

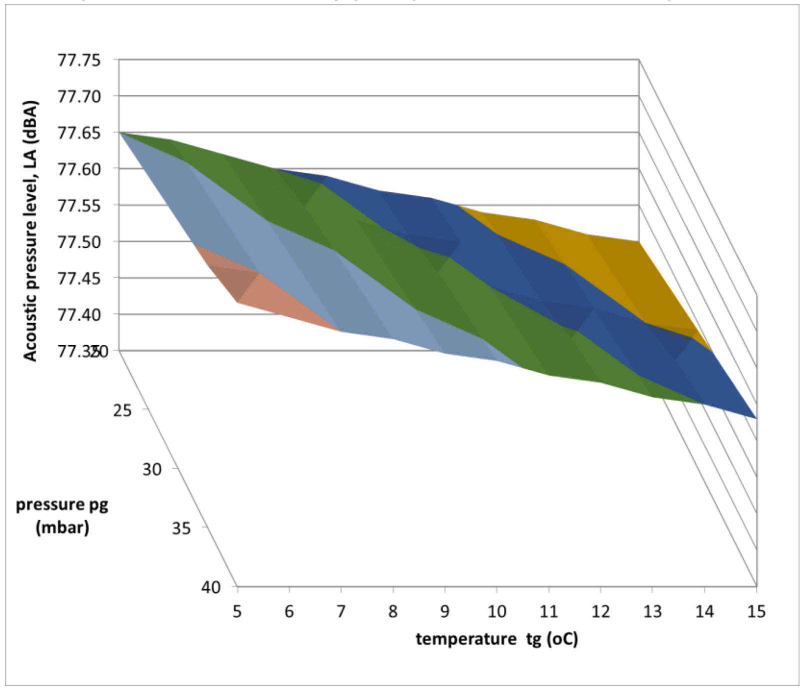
Table 2 Acoustic pressure level LAeq (dBA) for different gas temperatures and pressures

		Temp, tg, [°C]										
		5	6	7	8	9	10	11	12	13	14	15
Gas pres., p_g, [mbar]	20	77.74	77.72	77.70	77.69	77.67	77.66	77.64	77.63	77.61	77.60	77.58
	25	77.71	77.70	77.68	77.67	77.65	77.64	77.62	77.61	77.59	77.58	77.56
	30	77.69	77.68	77.66	77.65	77.63	77.62	77.60	77.58	77.57	77.55	77.54
	35	77.67	77.66	77.64	77.63	77.61	77.59	77.58	77.56	77.55	77.53	77.52
	40	77.65	77.64	77.62	77.60	77.59	77.57	77.56	77.54	77.53	77.51	77.50

The table above shows a difference of just 0.24 [dBA] between the minimum and maximum values of the Global A-weighted acoustic pressure level LAeq [dBA] based on thermal power. Considering this value we can conclude by the fact that real temperature and pressure of methane gas have a low influence on the burner noise.

Fig. 2 Global A-weighted acoustic pressure level LAeq (dBA) based on thermal power

LAmin = 77.5 dB(A)
LAmax=77.74 dB(A)
Variation = 0.24 dB(A)
0.31%



3. Experimental measurements made and in progress

Up to now, a total of 9 boiler plants out of the 50 proposed at the beginning of the doctoral thesis have been achieved. It should be borne in mind that for each thermal plant a number of 5-12 operational situations have been simulated, so the current database comprises almost 100 real operating situations.

Table 3 Table of accomplished and planned boiler plants in the future

Nr. crt	City	Institute	Building	Date	Stage work
1	Ploiesti	-	Isolate boiler plant	04/04/18	ACCOMPLISHED
2		-	Block of flats	04/04/18	ACCOMPLISHED
3	Brasov	-	Hotel	05/09/18	ACCOMPLISHED
4		-	Student Flats	05/09/18	ACCOMPLISHED
5		-	Colina	05/09/18	broken gas meter
6	Bucuresti	-	FII	11/20/17	ACCOMPLISHED
7		-	Cantina	04/24/18	ACCOMPLISHED
8		-	Geodesy	04/19/18	ACCOMPLISHED
9		-	Students Flats 5	04/24/18	ACCOMPLISHED
10		-	Students Flats 6	04/24/18	ACCOMPLISHED

Fig. 3 Boilers plants in Ploiesti

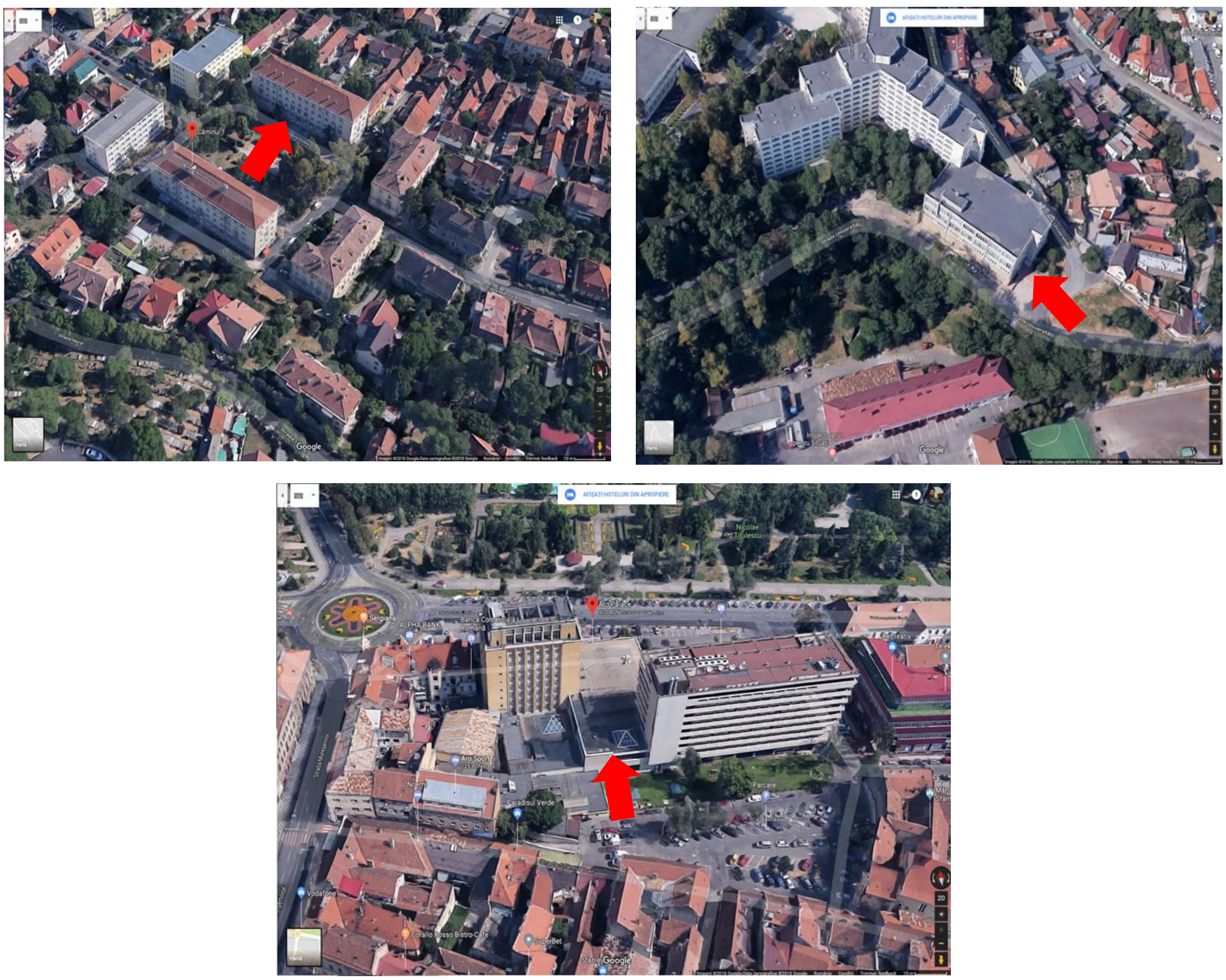


Fig. 4 Boilers plant of a Hotel in Brasov

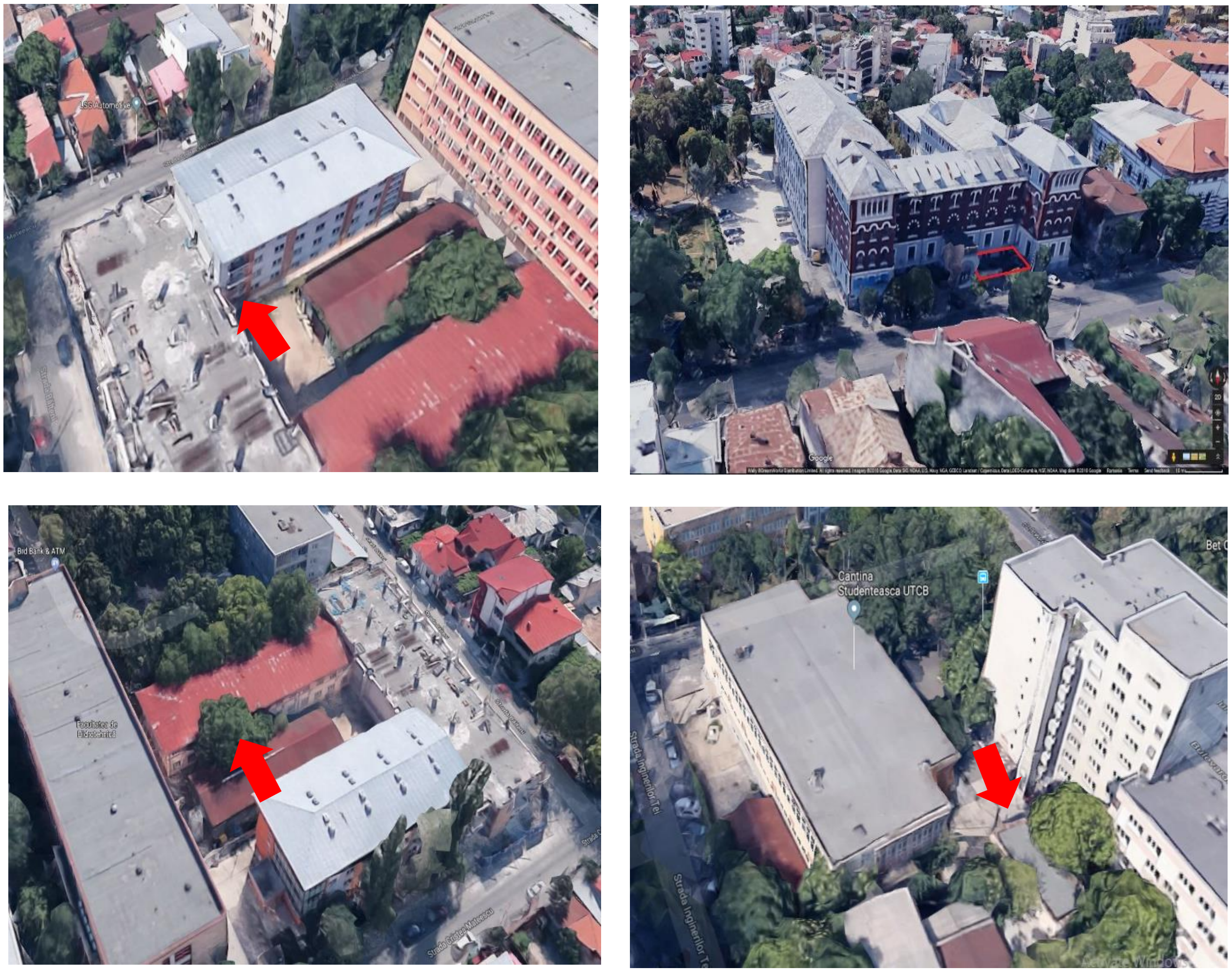


Fig. 5 Boilers plant in Bucharest

4. Experimental protocol

4.1 The subject of the experiment

The experiment consists of the experimental measurement of the noise level in the boiler plants stations using the portable type 2250 channel amplifier with 4-22 kHz carrier frequency.

Fig. 6 Equipment used in experiments sound meter and laser measure tool

The sound meter we used during experiments has been developed specifically for measuring occupational, environmental and product noise, while complying fully with all the relevant national and international standards.

Sound meter type 2250 it’s a Class 1 modular precision integrating-averaging soundmeter with an easy-to-use interface for quick and simple measurement setups and it have included the optional 1/1- and 1/3-octave frequency analysis software.

All the octaves are measured at the same instant, along with broadband A- and C-weighted values, so there is no filter switching or range changing.
We also have installed on the sound meter, a application witch supports two reverberation time measurement methods: impulsive excitation (Schroeder Method) and interrupted noise. In our experiments we use impulsive excitation method and Type 2250 automatically measures reverberation time when a balloon burst is used to excite the boiler plant.

Reverberation measurements in several positions can be carried out in sequence. T20, T30 and EDT parameters are all measured for both wide-band and in each octave band to automatically calculate the room averages.

We also use BZ-5503 Utility Software for Hand-held Analyzers to transfer data to an archive on the PC. Then we export data from the archive to a Excel. The export is controlled by your BZ-5503 software (we cannot open instrument data directly from the post-processing and reporting software, or Excel).

For the architectural measurements we use GLM40. The laser measure is simple to operate, so we need only press one button to get accurate measurements to within 3[mm] and a distance range measures up to 100[m].

4.2 Place, date, and preparation of the experiment:

The presented experiment has an applicative character and has the role of helping to compile a database necessary to determine a noise prediction model in the technical spaces.

The experiment is carried out in several thermal plants in Bucharest and Brasov.

To complete the experiment:

- Making photographs from different angles for analyzing the location's architecture and location from external sources (street type, etc.);
- Identify the type of absorbent material (wall type, floor, ceilling)
- Boiler type identification (maximum boiler output, burner type, cast iron boiler, steel);
- Identification of the gas meter;
- Identification of other noise generating equipment (pumps, heat exchanger, smoke box, etc.);
- Identification of acoustic treatment solutions (noise attenuator, massive door, insulated chimney, boiler dismantling, etc.)
- Analyzing the possibility of measuring the gas flow rate;
- Architectural measurements (room dimensions);
- The B & K Type 2250 portable acoustic analyzer (tripod mounting, commissioning, calibration, working parameters setting)
- Using the Pulse Labshop ver 15.1.0 software, 25 measurements will be performed for 10 seconds, totaling 250 acoustic pressure levels.

These values will be saved as .txt file, imported into Excel and subsequently processed, to obtain the sound pressure levels in dB.

- Using the Pulse Labshop ver 15.1.0 software, reverberation time measurements will be performed by breaking an air balloon near the burner.
- These values will be saved as a .txt file, imported into Excel and subsequently processed, to obtain the room's absorption capacities at different frequencies.
- Following the experiment, the following database will be obtained to generate input values: Φ_{burner}, $\log_{10}(\Phi_{burner})$, L_w, V, α_{125Hz} , α_{250Hz} , α_{500Hz} , α_{1000Hz} , α_{2000Hz} , α_{4000Hz} , α_{8000Hz} , architectural and outputs data are: L_{Aeq}, $L_{p\ 63\text{-}8000Hz}$, $T_{20,}$ $T_{30,}$ EDT.

4.3 The work done for experiments

For each experiment, significant efforts have been made. The experiments were performed at night, during the week and in different cities (Brasov, Ploiesti, Bucharest). For each experiment, a human resource of 3-4 people was needed. There was also a need for approvals from the management of the institutions in which measurements were made.

The measurements were carried out by a team of three or four people: one person registers the gas index, another one operates the boiler automation, and the third person carries out the noise measurements.

The experiments were attended by firefighters, automatists, students, teachers, and other people who are very grateful for their help.

5. Experimental protocol of boiler plant 1, thermal power 3300 KW

5.1 Location:

First thermal plant is located in Ploiesti and is a stand-alone building located next to the blocks and serves 6 blocks of dwellings with height of P + 10E, with an installed thermal capacity of 3300 kW.

Fig. 7 Central heating plant location

5.2 Architectural presentation of the room

The room has a rectangular shape, split in the middle by transversal beams, and its dimensions are: 17.72m long, 8.90m wide and 4.67m tall. The walls of the boiler plant are made of brick, hardwood, and the finished concrete floor. The two windows have a metal frame and a single sheet of glass, and at the bottom is a mesh material that allows pressure compensation on the inside.

The volume of the boiler room is 736.49 m^3. Surface of walls, ceilings and floors are of reflective materials, so the room absorption coefficient is very low.

Hard surfaced of this boiler room will have a longer reverberation time than rooms finished with sound absorbing materials. The immediate effect of multiple reflections is an increase in the sound intensity caused by the reflections. A fireman will hear the direct sound arriving at the ear along with all of the multiple reflections. Thus the combined loudness of the direct sound and the reflected sound will be greater than the direct sound alone.

Fig. 8 Boiler plant on the inside

5.3 The equipment of the thermal plant

The thermal plant has two 1400KW Chappee Arizona HR2 boilers and a 500KW Viessman Vitoplex100 boiler. The burners of these boilers are of the SICMA type GS151RAG with two power stages of 1000-2000KW, respectively Vitoflame 100 with two power stages between 380-560KW.

In the boiler assembly we find 22 Grundfoss pumps MG90LA4, two heat exchangers with plates, 2 buffer tank.

The Chappee Arizona boilers are equipped with a body of double-range heater of fumes. The pipes of the tubular bundle, forming the second course, are located at the top of the heating body avoiding so the formation of condensates. The burner of these boilers has two progressive stages of power and the possibility of operation with power modulation with the control panel of the automatic controller RWF40.

Vitoplex 100 type SX1, with thermal power of 500kW is a low temperature gas fired boiler This is a three-pass boiler for operation with modulating boiler water temperature. The burner of this boiler is a Vitoflame 100 pressure-jet gas burner, equipped with a Boiler control unit for constant boiler water temperature.

5.4 Existing noise protection solutions

The chimney of the boiler is made of metallic material without total insulation on the outside and is located inside and partially outdoors. The boilers are fixed by deconstruction: foundation and puffers.

The three burners do not have an phonoabsormant housing, and the pipe connections are made by metal bracelets. The heating installation does not have flexible connections to ducts of the boiler (thermal / gas / fluid).

There is no other noise protection like sound attenuator at chimney (in pipe or in quarter-wave) or walls captured with mineral wool or/and rigips.
The crossing of the walls by the pipes is without any solution to reduce the vibrations transmitted by the combustion of the gas.

Table 4 Equipment type and existing noise protection solutions table

Case [-]	Pump Burner 1 [-	Pump Burner 2 [-	Burner 1 [-]	Burner 2 [-]	Tr [s]	Volum [m3]	Boiler type [-]	Type of fuel[-]	Burner type [-]	Burner case [-]	WallAcoustic treatment [-]	Boiler dissociation [-]	Boiler fundation [-]	Flexible connection [-]	Passing pipes [-]	Chimmey isulation [-]
1	0	0	**0**	**0**	1.49	736.49	ReverseFlame	gas	Aer insuflat	0	0	1	1	0	0	0
2	0	1	**0**	**0**	1.49	736.49	ReverseFlame	gas	Aer insuflat	0	0	1	1	0	0	0
3	1	0	**0**	**0**	1.49	736.49	ReverseFlame	gas	Aer insuflat	0	0	1	1	0	0	0
4	1	1	**0**	**0**	1.49	736.49	ReverseFlame	gas	Aer insuflat	0	0	1	1	0	0	0
5	1	1	**0**	**1**	1.49	736.49	ReverseFlame	gas	Aer insuflat	0	0	1	1	0	0	0
6	1	1	**0**	**2**	1.49	736.49	ReverseFlame	gas	Aer insuflat	0	0	1	1	0	0	0
7	1	1	**1**	**0**	1.49	736.49	ReverseFlame	gas	Aer insuflat	0	0	1	1	0	0	0
8	1	1	**1**	**1**	1.49	736.49	ReverseFlame	gas	Aer insuflat	0	0	1	1	0	0	0
9	1	1	**1**	**2**	1.49	736.49	ReverseFlame	gas	Aer insuflat	0	0	1	1	0	0	0
10	1	1	**2**	**0**	1.49	736.49	ReverseFlame	gas	Aer insuflat	0	0	1	1	0	0	0
11	1	1	**2**	**1**	1.49	736.49	ReverseFlame	gas	Aer insuflat	0	0	1	1	0	0	0
12	1	1	**2**	**2**	1.49	736.49	ReverseFlame	gas	Aer insuflat	0	0	1	1	0	0	0

The table above is part of the doctoral thesis database and includes the constructive type of the noise generating equipment in the thermal plant and the existing acoustic treatment solutions. Also in this table is the volume of the inner space and the reverberation time measured during the experiment, both used for an easier calculation of the average absorption coefficient of the inner surfaces.

Fig. 9 Noise protection solutions in boiler plant

5.5 The experimental part

Five types of measurements were made for each thermal power plant:
- dimensions (room, equipment, windows, doors, chimney). Room dimensions are: 17.72m long, 8.90m wide and 4.67m tall.
- pressure and temperature of the gas. $p_g = 0.03$ *[bar]*; $T_g = 11.78$ *[°C]*;

- reverberation time inside the thermal plant (EDT, T20, T30);

Table 5 Reverberation time (EDT,T20,T30) measured with soundmeter

Frequency	(500 Hz-1 kHz)	63Hz	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz	8kHz	2kHz	4kHz	8kHz
T20	1.49	1.65	1.63	1.47	1.55	1.43	1.23	0.98	0.62	1.23	0.98	0.62
T30	1.48	1.81	1.70	1.54	1.51	1.44	1.22	1.00	0.66	1.22	1.00	0.66
EDT	1.28	1.64	1.43	1.71	1.35	1.22	0.97	0.65	0.37	0.97	0.65	0.37

- noise level for different thermal powers the equivalent continuous noise level (LAeq), soundpressure levels in the frequency bands Lp_{16Hz}, $Lp_{31.5Hz}$, Lp_{63Hz}, Lp_{125Hz}, Lp_{250Hz}, Lp_{500Hz}, Lp_{1000Hz}, Lp_{2000Hz}, Lp_{4000Hz}, Lp_{8000Hz}
- gas consumption for each thermal power.

Investigation consist of:
- wall types; walls are made of brick paitned white, floor and ceilling are made of concrete;
- equipment constructive type (burners, pumps, boilers)
  - Burner type: SICMA type GS151RAG with two power stages of 1000-2000KW, respectively Vitoflame 100 with two power stages between 380-560KW.
  - Boilers types: two 1400KW Chappee Arizona HR2 boilers and one 500KW Viessman Vitoplex100 boiler both with turndown ratio;
  - Pumps type: 22 Grundfoss pumps MG90LA4

Since the burners have two power stages, we were able to experiment a number of 12 real operating situations.

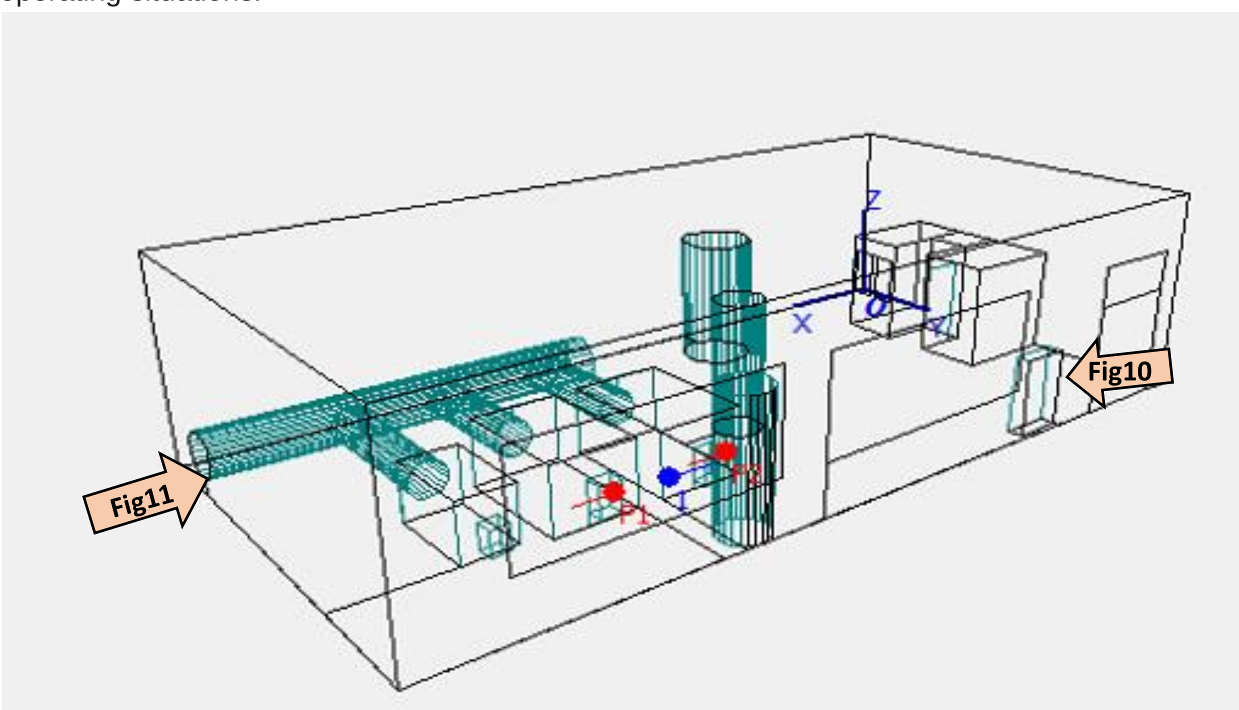


Fig.10 Burning position (noise sources) and receiver (Bruel & Kjaer sonometer)

The burner stage control was made by using the boiler control panel by selecting the desired step, as shown below.

Case [-]	Pump Burner 1 [-]	Pump Burner 2 [-]	**Burner 1 [-]**	**Burner 2 [-]**
1	0	0	**0**	**0**
2	0	1	**0**	**0**
3	1	0	**0**	**0**
4	1	1	**0**	**0**
5	1	1	**0**	**1**
6	1	1	**0**	**2**
7	1	1	**1**	**0**
8	1	1	**1**	**1**
9	1	1	**1**	**2**
10	1	1	**2**	**0**
11	1	1	**2**	**1**
12	1	1	**2**	**2**

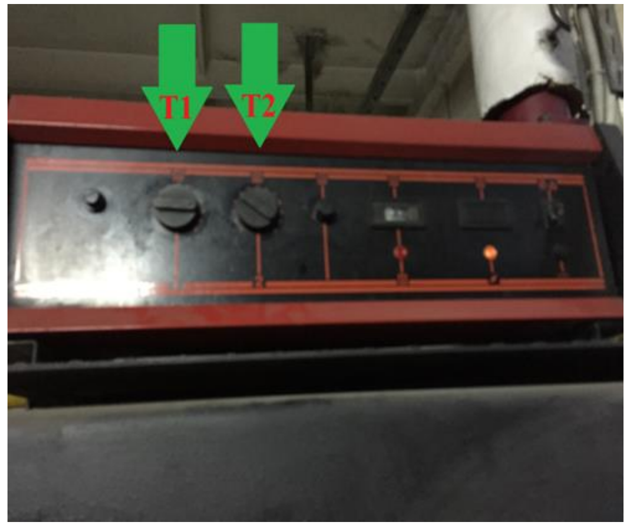


Fig.11 a) Operating conditions b)control panel of the boiler T1-stage1 / T2-stage2

For the fuel consumption measurement, the initial and final index for the gas meter was recorded for a period of 1 minute. During this time the noise measurements were made inside the technical space.

Before the actual measurements began, the gas temperature and pressure were recorded

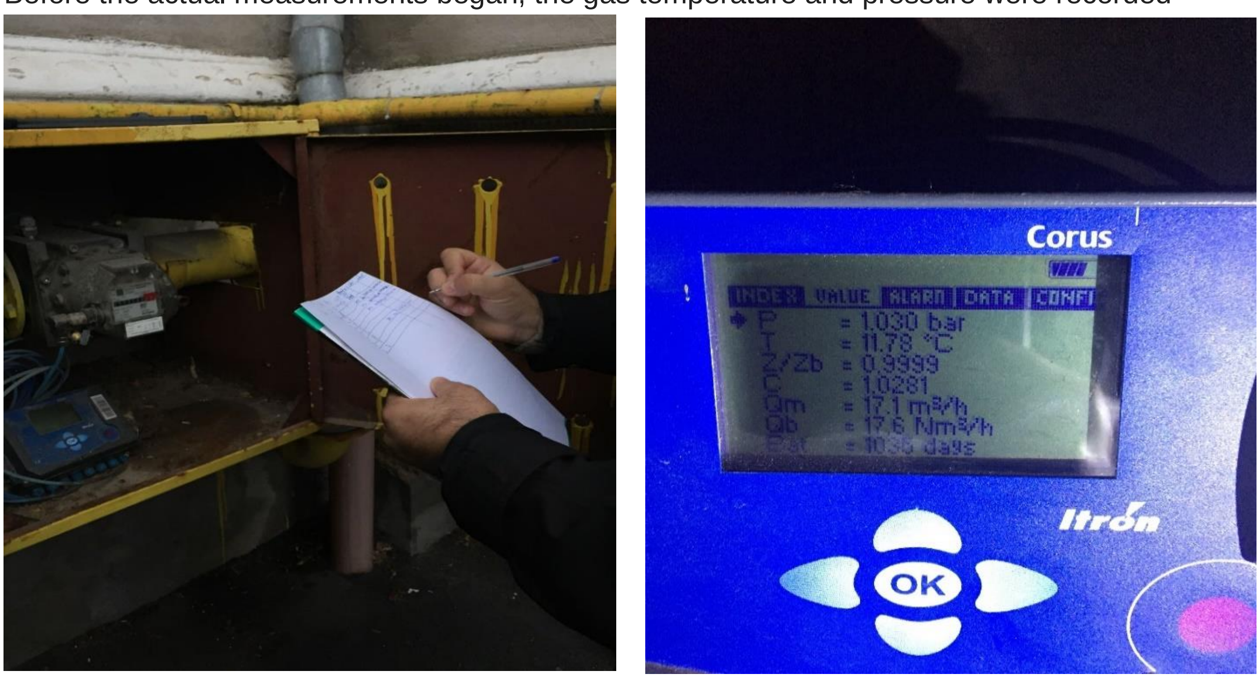


Fig.12 Reading of a)gas index b)gas parameters

The measurement of the noise level was carried out by means of a Bruel&Kjaer 2250 sound meter. The measurements were carried out by a team of three people: one person registers the gas index, another one operates the boiler automation, and the third person carries out the noise measurements.

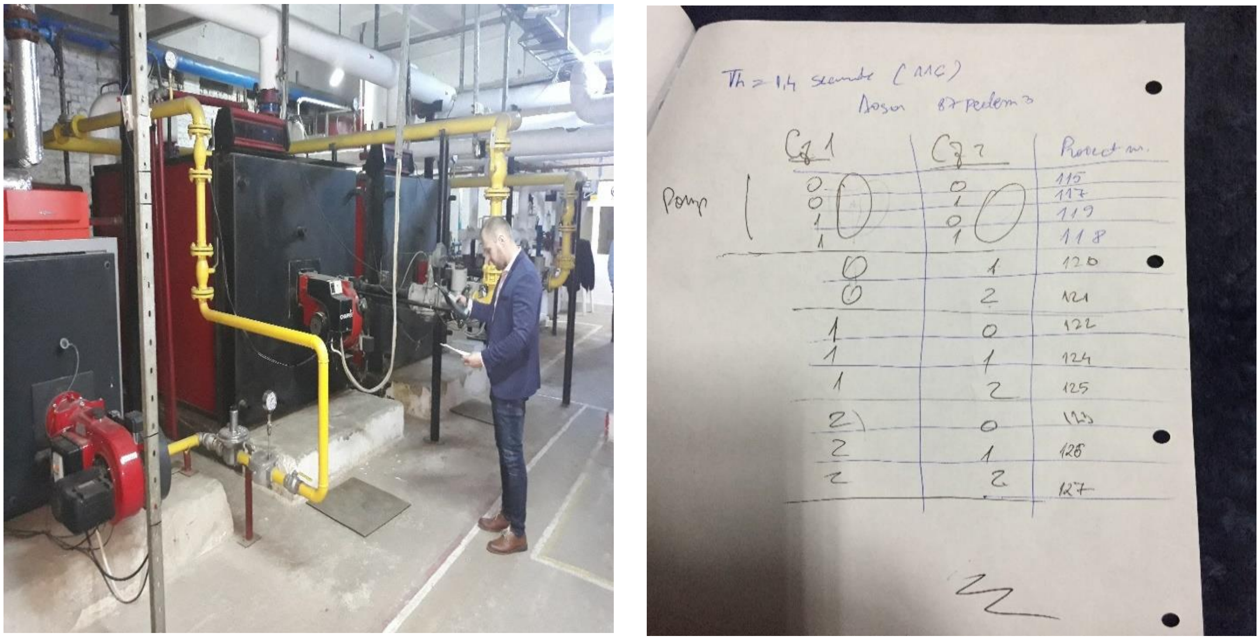


Fig.13 a) Noise level measurements b) Project and operating stage notation

Another measurement made during this experimental protocol is the reverberation time.The Impulse Excitation Method was used using the same B&K 2250 sound meter and a balloon.
We record the decay curves for all frequency bands and the reverberation time is calculated by means of the 7277 sound meter software for all frequencies.

5.6 The database

The following formula was used to determine the actual thermal load of the boiler:

$$\Phi_{burner} = \frac{I_F - I_I}{60} \cdot \frac{p_g \cdot 273.15}{p_0} \cdot \frac{p}{T} \cdot H_i$$

$$\Phi_{burner} = \frac{I_F - I_I}{60} \cdot \rho_{comb} \cdot H_{i\,comb}$$

where Φ_{burner}- real thermal power for 60 seconds, I_F *[m³]* and I_I *[m³]* final index and initially read recording from the gas meter, ρ_{comb} [-]; fuel density, $H_{i\ comb}$ [kJ/m^3_N] low fuel calorific value, *po* [bar], *po=1.01325* [bar] atmospheric pressure and *T[K]* gas temperature under normal conditions.

Table 7 Measurement table for the equivalent noise level

Case [-]	Pump Burner 1 [-]	Pump Burner 2 [-]	**Burner 1 [-]**	**Burner 2 [-]**	**Index I [m3]**	**Index F [m3]**	**Consum. [m3]**	**Time [s]**	**Flow [m3/s]**	**Hi [kj/m3N]**	p/po*To/T [-]	**Φ burner [kW]**	LOG10 (Φ**b) [kW]**	**Project Name [-]**	**LAeq [dB(A)]**
1	0	0	**0**	**0**	2525764.38	2525764.38	0.00	60	0.00	35371.70	0.99	0	0	Project 115	43.63
2	0	1	**0**	**0**	2525764.38	2525764.38	0.00	60	0.00	35371.70	0.99	0	0	Project 117	61.63
3	1	0	**0**	**0**	2525764.38	2525764.38	0.00	60	0.00	35371.70	0.99	0	0	Project 119	63.89
4	1	1	**0**	**0**	2525764.38	2525764.38	0.00	60	0.00	35371.70	0.99	0	0	Project 118	63.04
5	1	1	**0**	**1**	2525764.38	2525766.33	1.95	60	0.03	35371.70	0.99	1135	3.05	Project 120	86.15
6	1	1	**0**	**2**	2525768.80	2525770.35	1.55	60	0.03	35371.70	0.99	902	2.96	Project 121	83.99
7	1	1	**1**	**0**	2525773.30	2525774.80	1.50	60	0.03	35371.70	0.99	873	2.94	Project 122	86.87
8	1	1	**1**	**1**	2525781.30	2525784.76	3.46	60	0.06	35371.70	0.99	2013	3.30	Project 124	88.72
9	1	1	**1**	**2**	2525788.30	2525791.72	3.42	60	0.06	35371.70	0.99	1990	3.30	Project 125	87.48
10	1	1	**2**	**0**	2525776.20	2525777.38	1.18	60	0.02	35371.70	0.99	687	2.84	Project 123	86.29
11	1	1	**2**	**1**	2525797.40	2525800.85	3.45	60	0.06	35371.70	0.99	2008	3.30	Project 126	88.07
12	1	1	**2**	**2**	2525805.20	2525808.20	3.00	60	0.05	35371.70	0.99	1746	3.24	Project 127	87.34

In the first table the real thermal power was calculated based on the gas consumption, which is the difference between the final index and the initial reading from the gas meter by one of the participants in the experiment.

The time at which this consumption took place was 60 seconds, at which time an internal noise measurement was also recorded at 1 meter from the burner, measured according to the norms prescriptions.

The lower calorific value was calculated using the gas temperature and pressure indicated by the digital gas meter.

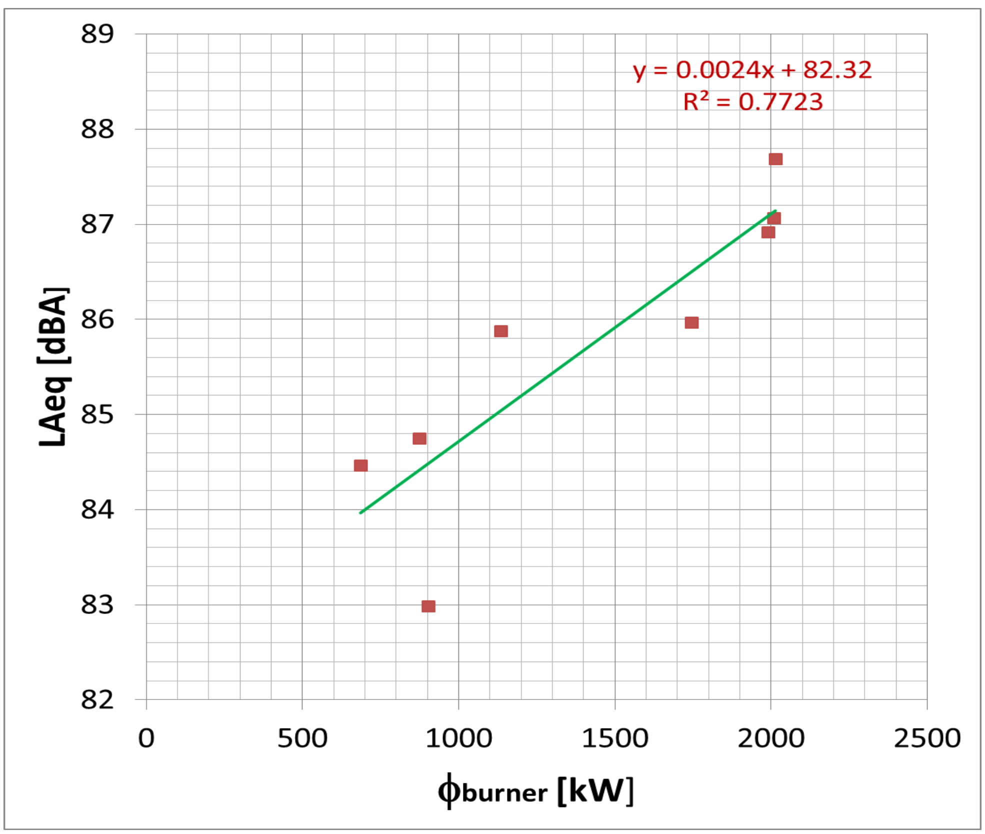


Fig.14 Equivalent noise level based on actual thermal power, equation and R^2

From this graph we can see the increasing tendency of the equivalent noise level depending on the thermal load of the boiler. This increase validates the prediction models from the literature, which have their component and thermal load, as the main parameter.

Table 8 Measurement table for equivalent noise level and each frequency noise level

Case [-]	Pump Burner 1 [-]	Pump Burner 2 [-]	Burner 1 [-]	Burner 2 [-]	LAeq [dB(A)]	LZeq_O 16Hz [dB]	LZeq_O 31.5Hz[dB	LZeq_O 63Hz[dB]	LZeq_O 125Hz[dB]	LZeq_O 250Hz[dB]	LZeq_O 500Hz[dB]	LZeq_O 1kHz[dB]	LZeq_O 2kHz[dB]	LZeq_O 4kHz[dB	LZeq_O 8kHz[dB]
1	0	0	0	0	43.63	58.59	50.06	45.09	44.46	40.02	37.43	37.18	32.47	27.31	20.67
2	0	1	0	0	61.63	58.93	57.56	56.63	56.78	57.12	60	54.96	48.96	42.32	47.47
3	1	0	0	0	63.89	54.52	52.75	48.31	59.27	58.86	62.02	57.86	49.88	42.73	50.63
4	1	1	0	0	63.04	57.8	57.08	53.38	60.76	57.85	60.79	56.99	50.82	44.14	49.38
5	1	1	0	1	86.15	84.07	82.75	80.86	81.68	78.72	85.88	77.82	76.57	73.01	65.46
6	1	1	0	2	83.99	81.85	79.02	75.81	79.47	77.38	82.99	76.74	76.02	71.49	63.25
7	1	1	1	0	86.87	78.32	76.22	80.55	82.02	81.43	84.75	80.18	79.36	75.92	68.48
8	1	1	1	1	88.72	81.31	81.42	82.69	85.1	82.5	87.69	81.22	80.08	75.72	67.93
9	1	1	1	2	87.48	81.94	80.55	82.04	82.65	81.19	86.92	80.14	78.55	74.23	65.88
10	1	1	2	0	86.29	74.97	76.61	78.82	77.87	79.4	84.47	78.14	78.48	74.6	68.13
11	1	1	2	1	88.07	82.63	81.76	82.76	84.77	81.73	87.07	80.59	79.69	75.78	67.41
12	1	1	2	2	87.34	77.36	80.05	81.67	80.08	78.66	85.97	80.23	79.5	74.31	65.89

Table 9 Table with equivalent noise level and noise level Cz80 according to norms

Nr crt. [-]	Laeq_No [dB(A)]	LZeq_No 16Hz [dB]	LZeq_No 31.5Hz[dB]	LZeq_No 63Hz[dB]	LZeq_No 125Hz[dB]	LZeq_No 250Hz[dB]	LZeq_No 500Hz[dB]	LZeq_No 1kHz[dB]	LZeq_No 2kHz[dB]	LZeq_No 4kHz[dB]	LZeq_No 8kHz[dB]
Cz80	85	121.1	109.9	98.7	91.6	86.4	82.7	80	77.7	75.9	74.4

The above tables shows the noise levels for each frequency as measured by the Bruel Kjaer sonometer during the experiments, and in table number two the noise level for technical spaces according to the Cz80 curve indicated in the Romanian noise protection norm.

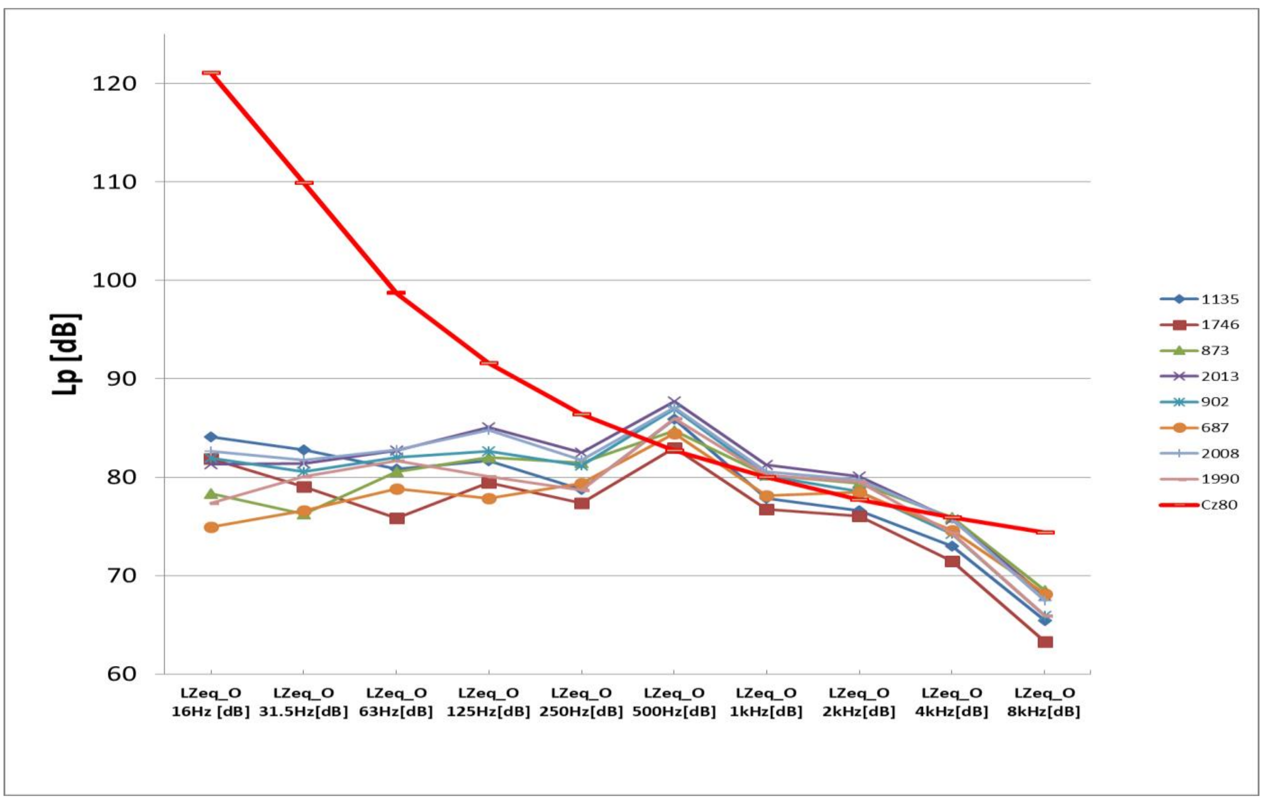


Fig. 15 Comparison between noise level on each frequency and Cz80 from norms

In the graph above, it is observed that up to the 250 Hz frequency for all noise levels exceeds the values indicated in the norms, resulting in the need for acoustic treatment for low frequencies (burning frequencies). For higher frequencies, the noise level is below the Cz80 curve, thus respecting the maximum allowable noise level in a boiler plant.

Table 10 Table with inspections carried out during the experiment on this thermal plant

Case [-]	Pumps [-]	Burner 1 [-]	Burner 1 [-]	Burner 1 [-]	Burner 2 [-]	Tr [s]	Volum [m3]	Type of fuel[-]	Burner type [-]	Burner case [-	Acoustic treatment [-	Boiler dissociation	Boiler fundation [-	Flexible connection [-	Passing pipes [-]	Chimmey isulation [-]
1	0	0	0	0	0	1.34	660.96	gas	Aer insuflat	0	0	1	1	0	0	0
2	0	1	0	0	0	1.34	660.96	gas	Aer insuflat	0	0	1	1	0	0	0
3	1	2	0	0	0	1.34	660.96	gas	Aer insuflat	0	0	1	1	0	0	0
4	1	0	0	1	0	1.34	660.96	gas	Aer insuflat	0	0	1	1	0	0	0
5	1	0	0	2	0	1.34	660.96	gas	Aer insuflat	0	0	1	1	0	0	0
6	1	1	0	2	0	1.34	660.96	gas	Aer insuflat	0	0	1	1	0	0	0
7	1	2	0	2	0	1.34	660.96	gas	Aer insuflat	0	0	1	1	0	0	0
8	1	1	0	1	0	1.34	660.96	gas	Aer insuflat	0	0	1	1	0	0	0
9	1	1	2	0	0	1.34	660.96	gas	Aer insuflat	0	0	1	1	0	0	0
10	1	1	2	1	0	1.34	660.96	gas	Aer insuflat	0	0	1	1	0	0	0
11	1	2	2	2	0	1.34	660.96	gas	Aer insuflat	0	0	1	1	0	0	0
12	1	2	2	2	2	1.34	660.96	gas	Aer insuflat	0	0	1	1	0	0	0

The above table shows the inspections carried out during the experiment on this thermal plant. It is noticed that another essential requirement regarding acoustic comfort, namely the reverberation time, respects the values indicated in C125.

There are many ways to control the boiler stage. This installation use sophisticated control panel to center and rotate boilers automatically according to the request. An on / off heat source must be operated with a differential in order to prevent short cycling. The boiler differential is divided around the boiler target temperature.

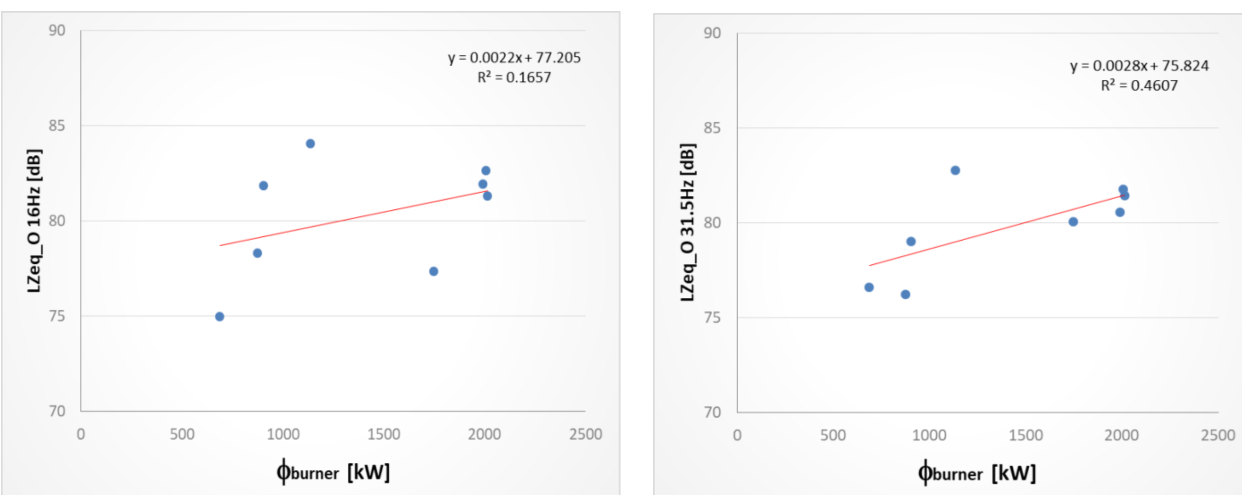


Fig.16 Measurement noise level for low frequency based on thermal power *equations & R^2*

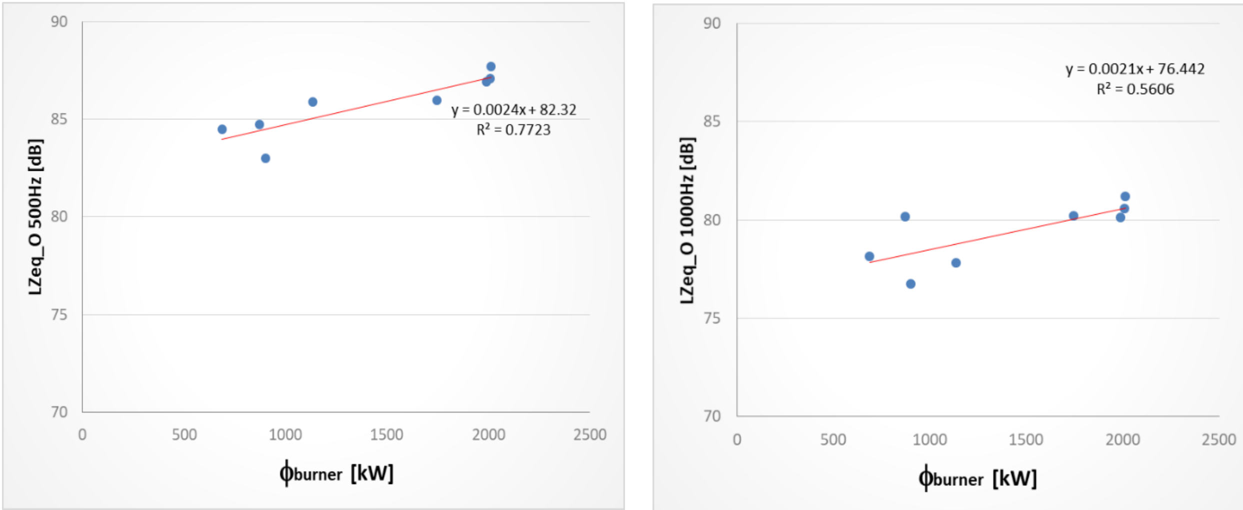


Fig.17 Measurement noise level for medium frequency based on thermal power *equations & R^2*

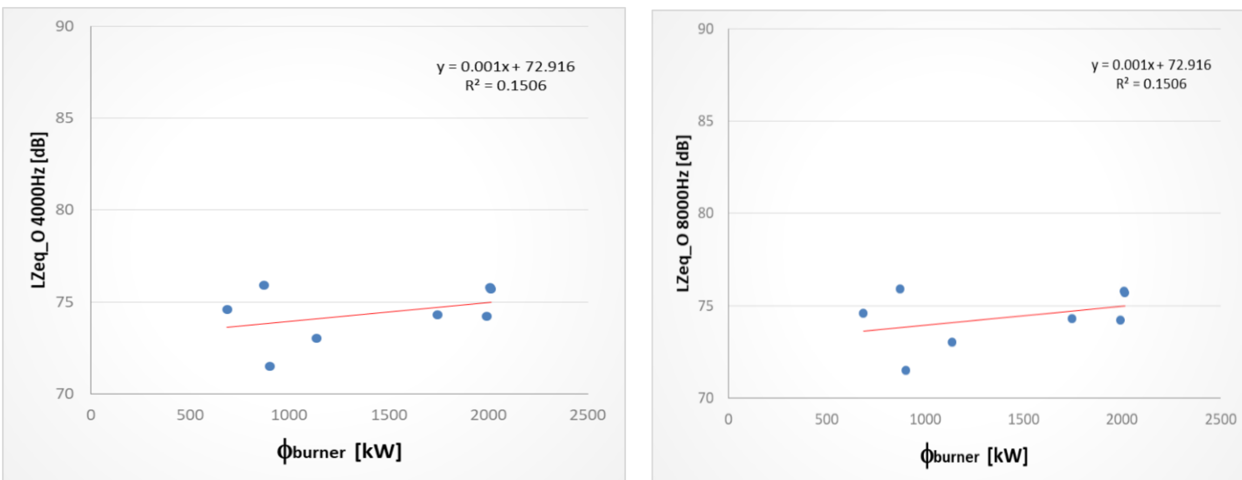


Fig.18 Measurement noise level for high frequency based on thermal power *equations & R^2*

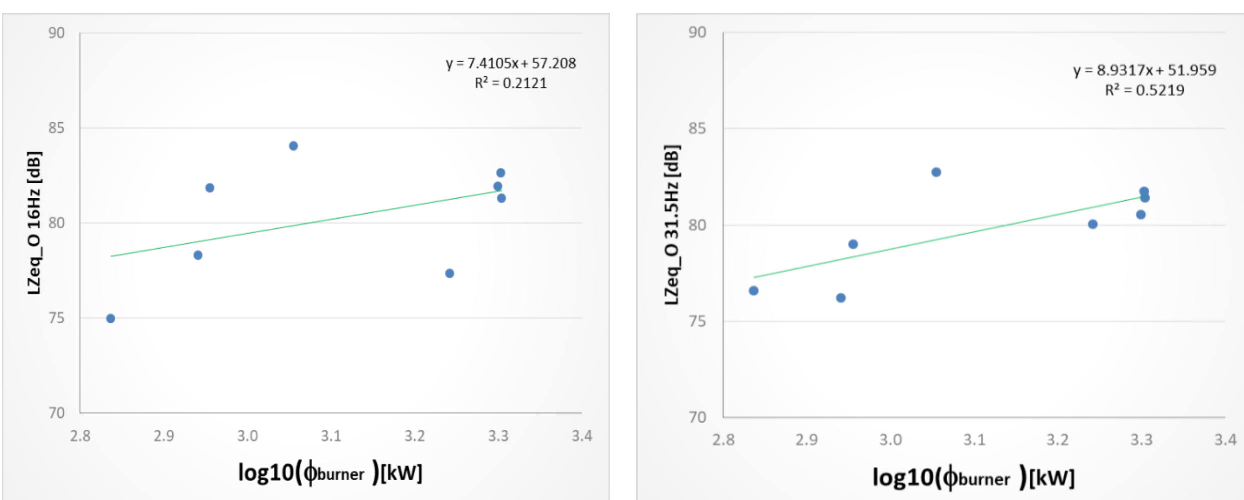


Fig.19 Measurement noise level for low frequency based on logarithm from thermal power *equations & R^2*

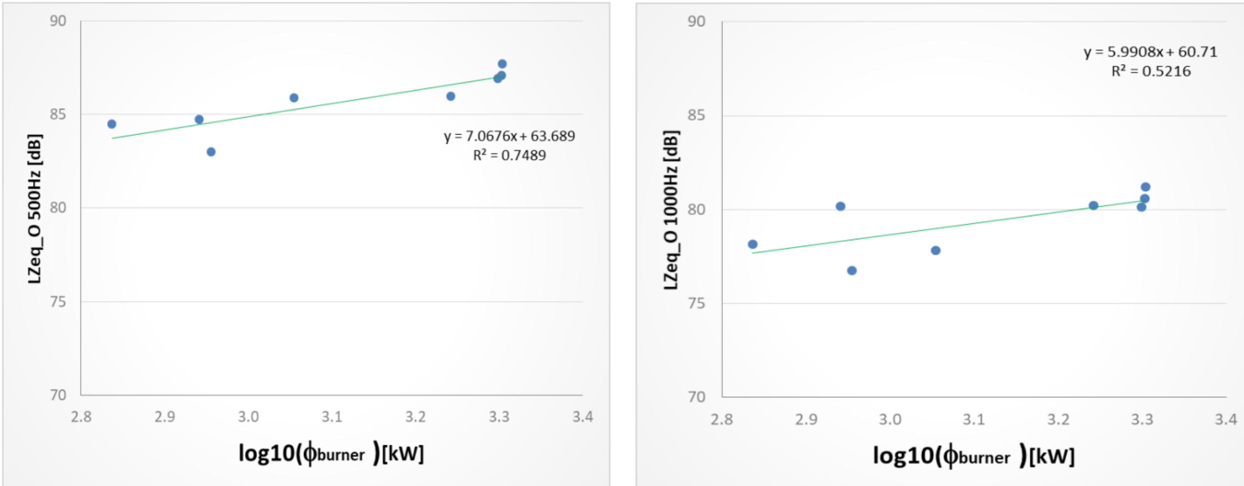


Fig.20 Measurement noise level for medium frequency based on logarithm from thermal *equations & R^2*

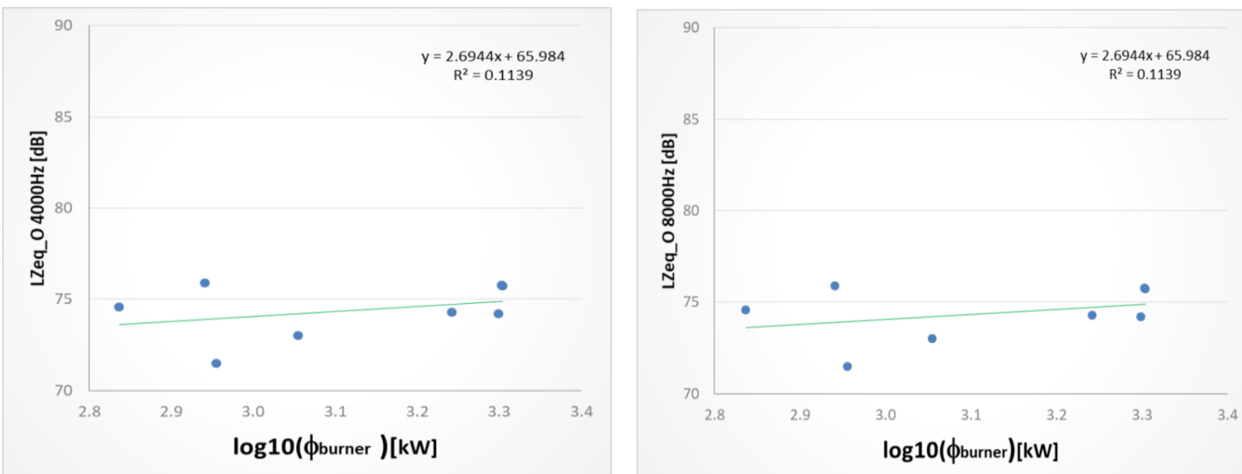


Fig.21 Measurement noise level for high frequency based on logarithm from thermal power *equations & R^2*

From the graphs above, there is an increasing tendency of the noise level on each frequency, depending on the increase of the thermal load, similar to the equivalent noise level, where it is possible to use a prediction model in both cases the real thermal load.

5.7 Interpretation of experimental data

In this chapter we will compare the values obtained from the experiment with the predictions of the noise level according to the formulas found in the literature:

$LAeq_{M1}$ [dBA] – prediction model of the LAeq as a function of the thermal power [Hamayon,1996]

$$\mathrm{LAeqM1} = 10.086 \cdot log_{10}\, \Phi_{burner} + 44.69$$

$LAeq_{M2}$ [dBA]– prediction model of the LAeq as a function of the thermal power and the volume [Cyssau ,1997];

$$\mathrm{LAeqM2} = 16 \cdot log_{10}\, \Phi_{burner} - 10 \cdot log_{10} V + 54$$

The error, between equivalent noise level measured and the equivalent noise level determined by one of the two prediction formulas, were calculated with root-mean-square error (RMSE),a frequently used measure of the differences between values (sample and population values) predicted by a model and the measured values.

$$RMSE_1 = \sqrt{\frac{\sum_{i=5}^{10}(LA_{eqM1\_i} - LA_{eq\_i})}{6}}$$

$$RMSE_2 = \sqrt{\frac{\sum_{i=5}^{10}(LA_{eqM2\_i} - LA_{eq\_i})}{6}},$$

where *LAmas1* [dB] is noise level measured in case 1, *V* is Volume, ϕ is real thermal power, i [-] measurement number coefficient; *j* [-] is model number, *j*=1 coresponds to the Cyssau and *j*=2 coresponds to the Cyssau.

Table 11 Comparition measured values vs literature model predictions

Case [-]	Pump Burner 1 [-	Pump Burner 2 [-	**Burner 1 [-]**	**Burner 2 [-]**	**Φ burner [kW]**	LOG10 (**Φb) [kW]**	**Project Name [-]**	**LAeq [dB(A)]**	**Volum [m3]**	**LAeqM1 [dBA]**	**LAeqM2 [dBA]**	**Err_LAeq1 [dBA]**	**Err_LAeq2 [dBA]**	**Err2_LAeq1 [dBA]**	**Err2_LAeq2 [dBA]**
1	0	0	**0**	**0**	0	0	Project 115	43.63	736.49	0	0	0	0	0	0
2	0	1	**0**	**0**	0	0	Project 117	61.63	736.49	0	0	0	0	0	0
3	1	0	**0**	**0**	0	0	Project 119	63.89	736.49	0	0	0	0	0	0
4	1	1	**0**	**0**	0	0	Project 118	63.04	736.49	0	0	0	0	0	0
5	1	1	**0**	**1**	1135	3.05	Project 120	86.15	736.49	75.50	74.21	10.65	11.94	7.09	6.21
6	1	1	**0**	**2**	902	2.96	Project 121	83.99	736.49	74.49	72.61	9.50	11.38	7.84	6.38
7	1	1	**1**	**0**	873	2.94	Project 122	86.87	736.49	74.35	72.38	12.52	14.49	5.94	5.00
8	1	1	**1**	**1**	2013	3.30	Project 124	88.72	736.49	78.01	78.19	10.71	10.53	7.28	7.43
9	1	1	**1**	**2**	1990	3.30	Project 125	87.48	736.49	77.96	78.11	9.52	9.37	8.19	8.34
10	1	1	**2**	**0**	687	2.84	Project 123	86.29	736.49	73.30	70.72	12.99	15.57	5.64	4.54
11	1	1	**2**	**1**	2008	3.30	Project 126	88.07	736.49	78.00	78.17	10.07	9.90	7.74	7.90
12	1	1	**2**	**2**	1746	3.24	Project 127	87.34	736.49	77.38	77.20	9.96	10.14	7.77	7.61
													RMSE	7.24	6.80

In the above table it is observed that for the first 4 cases the predicted noise level due to the thermal plant operation should be 0, although the actual noise level for the situation where the boiler does not work is 43.63 dBA due to the background noise level.
In cases 2-4 when pumps works, the noise level has values between 61.63-63.04 dBA.

To compare predicted values with real values, errors were calculated (root-mean-square error and R-squared).

Analysis no.1: Comparison between experimental values and norms maximum admissible value

In the chart below the measured values exceed the values indicated in the C125 / 2012 norm (maximum of 85 dB(A)) for boiler plants in almost all operating conditions of the boilers. The conclusion is that this thermal plant needs an acoustic refurbishment in order to fulfill today's acoustic norms.

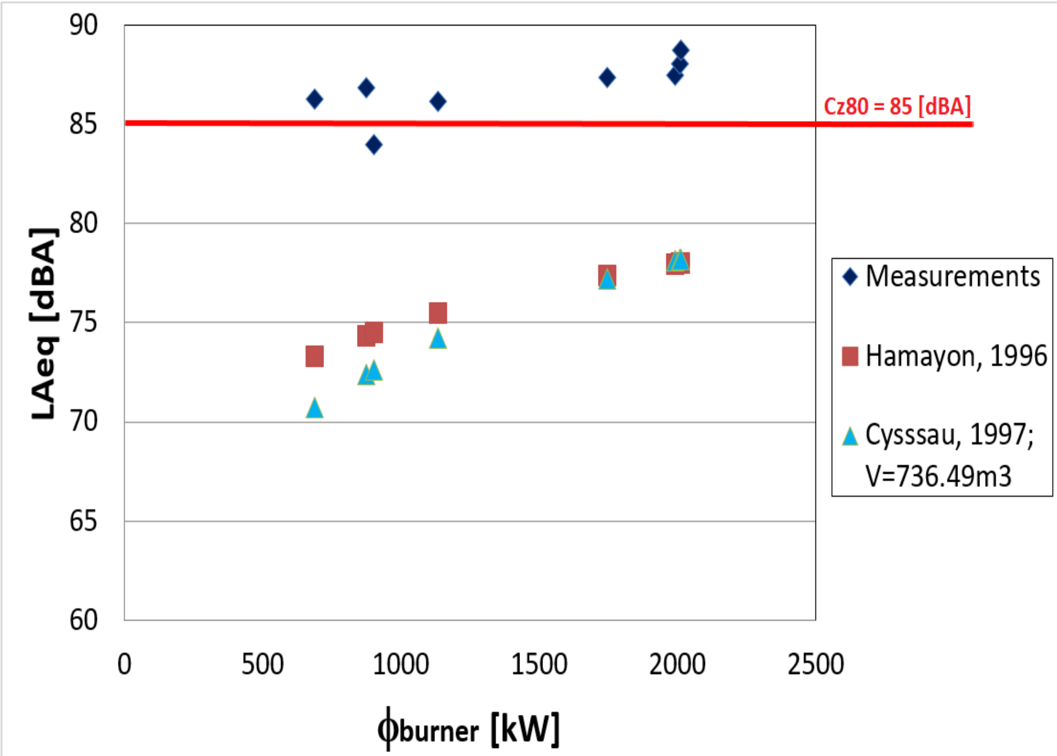


Fig.22 Scatter graph to compare the real noise level with the noise levels in the literature

It can be seen that Hamayon's model has an error up of 7.24dBA, value close to the precision range of the formula. In contrast, Cyssau's model has an error of 6.8dBA, much higher than the 5dBA declared.

Analysis no.2: Comparison between experimental values and prediction model Hamayon, 1996

Below will graphically represent a purchase between the level of real measured noise and the predicted noise level with the Hamayon. (1996). Also, the limitations of this model will be represented in the graphs.

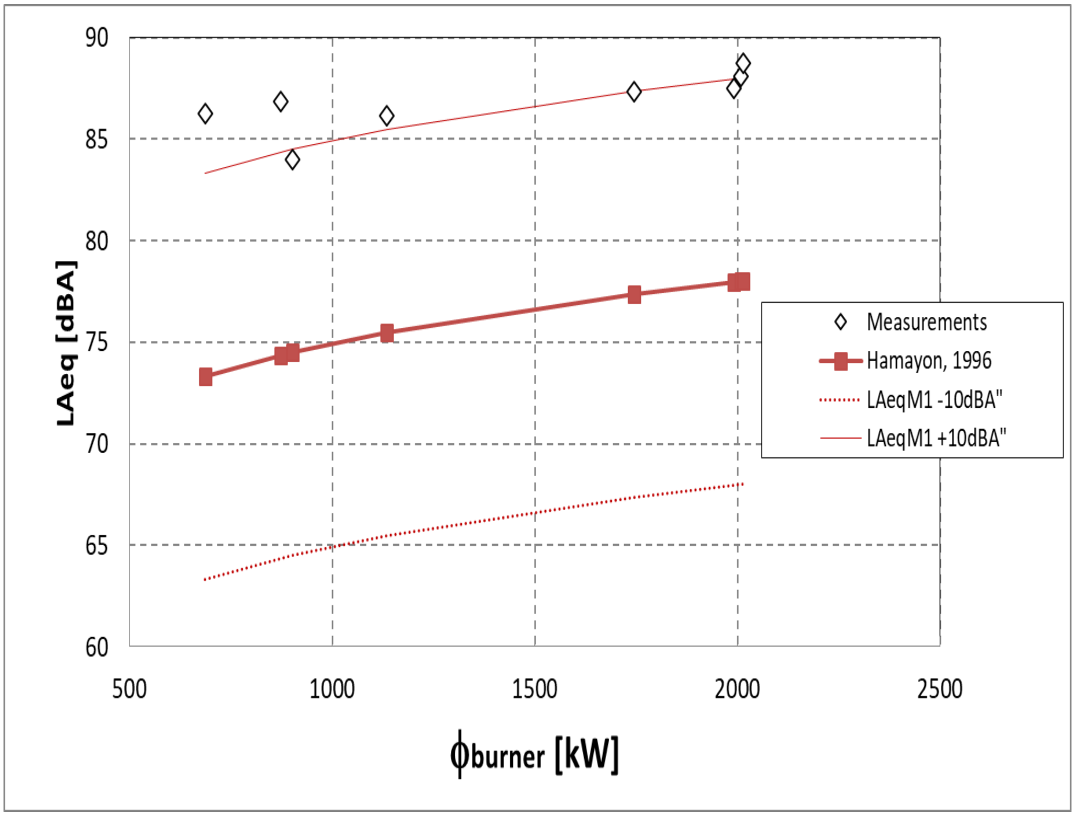


Fig.23 Comparative graph between the measured equivalent noise level, prediction model LAeqM1 [Hamayon, 1996] and its ±10dBA declared error.

The errors of the Hamayon's model compared to our experimental data is not centered in zero,, thus there is a phenomenon that the fast prediction Hamayon's model does not take into consideration. We conclude that Hamayon's model is not suited for today's thermal powers and new thermal generation equipment. Therefore there is need for an adaptation of the noise prediction models to today's thermal conditions (larger thermal power stations, noisier equipment, automation control).

Analysis no.3: Comparison between experimental values and prediction model Cyssau, 1997

Below will graphically represent a purchase between the level of real measured noise and the predicted noise level with the Cyssau, (1997). Also, the limitations of this model will be represented in the graphs.

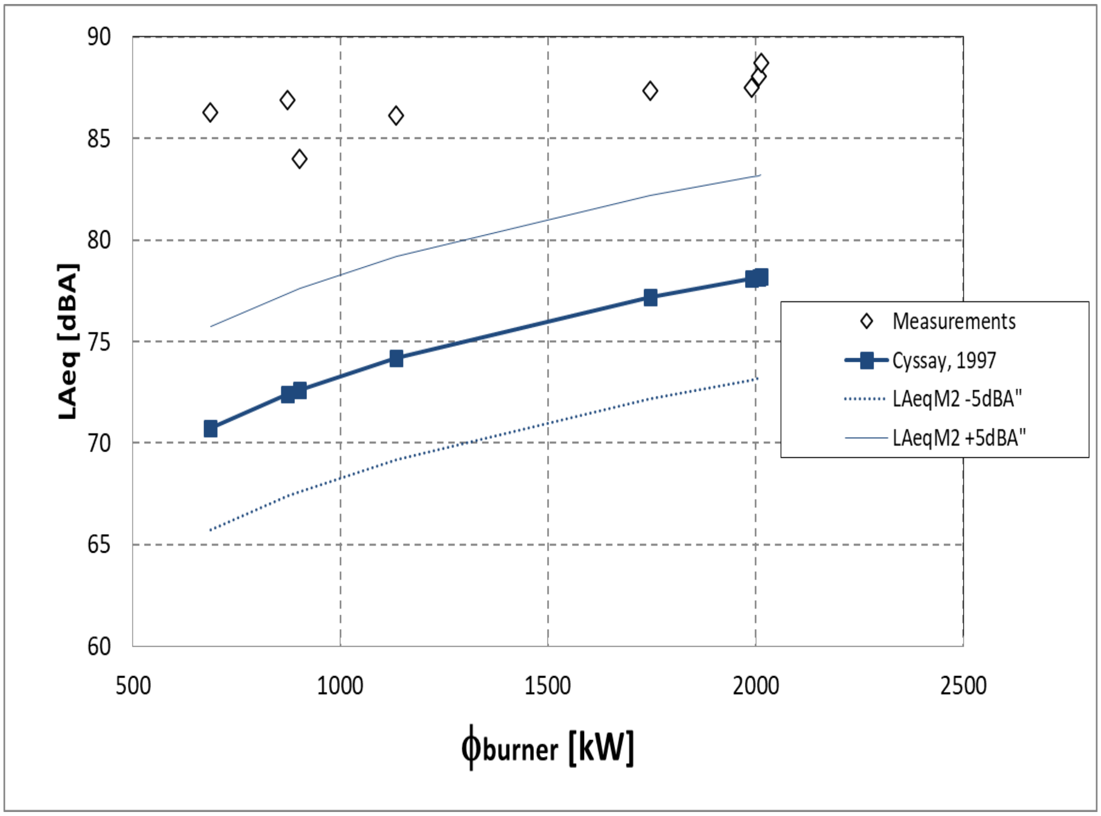


Fig.24 Comparative graph between the measured equivalent noise level, predction model LAeqM2 [Cyssau, 1997] and its ±5dBA declared error.

The graph bellow show that Cyssau model predicts lower noise levels than those measured for 8 different thermal powers, and the lower and upper limit of its error is far from the measurements made during the experiment.

Similar to Hamayon, Cyssau model, which theoretically has a lower error is not suited for today's thermal powers and new thermal generation equipment. Therefore there is need for an adaptation of the noise prediction models to today's thermal conditions (larger thermal power stations, noisier equipment, automation control).

6. Experimental protocol of boiler plant 2, thermal power 4800 kw

6.1 Location:

The second thermal plant is located in Bucharest, on demibasement of a faculty and serves a group of five faculties and anexes, with an installed thermal capacity of 4800 kW.

Fig.25 Central heating plant location

6.2 Architectural presentation of the room

The room has a complex shape, and its dimensions are: 12.46m long, 10.96m wide and 4.84m tall. The walls of the boiler plant are made of brick, and the finished concrete floor. The three windows have a metal frame and a single sheet of glass, and the door have at the bottom is a mesh material that allows pressure compensation on the inside.

The volume of the boiler room is 660.96 m^3. Surface of walls, ceilings and floors are of reflective materials, so the room absorption coefficient is very low.

Hard surfaced of this boiler room will have a longer reverberation time than rooms finished with sound absorbing materials. The immediate effect of multiple reflections is an increase in the sound intensity caused by the reflections. A fireman will hear the direct sound arriving at the ear along with all of the multiple reflections.Thus the combined loudness of the direct sound and the reflected sound will be greater than the direct sound alone.

Fig.26 Central heating on the inside

6.3 The equipment of the thermal plant

The thermal plant has three 1480KW Prextherm RSW and one 399KW Prextherm RSW. The burners of these boilers are of the RBL type RS190 with two power stages of 470-2290KW, respectively RBL type R38 with two power stages of 105-440KW

In the boiler assembly we find 12 Grundfoss pumps MG90LA4, two heat exchangers with plates, 2 buffer tank.

6.4 Existing noise protection solutions

The chimney of the boiler is made of metallic material without total insulation on the outside and is located inside and partially outdoors. The boilers are fixed by deconstruction: foundation and puffers.

The four burners do not have an phonoabsormant housing, and the pipe connections are made by metal bracelets. The heating installation does not have flexible connections to ducts of the boiler (thermal / gas / fluid).

There is no other noise protection like sound attenuator at chimney (in pipe or in quarter-wave) or walls captured with mineral wool or/and rigips.
The crossing of the walls by the pipes is without any solution to reduce the vibrations transmitted by the combustion of the gas.

Table 12 Equipment type and existing noise protection solutions table

Case [-]	Pumps [-]	Burner 1 [-]	Burner 1 [-]	Burner 1 [-]	Burner 2 [-]	Tr [s]	Volum [m3]	Type of fuel[-]	Burner type [-]	Burner case [-	Acoustic treatment [-	Boiler dissociation	Boiler fundation [-	Flexible connection [-	Passing pipes [-]	Chimmey isulation [-]
1	0	0	0	0	0	1.34	660.96	gas	Aer insuflat	0	0	1	1	0	0	0
2	0	1	0	0	0	1.34	660.96	gas	Aer insuflat	0	0	1	1	0	0	0
3	1	2	0	0	0	1.34	660.96	gas	Aer insuflat	0	0	1	1	0	0	0
4	1	0	0	1	0	1.34	660.96	gas	Aer insuflat	0	0	1	1	0	0	0
5	1	0	0	2	0	1.34	660.96	gas	Aer insuflat	0	0	1	1	0	0	0
6	1	1	0	2	0	1.34	660.96	gas	Aer insuflat	0	0	1	1	0	0	0
7	1	2	0	2	0	1.34	660.96	gas	Aer insuflat	0	0	1	1	0	0	0
8	1	1	0	1	0	1.34	660.96	gas	Aer insuflat	0	0	1	1	0	0	0
9	1	1	2	0	0	1.34	660.96	gas	Aer insuflat	0	0	1	1	0	0	0
10	1	1	2	1	0	1.34	660.96	gas	Aer insuflat	0	0	1	1	0	0	0
11	1	2	2	2	0	1.34	660.96	gas	Aer insuflat	0	0	1	1	0	0	0
12	1	2	2	2	2	1.34	660.96	gas	Aer insuflat	0	0	1	1	0	0	0

The table above is part of the doctoral thesis database and includes the constructive type of the noise generating equipment in the thermal plant and the existing acoustic treatment solutions. Also in this table is the volume of the inner space and the reverberation time measured during the experiment, both used for an easier calculation of the average absorption coefficient of the inner surfaces.

Fig.27 Noise protection solutions in boiler plant

6.5 The experimental part

Five types of measurements were made for each thermal power plant:

- dimensions (room, equipment, windows, doors, chimney). Room dimensions are: 12.46m long, 10.96m wide and 4.84m
- pressure and temperature of the gas. $p_g = 0.06$ *[bar]*; $T_g = 18.83$ *[^{o}C]*;
- reverberation time inside the thermal plant (EDT, T20, T30);

Table 13 Reverberation time (EDT,T20,T30) measured with soundmeter

Frequency	(500 Hz-1 kHz)	63Hz	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz	8kHz
T20	1.34	1.59	1.59	1.59	1.44	1.24	1.04	0.81	0.62
T30	1.32	1.50	1.50	1.50	1.44	1.19	1.04	0.82	0.60
EDT	1.16	3.27	1.53	1.36	1.24	1.09	0.92	0.77	0.54

- noise level for different thermal powers the equivalent continuous noise level (LAeq), sound pressure levels in the frequency bands Lp_{16Hz}, $Lp_{31.5Hz}$, Lp_{63Hz}, Lp_{125Hz}, Lp_{250Hz}, Lp_{500Hz}, Lp_{1000Hz}, Lp_{2000Hz}, Lp_{4000Hz}, Lp_{8000Hz}
- gas consumption for each thermal power.

Investigation consist of:
- wall types; walls are made of brick paitned white, floor and ceilling are made of concrete;
- equipment constructive type (burners, pumps, boilers)
  - Burner type: RBL type RS190 with two power stages of 470-2290KW, respectively RBL type R38 with two power stages of 105-440KW
  - Boilers types: three 1480KW Prextherm RSW de 1480KW and one 399KW Prextherm RSW.
  - Pumps type: 12 Grundfoss pumps MG90LA4

Since the burners have two power stages, we were able to experiment a number of 12 real operating situations.

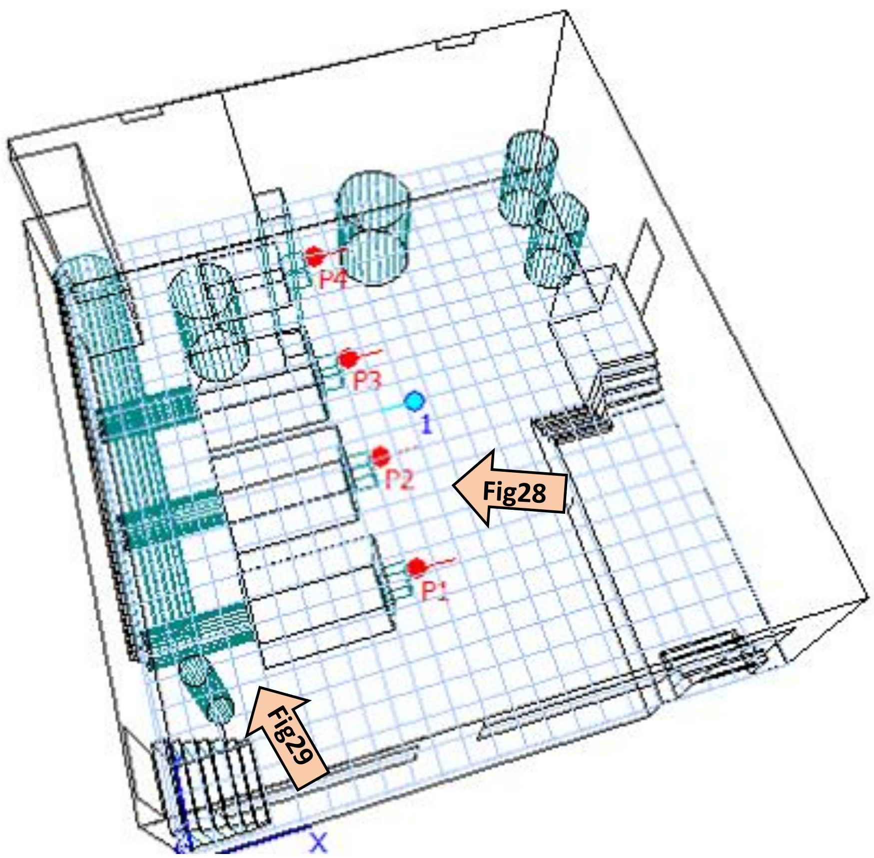


Fig.28 Burning position (noise sources) and receiver (Bruel & Kjaer sonometer)

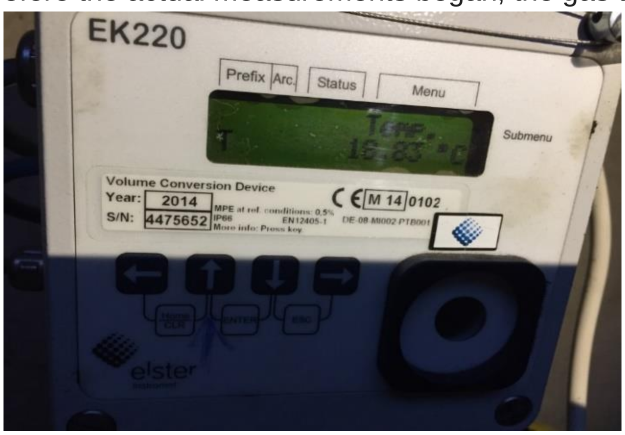
The burner stage control was made by using the boiler control panel by selecting the desired step, as shown below.

Case [-]	Pumps [-]	Burner 1 [-]	Burner 2 [-]	Burner 3 [-]	Burner 4 [-]
1	0	0	0	0	0
2	0	1	0	0	0
3	1	2	0	0	0
4	1	0	0	1	0
5	1	0	0	2	0
6	1	1	0	2	0
7	1	2	0	2	0
8	1	1	0	1	0
9	1	1	2	0	0
10	1	1	2	1	0
11	1	2	2	2	0
12	1	2	2	2	2

Fig.29 a)Operating conditions b)control panel of the boiler T1-stage1 / T2-stage2

For the fuel consumption measurement, the initial and end index for the gas meter was recorded for a period of 1 minute. During this time the noise measurements were made inside the technical space.

Before the actual measurements began, the gas temperature and pressure were recorded



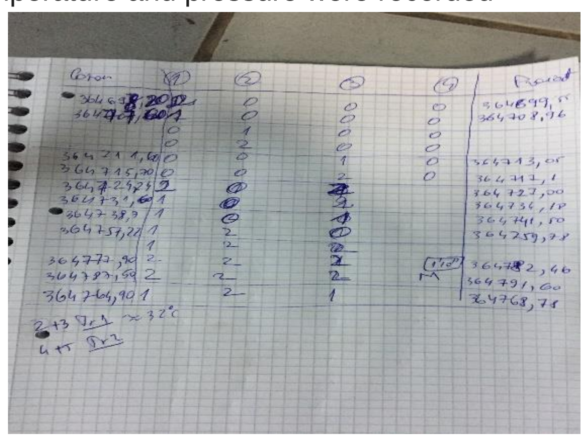


Fig.30 Reading of a)gas index b)gas parameters

The measurement of the noise level was carried out by means of a Bruel&Kjaer 2250 sound meter. The measurements were carried out by a team of three people: one person registers the gas index, another one operates the boiler automation, and the third person carries out the noise measurements.

Another measurement made during this experimental protocol is the reverberation time.The Impulse Excitation Method was used using the same B&K 2250 sound meter and a balloon.

We record the decay curves for all frequency bands and the reverberation time is calculated by means of the 7277 sound meter software for all frequencies.

6.6 The database and Interpretation of experimental data

In this chapter we used the same formulas described in above boiler plant reports for completing the database with the values resulting from the experiment

In the table below the real thermal power was calculated based on the gas consumption, which is the difference between the final index and the initial reading from the gas meter by one of the participants in the experiment. The time at which this consumption took place was 60 seconds, at which time an internal noise measurement was also recorded at 1 meter from the burner, measured according to the norms prescriptions.

The lower calorific value was calculated using the gas temperature and pressure indicated by the digital gas meter.

Table 14 Measurement table for the equivalent noise level

Case [-]	Pumps [-]	Burner 1 [-]	Burner 2 [-]	Burner 3 [-]	Burner 4 [-]	Index I [m3]	Index F [m3]	Consum.	Time [s]	Flow [m3/s]	Hi [kj/m3N]	p/po*To/T [-]	Φ burner [kW]	LOG10 (Φb) [kW]	Project Name [-]	LAeq [dB(A)]
1	0	0	0	0	0	364698.20	364698.20	0.00	60	0.00	35371.70	0.99	0	0	Project 148	33.19
2	0	1	0	0	0	364707.60	364708.96	1.36	60	0.02	35371.70	0.99	794	2.90	Project 149	62.8
3	1	2	0	0	0	364698.20	364699.55	1.35	60	0.02	35371.70	0.99	787	2.90	Project 151	80.21
4	1	0	0	1	0	364711.60	364713.05	1.45	60	0.02	35371.70	0.99	847	2.93	Project 152	78.46
5	1	0	0	2	0	364715.70	364717.10	1.40	60	0.02	35371.70	0.99	818	2.91	Project 153	78.18
6	1	1	0	2	0	364731.60	364734.18	2.58	60	0.04	35371.70	0.99	1507	3.18	Project 155	81.19
7	1	2	0	2	0	364724.24	364727.00	2.76	60	0.05	35371.70	0.99	1612	3.21	Project 154	80.94
8	1	1	0	1	0	364738.70	364741.50	2.80	60	0.05	35371.70	0.99	1636	3.21	Project 156	81.05
9	1	1	2	0	0	364757.22	364759.78	2.56	60	0.04	35371.70	0.99	1495	3.17	Project 158	81.71
10	1	1	2	1	0	364764.90	364768.78	3.88	60	0.06	35371.70	0.99	2266	3.36	Project 159	82.99
11	1	2	2	2	0	364777.90	364782.46	4.56	60	0.08	35371.70	0.99	2664	3.43	Project 160	82.89
12	1	2	2	2	2	364787.50	364791.60	4.10	60	0.07	35371.70	0.99	2395	3.38	Project 161	82.98

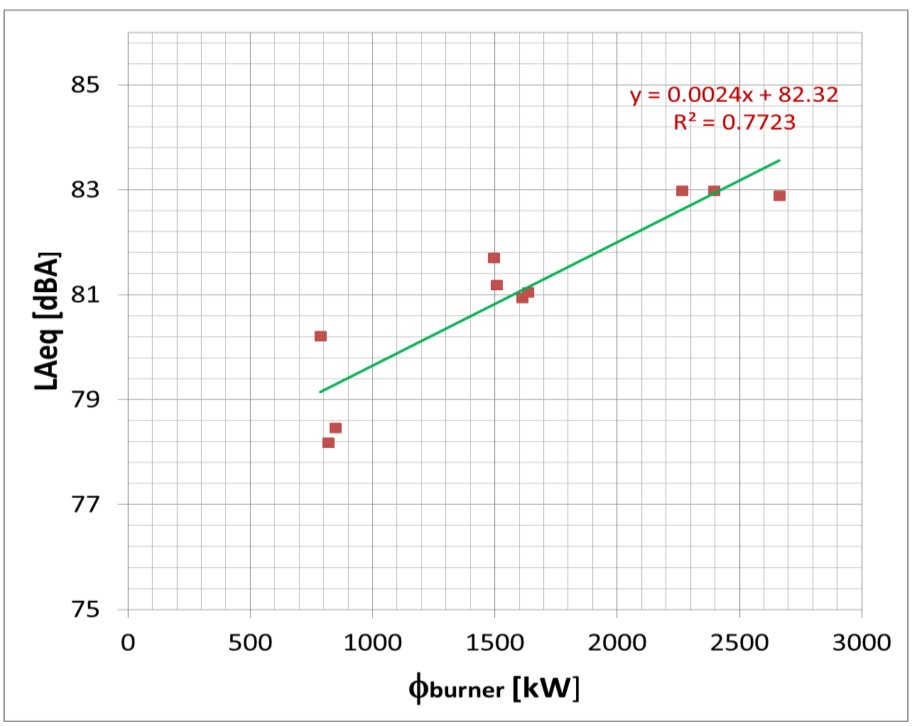


Fig.31 Equivalent noise level based on actual thermal power, equation and R^2

From this graph we can see the increasing tendency of the equivalent noise level depending on the thermal load of the boiler. This increase validates the prediction models in the literature, which have their component and thermal load, as the main parameter.

Table 15 Measurement table for equivalent noise level and each frequency noise level

Case [-]	Pumps [-]	Φ burner [kW]	LAeq [dB(A)]	LZeq_O 16Hz [dB]	LZeq_O 31.5Hz[dB	LZeq_O 63Hz[dB]	LZeq_O 125Hz[dB]	LZeq_O 250Hz[dB]	LZeq_O 500Hz[dB]	LZeq_O 1kHz[dB]	LZeq_O 2kHz[dB]	LZeq_O 4kHz[dB	LZeq_O 8kHz[dB]
1	0	0	33.19	53.12	53.23	50.18	42.27	32.91	28.39	26.63	22.38	22.81	19.28
2	0	794	62.8	55.4	58.43	59.41	60.49	60.82	59.97	59.82	53.69	44.05	34.4
3	1	787	80.21	73.4	85.23	81.17	85.52	79.5	76.12	75.03	71.54	69.07	68.15
4	1	847	78.46	72.62	84.1	80.65	84.56	78.24	74	73	70.64	65.68	63.31
5	1	818	78.18	72.6	84.29	80.69	85.05	78.2	73.6	72.42	70.42	65.68	62.84
6	1	1507	81.19	74.46	87.74	83.01	88.15	81.71	77.14	75.69	72.3	68.64	66.96
7	1	1612	80.94	73.83	88.57	83.49	87.86	81.08	76.7	75.51	72.28	68.27	66.31
8	1	1636	81.05	73.74	87.91	83.01	88.29	81.03	76.33	75.7	72.46	68.57	65.91
9	1	1495	81.71	73.87	87.63	83.39	88.04	80.92	78.01	76.44	72.85	69.15	68.75
10	1	2266	82.99	75.31	87.81	84.89	89.45	82.36	79.03	77.6	74.65	70.55	68.72
11	1	2664	82.89	74.84	88.48	85.53	88.72	82.04	79.09	77.59	74.72	70.59	68.17
12	1	2395	82.98	73.5	88.81	85.54	89.06	82.58	79.32	77.48	74.55	70.53	68.42

Table 16 Table with equivalent noise level and noise level Cz80 according to norms

Nr crt. [-]	Laeq_No [dB(A)]	LZeq_No 16Hz [dB]	LZeq_No 31.5Hz[dB]	LZeq_No 63Hz[dB]	LZeq_No 125Hz[dB]	LZeq_No 250Hz[dB]	LZeq_No 500Hz[dB]	LZeq_No 1kHz[dB]	LZeq_No 2kHz[dB]	LZeq_No 4kHz[dB]	LZeq_No 8kHz[dB]
Cz80	85	121.1	109.9	98.7	91.6	86.4	82.7	80	77.7	75.9	74.4

The above tables shows the noise levels for each frequency as measured by the Bruel Kjaer sonometer during the experiments, and in table number two the noise level for technical spaces according to the Cz80 curve indicated in the Romanian noise protection norm.

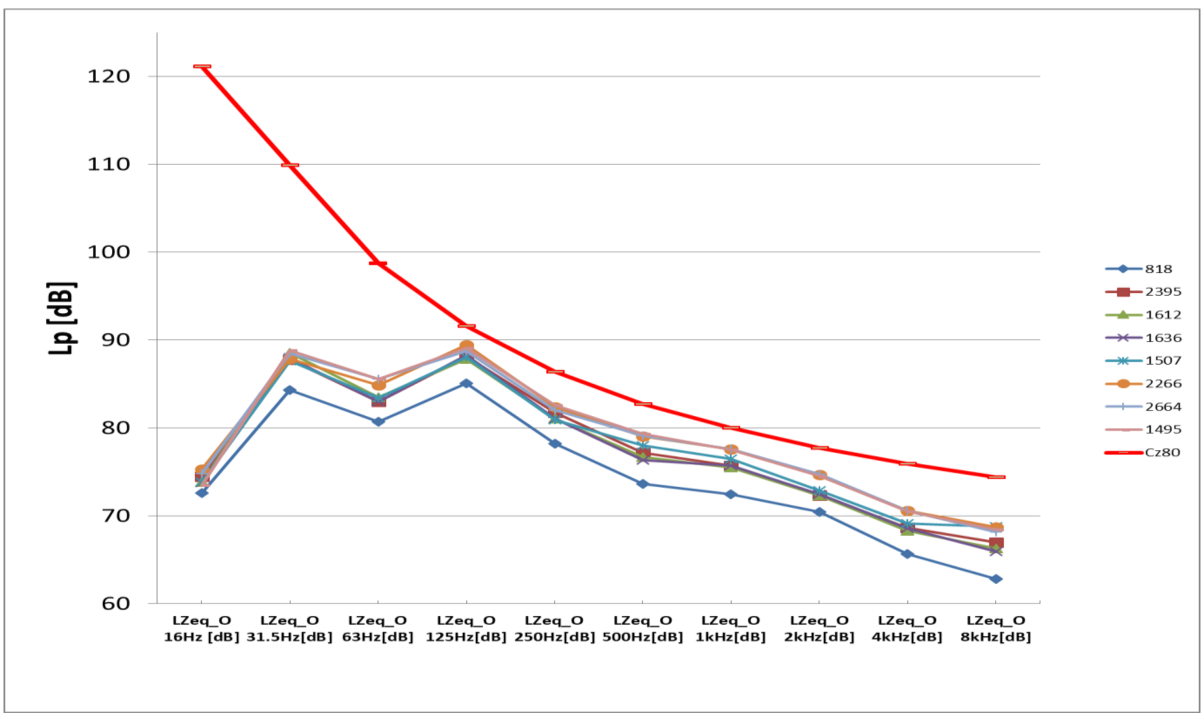


Fig.32 Comparison between noise level on each frequency and Cz80 from norms

In the graph above, it is observed that the noise level is below the Cz80 curve, thus respecting the maximum allowable noise level in a boiler plant.

Table 17 Table with inspections carried out during the experiment on this thermal plant

Case [-]	Tr [s]	Volum [m3]	Boiler type [-]	Type of fuel[-]	Burner type [-]	Burner case [-]	WallAcoustic treatment [-]	Boiler dissociation [-]	Boiler fundation [-]	Flexible connection [-]	Passing pipes [-]	Chimmey isulation [-]	Gas pres [mbar]	Gas temp [oC]
1	1.34	660.96	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0	60	18.83
2	1.34	660.96	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0	60	18.83
3	1.34	660.96	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0	60	18.83
4	1.34	660.96	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0	60	18.83
5	1.34	660.96	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0	60	18.83
6	1.34	660.96	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0	60	18.83
7	1.34	660.96	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0	60	18.83
8	1.34	660.96	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0	60	18.83
9	1.34	660.96	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0	60	18.83
10	1.34	660.96	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0	60	18.83
11	1.34	660.96	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0	60	18.83
12	1.34	660.96	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0	60	18.83

The above table shows the inspections carried out during the experiment on this thermal plant. It is noticed that another essential requirement regarding acoustic comfort, namely the reverberation time, respects the values indicated in C125.

Similar to precedent chapter we will compare the values obtained from the experiment with the predictions of the noise level according to the formulas found in the literature:

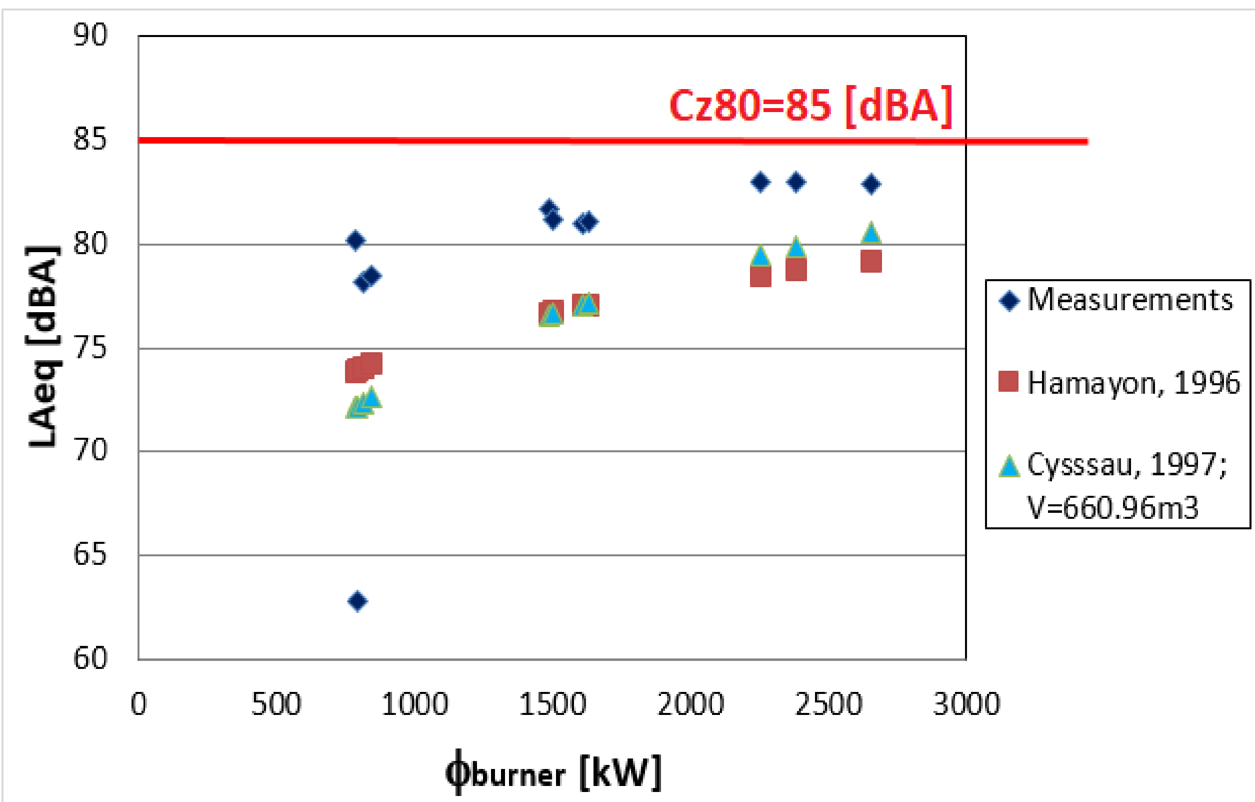


Fig.33 Scatter graph to compare the real noise level with the noise levels in the literature

The measured values is below the values indicated in the C125 / 2012 norm (maximum of 85 dB(A)) for boiler plants in all operating conditions of the boilers. The conclusion is that this thermal plant don’t need an acoustic treatment.

It can be seen that Hamayon's model has an error up of 11.31dBA, value close to the precision range of the formula. In contrast, Cyssau's model has an error of 9.39dBA, much higher than the 5dBA declared.

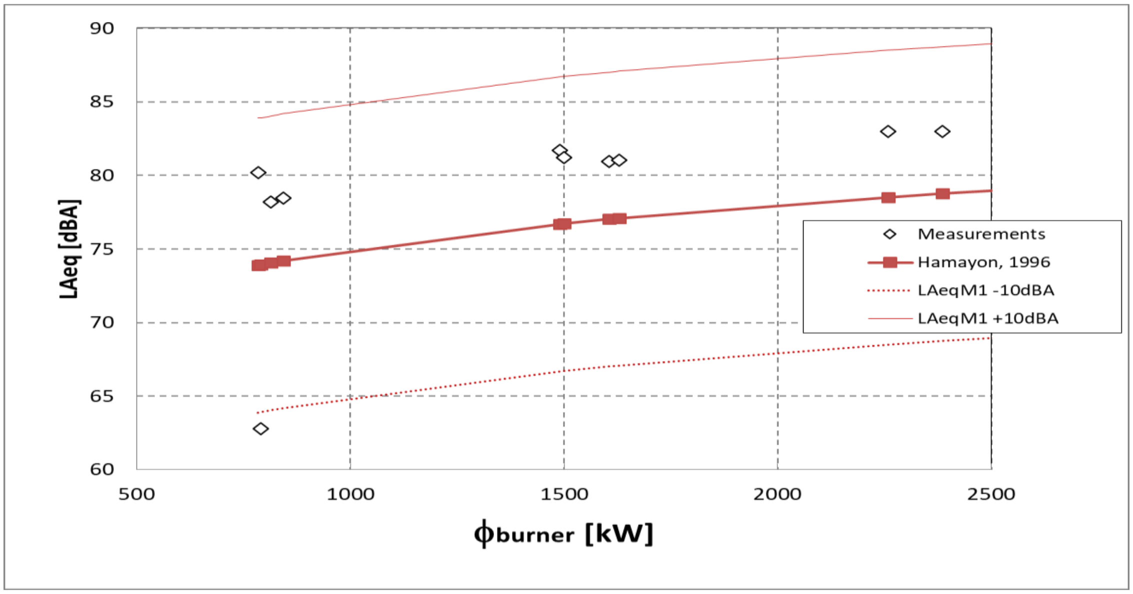


Fig.34 Comparative graph between the measured equivalent noise level, prediction model LAeqM1 [Hamayon, 1996] and its ±10dBA declared error.

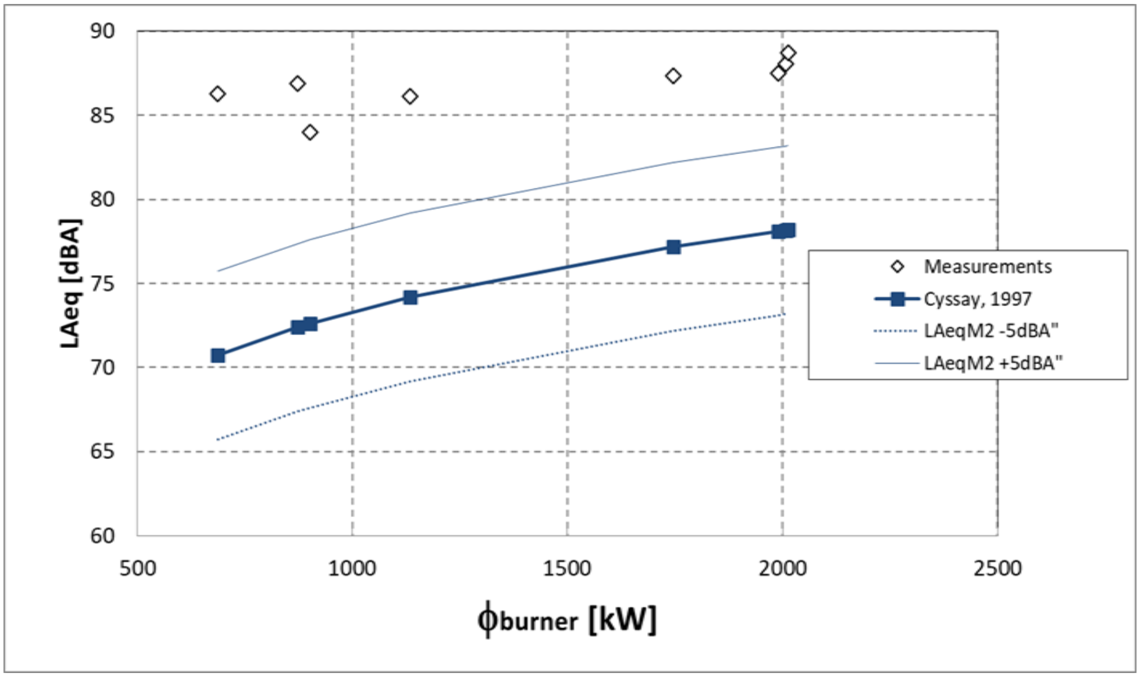


Fig.35 Comparative graph between the measured equivalent noise level, predction model LAeqM2 [Cyssau, 1997] and its ±5dBA declared error.

The errors of the Hamayon's and Cyssau's model compared to our experimental data is not centered in zero, thus there is a phenomenon that the fast prediction Hamayon's model does not take into consideration. We conclude that Hamayon's model is not suited for today's thermal powers and new thermal generation equipment. Therefore there is need for an adaptation of the noise prediction models to today's thermal conditions (larger thermal power stations, noisier equipment, automated control).

7. Experimental protocol of thermal plant 3, thermal power 1540 kw

7.1 Location:

Thermal plant 3 is a plant located on demibasement of the faculty in Bucharest and serves faculty building and annexes, with an installed thermal capacity of 1540 kW.

Fig.36 Central heating plant location

7.2 Architectural presentation of the room

The room has a complex shape, and its dimensions are: 14.45m long, 9.05m wide and 5.09 tall. The walls of the boiler plant are made of brick, and the finished concrete floor. The two windows have a wood frame and a single sheet of glass, and the door have at the bottom is a mesh material that allows pressure compensation on the inside.

The volume of the boiler room is 665.63 m^3. Surface of walls, ceilings and floors are of reflective materials, so the room absorption coefficient is very low.

Hard surfaced of this boiler room will have a longer reverberation time than rooms finished with sound absorbing materials. The immediate effect of multiple reflections is an increase in the sound intensity caused by the reflections. A fireman will hear the direct sound arriving at the ear along with all of the multiple reflections. Thus the combined loudness of the direct sound and the reflected sound will be greater than the direct sound alone.

Fig.37 Central heating on the inside

7.3 The equipments of the thermal plant

The thermal plant has two 760KW DeDietrich type GTE514. The burners of these boilers are of the FBR type GAS P100/2CE with two power stages of 581-1162KW.

In the boiler assembly we find 14 NOCCHI pumps model R2C 65-23, two heat exchangers with plates, 2 buffer tank.

7.4 Existing noise protection solutions

The chimney of the boiler is made of metallic material without total insulation on the outside and is located inside and partially outdoors. The boilers are fixed by deconstruction: foundation and puffers.

The four burners do not have an phonoabsormant housing, and the pipe connections are made by metal bracelets. The heating installation does not have flexible connections to ducts of the boiler (thermal / gas / fluid).

There is no other noise protection like sound attenuator at chimney (in pipe or in quarter-wave) or walls captured with mineral wool or/and rigips.

The crossing of the walls by the pipes is without any solution to reduce the vibrations transmitted by the combustion of the gas.

Table 18 Equipment type and existing noise protection solutions table

Case [-]	Pumps [-]	Burner 1 [-]	Burner 2 [-]	Tr [s]	Volum [m3]	Boiler type [-]	Type of fuel[-]	Burner type [-]	Burner case [-]	WallAcoustic treatment [-]	Boiler dissociation [-]	Boiler fundation [-]	Flexible connection [-]	Passing pipes [-]	Chimmey isulation [-]
1	0	0	0	1.34	665.83	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0
2	1	0	0	1.34	665.83	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0
3	1	0	1	1.34	665.83	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0
4	1	0	2	1.34	665.83	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0
5	1	1	0	1.34	665.83	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0
6	1	1	1	1.34	665.83	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0
7	1	1	2	1.34	665.83	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0
8	1	2	0	1.34	665.83	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0
9	1	2	1	1.34	665.83	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0
10	1	2	2	1.34	665.83	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0

The table above is part of the doctoral thesis database and includes the constructive type of the noise generating equipment in the thermal plant and the existing acoustic treatment solutions. Also in this table is the volume of the inner space and the reverberation time measured during the experiment, both used for an easier calculation of the average absorption coefficient of the inner surfaces.

Fig.38 Noise protection solutions in boiler plant

7.5 The experimental part

Five types of measurements were made for each thermal power plant:

- dimensions (room, equipment, windows, doors, chimney). Room dimensions are: 14.45m long, 9.05m wide and 5.09 tall;
- pressure and temperature of the gas. $p_g = 0.025$ *[bar]*; $T_g = 8.88$ *[^{o}C]*;
- reverberation time inside the thermal plant (EDT, T20, T30);

Table 19 Reverberation time (EDT, T20, T30) measured with sound meter

Frequency	(500 Hz-1 kHz)	63Hz	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz	8kHz
T20	1.34	2.49	1.43	1.47	1.36	1.38	1.36	1.08	0.66
T30	1.31	2.5	1.56	1.5	1.42	1.44	1.37	1.09	0.72
EDT	1.24	1.99	1.56	1.56	1.35	1.25	1.11	0.96	0.54

- noise level for different thermal powers the equivalent continuous noise level (LAeq), sound pressure levels in the frequency bands Lp_{16Hz}, $Lp_{31.5Hz}$, Lp_{63Hz}, Lp_{125Hz}, Lp_{250Hz}, Lp_{500Hz}, Lp_{1000Hz}, Lp_{2000Hz}, Lp_{4000Hz}, Lp_{8000Hz}
- gas consumption for each thermal power.

Investigation consist of:
- wall types; walls are made of brick paitned white, floor and ceilling are made of concrete;
- equipment constructive type (burners, pumps, boilers)
    - Burner type: FBR type GAS P100/2CE with two power stages of 581-1162KW.
    - Boilers types: 760KW DeDietrich type GTE514
    - Pumps type: 14 Grundfoss pumps NOCCHI model R2C 65-23

Since the burners have two power stages, we were able to experiment a number of 10 real operating situations.

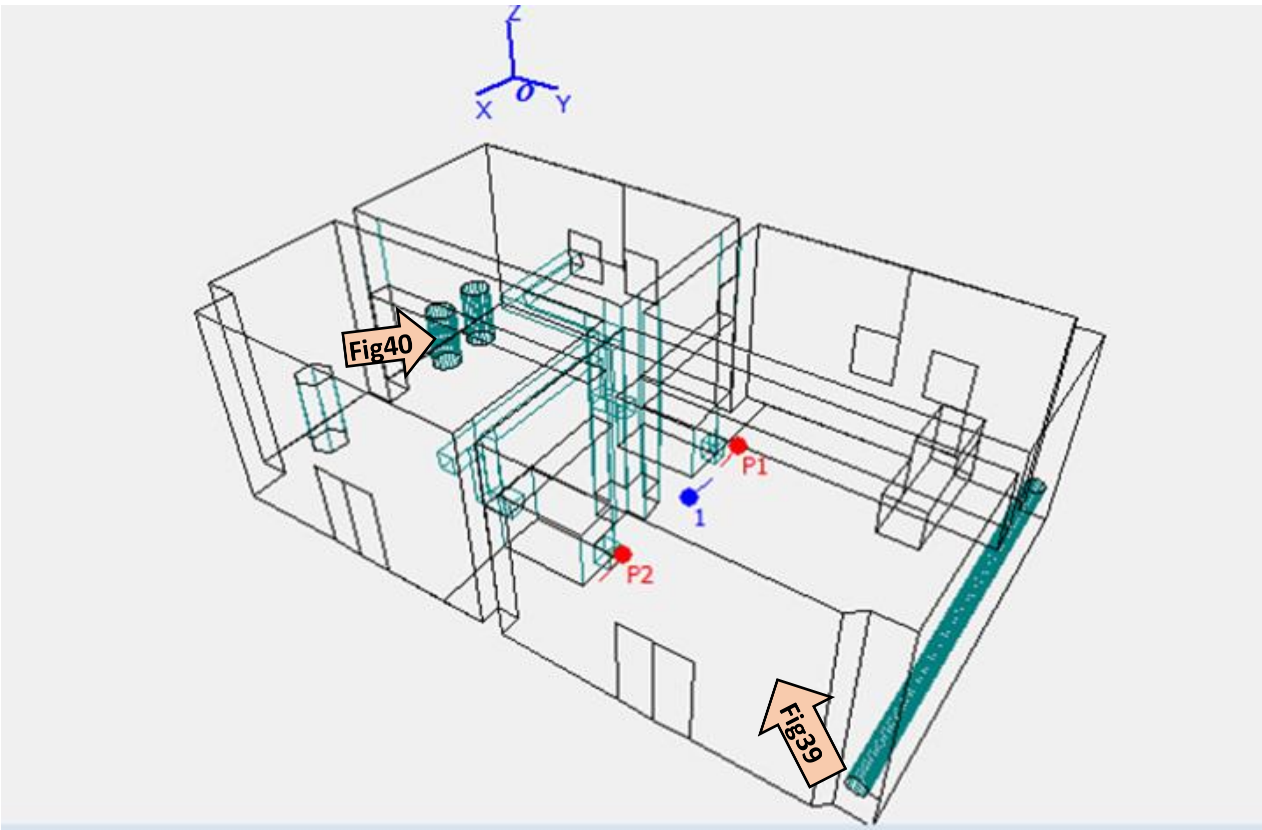


Fig.39 Burning position (noise sources) and receiver (Bruel & Kjaer sonometer)

The burner stage control was made by using the boiler control panel by selecting the desired step, as shown below.

Case [-]	Pumps [-]	**Burner 1 [-]**	**Burner 2 [-]**
1	0	**0**	**0**
2	1	**0**	**0**
3	1	**0**	**1**
4	1	**0**	**2**
5	1	**1**	**0**
6	1	**1**	**1**
7	1	**1**	**2**
8	1	**2**	**0**
9	1	**2**	**1**
10	1	**2**	**2**

Fig.40 a)Operating conditions b)control panel of the boiler T1-stage1 / T2-stage2

For the fuel consumption measurement, the initial and end index for the gas meter was recorded for a period of 1 minute. During this time the noise measurements were made inside the technical space.

Before the actual measurements began, the gas temperature and pressure were recorded

Fig.41 Reading of a)gas index b)gas parameters

The measurement of the noise level was carried out by means of a Bruel&Kjaer 2250 sound meter. The measurements were carried out by a team of three people: one person registers the gas index, another one operates the boiler automation, and the third person carries out the noise measurements.

Another measurement made during this experimental protocol is the reverberation time.The Impulse Excitation Method was used using the same B&K 2250 sound meter and a balloon.

We record the decay curves for all frequency bands and the reverberation time is calculated by means of the 7277 sound meter software for all frequencies.

7.6 The database and Interpretation of experimental data

In this chapter we used the same formulas described in above boiler plant reports for completing the database with the values resulting from the experiment

In the table below the real thermal power was calculated based on the gas consumption, which is the difference between the final index and the initial reading from the gas meter by one of the participants in the experiment. The time at which this consumption took place was 60 seconds, at which time an internal noise measurement was also recorded at 1 meter from the burner, measured according to the norms prescriptions.

The lower calorific value was calculated using the gas temperature and pressure indicated by the digital gas meter.

Table 20 Measurement table for the equivalent noise level

Case [-]	Pumps [-]	Burner 1 [-]	Burner 2 [-]	Index I [m3]	Index F [m3]	Consum.	Time [s]	Flow [m3/s]	Hi [kj/m3N]	p/po*To/T [-]	Φ burner [kW]	LOG10 (Φb) [kW]	Project Name [-]	LAeq [dB(A)]	LZeq_O 16Hz [dB]
1	0	0	0	1503755.83	1503755.83	0.00	60	0.00	35371.70	0.99	0	0	Project 119	27.28	39.76
2	1	0	0	1503755.83	1503755.83	0.00	60	0.00	35371.70	0.99	0	0	Project 118	54.77	57.79
3	1	0	1	1503755.83	1503757.56	1.73	180	0.01	35371.70	0.99	337	2.53	Project 120	83.36	66.08
4	1	0	2	1503762.40	1503763.83	1.43	60	0.02	35371.70	0.99	838	2.92	Project 121	83.52	66.23
5	1	1	0	1503766.18	1503766.69	0.51	60	0.01	35371.70	0.99	299	2.48	Project 122	78.39	73.54
6	1	1	1	1503773.84	1503774.92	1.08	60	0.02	35371.70	0.99	635	2.80	Project 124	84.76	69.7
7	1	1	2	1503780.38	1503782.34	1.96	60	0.03	35371.70	0.99	1144	3.06	Project 125	84.42	68.08
8	1	2	0	1503769.06	1503769.87	0.82	60	0.01	35371.70	0.99	479	2.68	Project 123	81.9	73.41
9	1	2	1	1503786.60	1503787.99	1.39	60	0.02	35371.70	0.99	811	2.91	Project 126	85.42	68.67
10	1	2	2	1503790.95	1503793.18	2.23	60	0.04	35371.70	0.99	1305	3.12	Project 127	85.44	69.48

In the first table the real thermal power was calculated based on the gas consumption, which is the difference between the final index and the initial reading from the gas meter by one of the participants in the experiment.

The time at which this consumption took place was 180 and 60 seconds, at which time an internal noise measurement was also recorded at 1 meter from the burner, measured according to the norms prescriptions.

The lower calorific value was calculated using the gas temperature and pressure indicated by the digital gas meter.

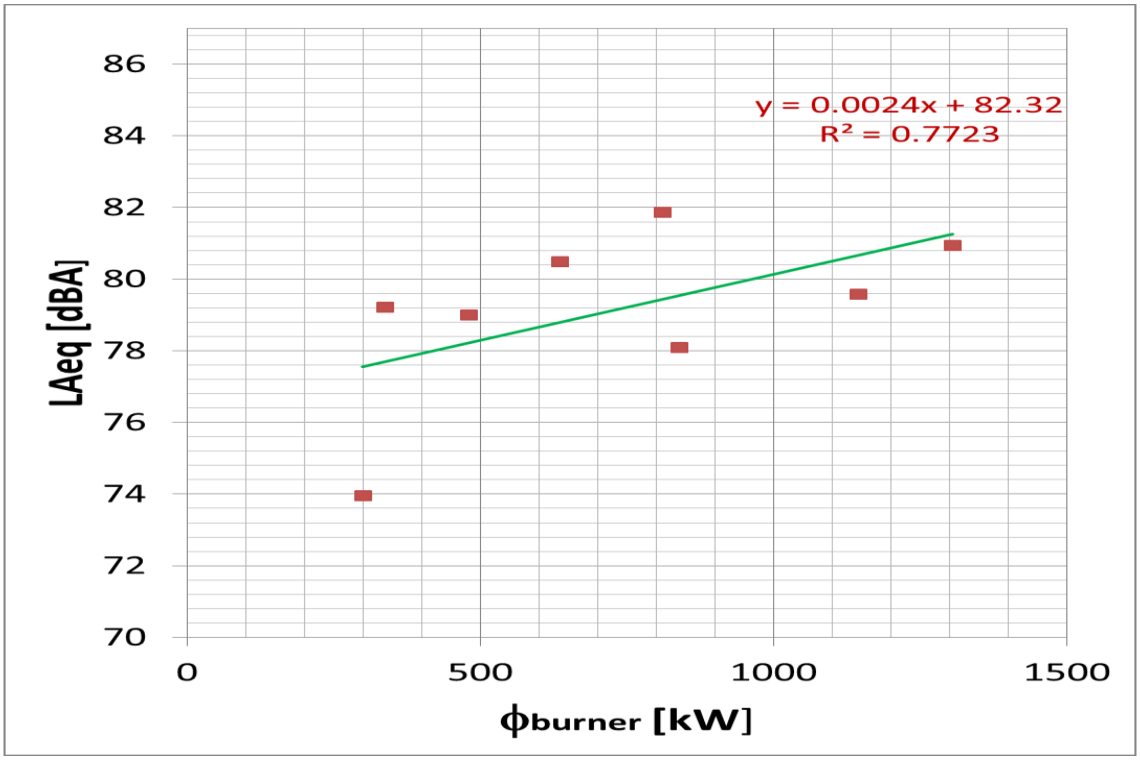


Fig.42 Equivalent noise level based on actual thermal power, equation and R^2

From this graph we can see the increasing tendency of the equivalent noise level depending on the thermal load of the boiler. This increase validates the prediction models in the literature, which have their component and thermal load, as the main parameter.

Table 21 Measurement table for equivalent noise level and each frequency noise level

Case [-]	Pumps [-]	Burner 1 [-]	Burner 2 [-]	Φ burner [kW]	LAeq [dB(A)]	LZeq_O 16Hz [dB]	LZeq_O 31.5Hz[dB	LZeq_O 63Hz[dB]	LZeq_O 125Hz[dB]	LZeq_O 250Hz[dB]	LZeq_O 500Hz[dB]	LZeq_O 1kHz[dB]	LZeq_O 2kHz[dB]	LZeq_O 4kHz[dB	LZeq_O 8kHz[dB]
1	0	0	0	0	27.28	39.76	34.34	40.33	35.65	27.2	24.12	22.49	13.45	15.62	11.98
2	1	0	0	0	54.77	57.79	52.31	59.44	61.88	59.47	54.27	45.5	40.91	32.79	26.76
3	1	0	1	337	83.36	66.08	63.01	72.47	70.4	72.48	79.23	77.48	77.93	73.79	65.51
4	1	0	2	838	83.52	66.23	69.69	78.13	80.28	76.26	78.09	79.7	77.16	72.27	65.65
5	1	1	0	299	78.39	73.54	61.54	67.56	69.49	72.65	73.96	73.03	72	69.35	62.57
6	1	1	1	635	84.76	69.7	64.78	73.87	71.86	76.41	80.49	79.56	78.83	74.78	67.08
7	1	1	2	1144	84.42	68.08	70.9	77.97	80.48	78.5	79.58	79.91	78.33	73.8	67.26
8	1	2	0	479	81.9	73.41	64.59	69.6	77.17	80.33	79.01	77.36	74.07	69.96	62.66
9	1	2	1	811	85.42	68.67	67.69	74.33	77.53	82.37	81.88	80.31	78.81	74.43	66.39
10	1	2	2	1305	85.44	69.48	75.15	78.88	81.53	83.95	80.94	81.17	78.23	73.77	66.97

Table 22 Table with equivalent noise level and noise level Cz80 according to norms

Nr crt. [-]	Laeq_No [dB(A)]	LZeq_No 16Hz [dB]	LZeq_No 31.5Hz[dB]	LZeq_No 63Hz[dB]	LZeq_No 125Hz[dB]	LZeq_No 250Hz[dB]	LZeq_No 500Hz[dB]	LZeq_No 1kHz[dB]	LZeq_No 2kHz[dB]	LZeq_No 4kHz[dB]	LZeq_No 8kHz[dB]
Cz80	85	121.1	109.9	98.7	91.6	86.4	82.7	80	77.7	75.9	74.4

The above tables shows the noise levels for each frequency as measured by the Bruel Kjaer sonometer during the experiments, and in table number two the noise level for technical spaces according to the Cz80 curve indicated in the Romanian noise protection norm.

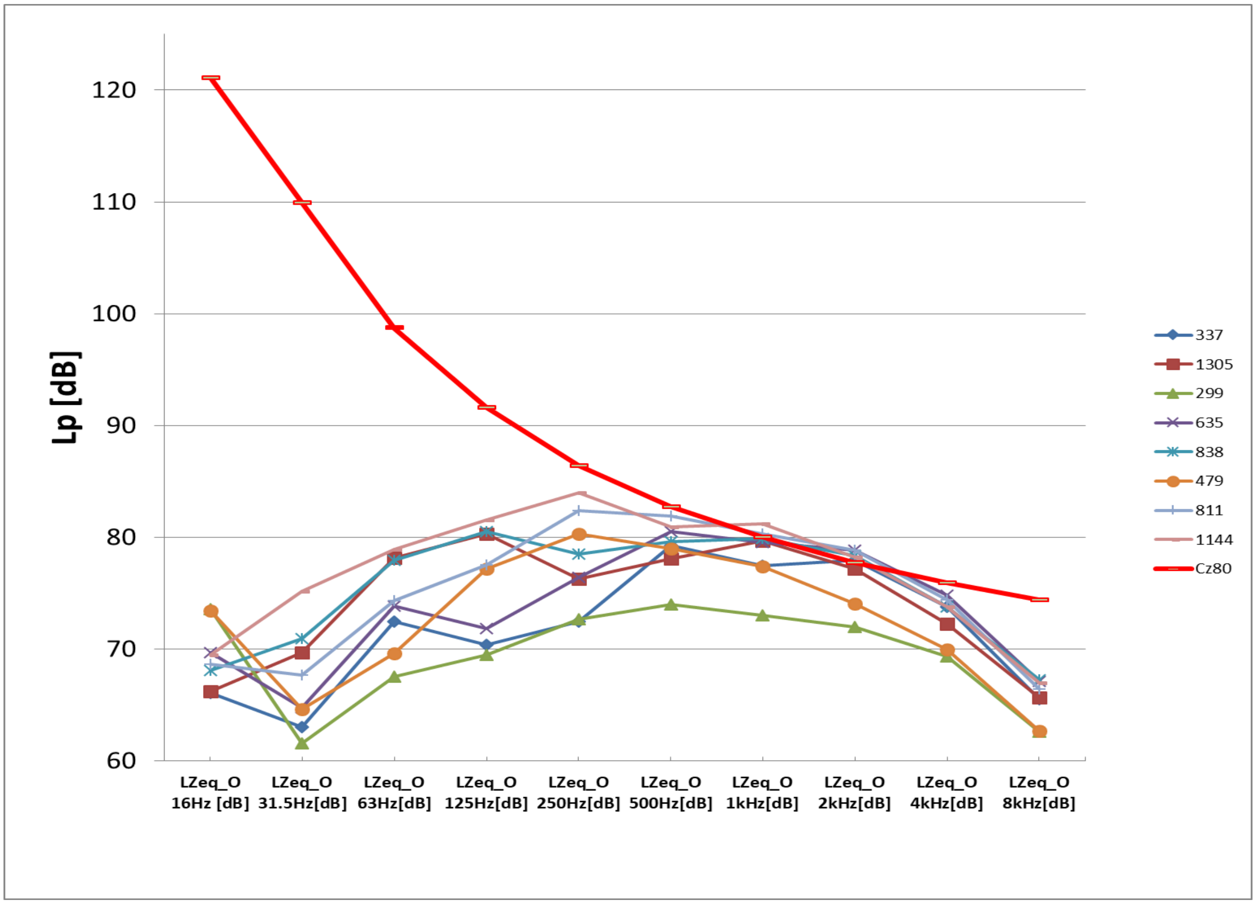


Fig.43 Comparison between noise level on each frequency and Cz80 from norms

In the graph above, it is observed that up to the 500 Hz frequency for all noise levels exceeds the values indicated in the norms, resulting in the need for acoustic treatment for low frequencies (burning frequencies). For higher frequencies, the noise level is below the Cz80 curve, thus respecting the maximum allowable noise level in a boiler plant.

Table 23 Table with inspections carried out during the experiment on this thermal plant

Case [-]	Tr [s]	Volum [m3]	Boiler type [-]	Type of fuel[-]	Burner type [-]	Burner case [-]	WallAcoustic treatment [-]	Boiler dissociation [-]	Boiler fundation [-]	Flexible connection [-]	Passing pipes [-]	Chimmey isulation [-]	Gas pres [mbar]	Gas temp [oC]
1	1.34	66.5.83	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0	30	11.75
2	1.34	736.49	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0	30	11.75
3	1.34	736.49	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0	30	11.75
4	1.34	736.49	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0	30	11.75
5	1.34	736.49	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0	30	11.75
6	1.34	736.49	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0	30	11.75
7	1.34	736.49	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0	30	11.75
8	1.34	736.49	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0	30	11.75
9	1.34	736.49	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0	30	11.75
10	1.34	736.49	ReverseFlame	gas	Turndown	0	0	1	1	0	0	0	30	11.75

The above table shows the inspections carried out during the experiment on this thermal plant. It is noticed that another essential requirement regarding acoustic comfort, namely the reverberation time, respects the values indicated in C125.

Similar to precedent chapter we will compare the values obtained from the experiment with the predictions of the noise level according to the formulas found in the literature

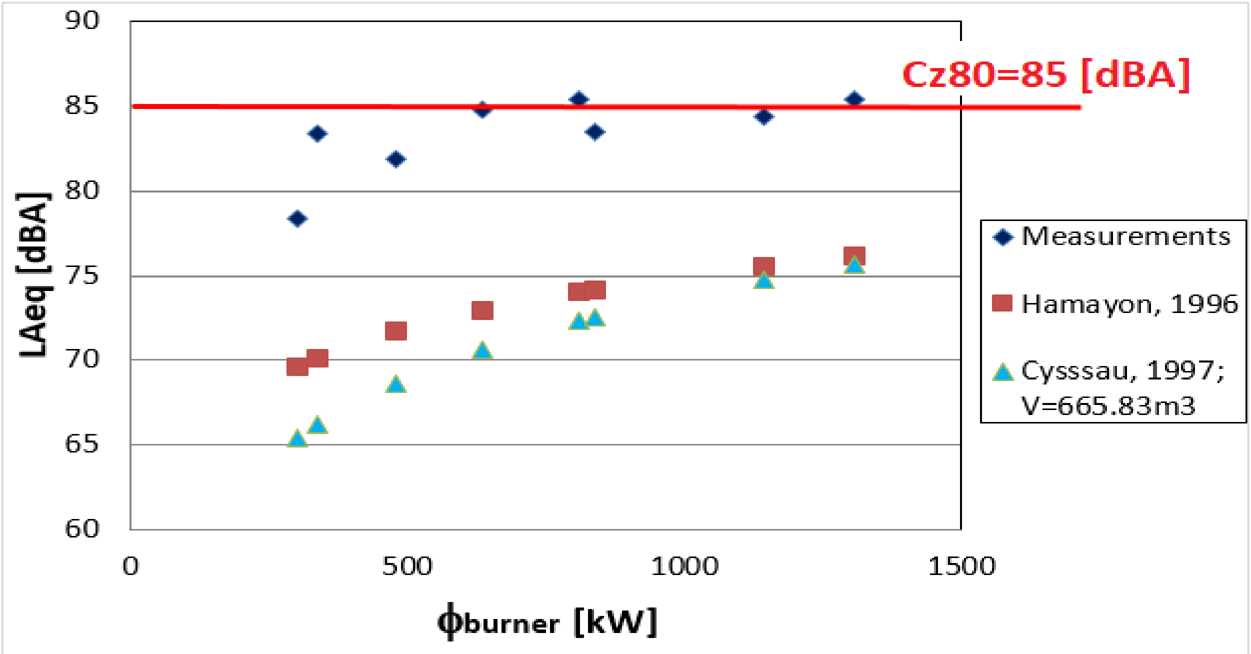


Fig.44 Scatter graph to compare the real noise level with the noise levels in the literature

The measured values exceed the values indicated in the C125 / 2012 norm (maximum of 85 dB(A)) for boiler plants in three operating conditions of the boilers. The conclusion is that this thermal plant needs an acoustic refurbishment in order to fulfill today's acoustic norms.

It can be seen that Hamayon's model has an error up of 13.18dBA, value close to the precision range of the formula. In contrast, Cyssau's model has an error of 17.16dBA, much higher than the 5dBA declared.

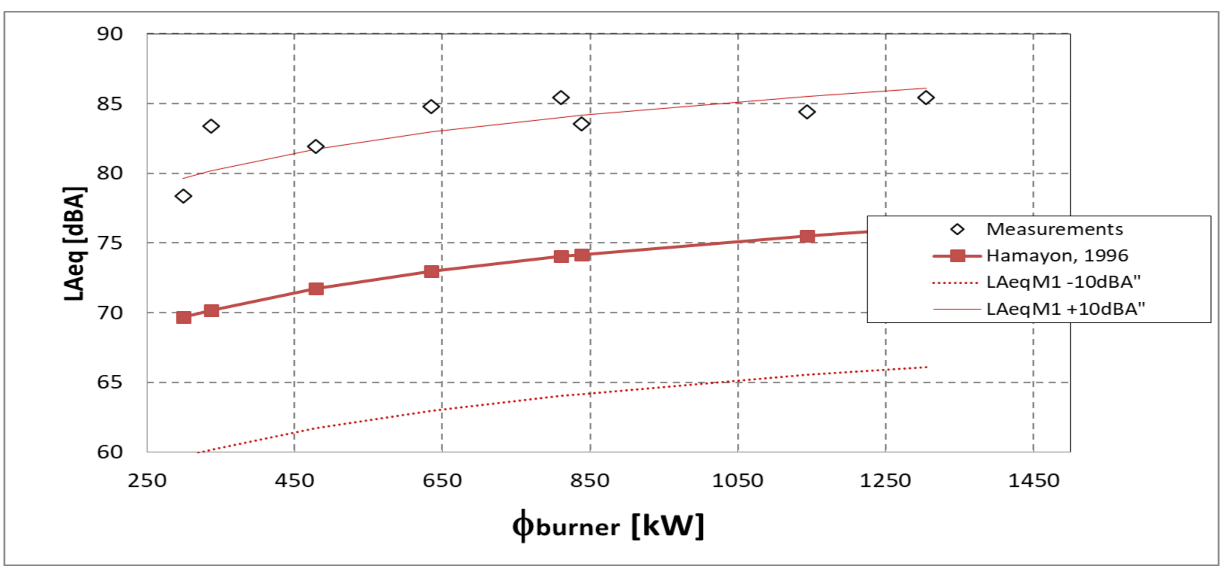


Fig.45 Comparative graph between the measured equivalent noise level, prediction model LAeqM1 [Hamayon, 1996] and its ±10dBA declared error.

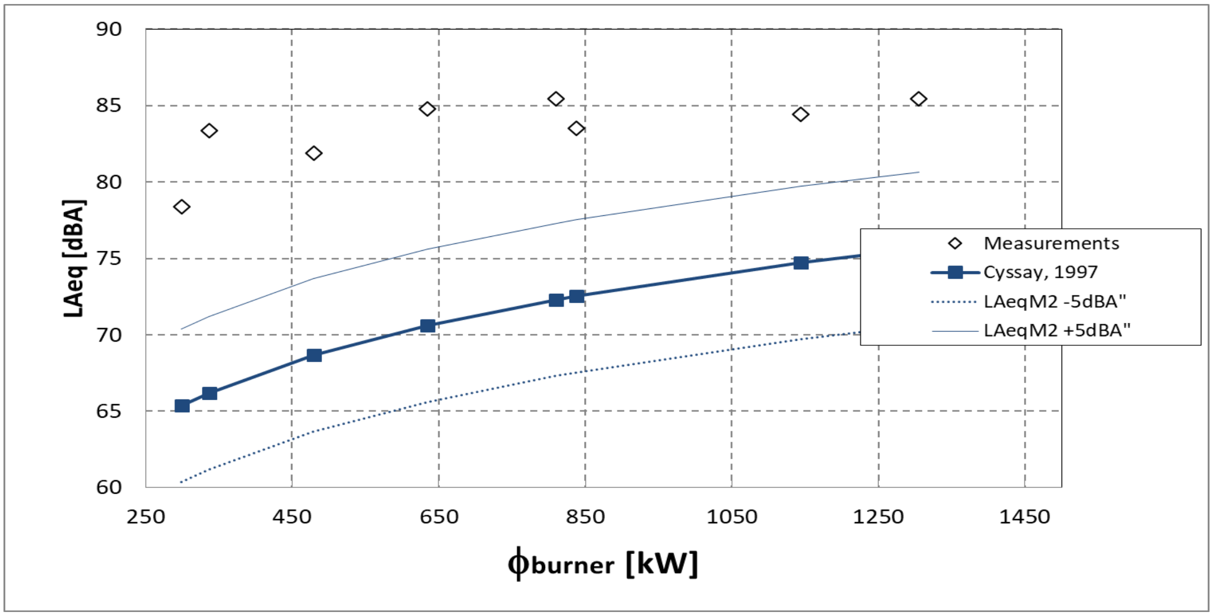


Fig.46 Comparative graph between the measured equivalent noise level, prediction model LAeqM2 [Cyssau, 1997] and its ±5dBA declared error

The errors of the Hamayon's and Cyssau's model compared to our experimental data is not centered in zero, thus there is a phenomenon that the fast prediction Hamayon's model does not take into consideration. We conclude that Hamayon's model is not suited for today's thermal powers and new thermal generation equipment. Therefore there is need for an adaptation of the noise prediction models to today's thermal conditions (larger thermal power stations, noisier equipment, automated control).

8.Conclusions

After comparing the models in the literature with the values obtained experimentally in the 12 simulated functioning situations, it turned out that the models in the literature are not sufficiently accurate from the point of view of precision, thus revealing the need to improving this model by completing the database and validate the theoretically obtained models by experiments similar to those obtained in this protocol.

These experiments are designed to create a database that will be used to identify another parameter beyond those already known.

In report number 3 the database will be extended with other measurements. Some of the management director of these plants has been contacted, and the next experimental campaign will be overdue.

In the graph below, there are bullet locations with thermal power and volume for each of the 10 boilers plants in which experiments were carried out.

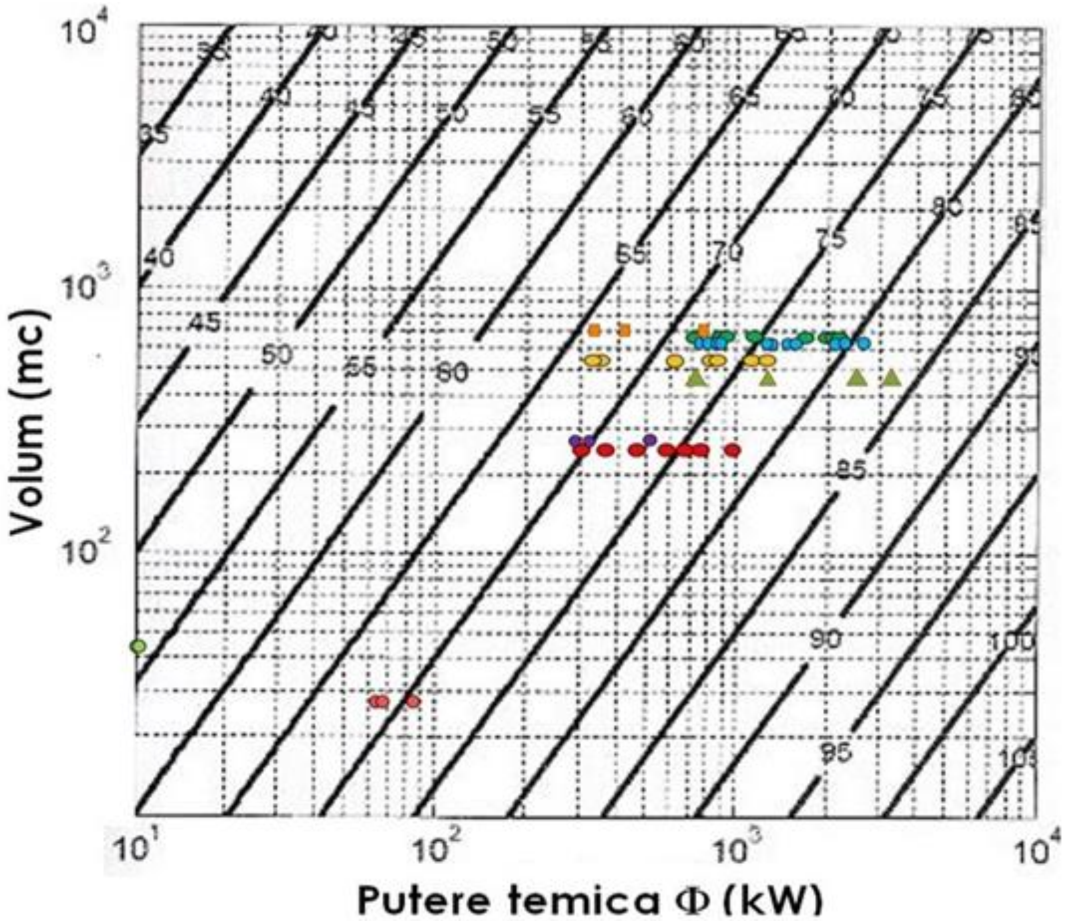


Fig.47 Graph with measurements of thermal power and volume made for each boiler plant

Color legend: Ploiesti: Isolate boiler plant- dark green; Block of flats- green triangle Brasov: Hotel- orange; Student Flats- mauve; FII- yellow.; Cantina- dark green; Geodesy- cyan; Students Flats 5- dark orange; Students Flats 6- light green.

It can be noticed that values for small thermal loads with large volumes, respectively high thermal loads with small volumes are missing. In order to create a model with a higher applicability it will try to fill in the database with the missing points.

Also in the next report will be the statistical analysis after the completion of the database, which will result also the influence of the different parameters on the noise level in the thermal power plant.

The Thesis will additionally come with the determination of prediction models of the Global A-weighted acoustic pressure level LAeq [dBA] produced by boiler plants according to the most influential parameters, model testing, comparison with existing models in literature and scientific publishing articles.

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