TECHNICAL UNIVERSITY OF LODZ
INTERNATIONAL FACULTY OF ENGINEERING

Łódź

Road Acoustic Screens

Technical Analysis and Promotion Strategy

Aneta Kurzawa
Joseph Apasa
Alexandre Bretton
Sergio García
Gerard Villadelprat

EPS 2011

Preface

The current Project is the result of 4 months of work as the main part of the European Project Semester. It has been done between March and June 2011 at the International Faculty of Engineering of Technical University of Lódz by an international team built by Aneta Kurzawa, Joseph Apasa, Alexandre Bretton, Sergio García and Gerard Villadelprat.

During this time our team has learned a lot and has acquired new knowledge about the main topic of this work: road acoustic screens, from a technical and an economical point of view, in the context of acoustic pollution and ways to reduce it, noise related effects on human beings. We hope that our research could be useful for further considerations.

Before going into detail in this project we want to express our respect and gratitude to our supervisors, Dr Magdalena Grębosz and Dr Jarosław Błaszczak, who have guide us during this semester in our project and who we have been allowed to rely on for any questions, doubts or problems. In the same way, we want to thank other teachers involved in this EPS programme for their collaboration as well as the IFE as Institution and Host University.

Best regards,

THE TEAM

Fig. 1.1: EPS-RAS Team Logo

Table of Content

Content

1. INTRODUCTION

Today we can observe an intensive growth of investment in infrastructural construction, and the need to meet new standards creates favourable conditions for a dynamic development of acoustic screen construction sector. The development of motorways, express roads, ring roads, roads, streets and railway line networks guarantees faster economic development in the country and higher prosperity of its people. But together with the growing intensity of road traffic and of all kinds of manufacturing, hazards to natural environment are also on the increase. Among influence the most dangerous factors that have an impact on the degradation of natural environment and people health are noise and vibrations.

Acoustic screen is a natural or artificial barrier, placed between the source of noise and the point of observation. What occurs beyond the barrier is the area of reduced sound intensity, called acoustic shadow. The shadow area is determined by the same method as the area of optical shadow, but it is narrowed down for sound waves of considerable length because of their diffraction. Screens are useful owing to their two basic physical parameters – acoustic isolation and sound absorption coefficient. The first is responsible for the amount of acoustic power which penetrates through a screen to the zone it strives to protect. The second is accountable for the amount of power of acoustic wave that is reflected towards the sound source. For the high effectiveness of acoustic screens to be high, both of these parameters must be as high as possible, i.e. the amount of power of a reflected acoustic wave and a wave penetrating through the layer of a screen should be as low as possible. Road acoustic screens are made of transparent or semi-transparent glass panels, mostly out of polycarbonate or acrylic glass (whose aim is usually to reflect sound waves) and the reflecting-absorbing materials, such as concrete, wood, various types of sawdust concrete and keramsite concrete etc., out of ceramics, and finally out of special acoustic panels filled with mineral wool, placed between steel nets (so called green wall), inside perforated sheet metal or PCV panel. Owing to a variety of its construction, it is possible to grow and maintain creeping plants on this type of acoustic screens. There are also green screens, which are earth embankments overgrown with plantation.

The present work is the report of the academic project that we have conducted about road acoustic screens. The project has been initiated and accomplished at the International Faculty of Engineering (IFE), -Technical University of Lodz (Politechnika Łódzka)-, in the framework of European Project Semester (EPS) by an international team comprising students from different universities and countries.

1.1. The report structure

In this report, you will find four core parts of our research work:

- An introduction to the problem of noise in general and environmental noise in particular under the title: NOISE POLLUTION. It concerns definition of noise and noise environment, as well as its classification, its effects and the European noise directive.
- Next, a relatively rich analysis of noise in Acoustics, the science of sound, with the title: TECHNICAL ANALYSIS. This part presents outcomes of both theory and experiments oriented research that we have done. The descriptions of the laboratory, the anechoic room, the instrumentation, and the screens and of the experiments are also enclosed.
- A business-oriented analysis. This part comprises selected marketing aspects, some marketing theoretical basis and emphasizes determination of PROMOTION STRATEGY: tools of promotion, the decision making process and finally the promotion strategy for acoustic screens producers.
- Lastly a cost-related research under the title ECONOMICAL ANALYSIS. Here you can find a simulation of the screens costs estimation as well as the social costs and profits estimation.

The four core chapters quoted above are:

- Preceded by formal presentations of the project and our project team
- Followed by personal comments.

1.2. General Objectives of the project

- To understand the problem of noise and noise environment, as well as the noise classification
- To analyse the economic and social effects of noise
- To comprehend the traffic noise aspects
- To identify different methods and tools of traffic noise reduction
- To know and apply the experimental research in anechoic room
- To analyse effectiveness of acoustic screens (from technical and scientific point of view)
- To make economic analysis of chosen acoustic screens application
- To prepare promotion strategy for acoustic screens producer (with use of different tools and taking into consideration different public)

2. THE EUROPEAN PROJECT SEMESTER

2.1. Structure

European Project Semester is known as EPS. It is a special form of learning which helps students to be employable and helps to gain knowledge about every aspect of well- rounded education. It does not only help to gain knowledge but it also contributes to improving communication skills. That is one semester where the language of instruction is English. In case of ECTS (European Credit Transfer System), it is worth 30 ECTS. Today European Project Semester is available in eight schools in six European countries and one school in the USA. Every Erasmus student from different field of study can participate in EPS. Moreover, there is the possibility for domestic students to join the EPS programme in the own home country.

The semester consists of:

- Interdisciplinary group project. This part is worth 20 ECTS. During this course the method of “Problem Based Project Organized Learning” is used. Students draw their project’s group. The group is an international team. Every student comes from a different country. It is the first part of learning because they are forced to communicate between each other.

- Support items. This part consists of a few courses to help and show students the proper way of communication, creation of projects, how to work in a team and how to cope with a problem. During this part the students get 10 ECTS.

- Students also have a choice of project’s topics. Topics are drawn from various fields to improve students’ creativity and ingenuity. Topics have a wide range from medicine to mechanics. Students have to acquire knowledge together and later use it. They also make many measurements and study other problems. Moreover, students are often faced with difficult problems which they must cope with. Due to this fact they can be assisted by supervisors.

The courses promoting international perspective are the following:

- Team Building and Communication Skills
- Polish Language and Culture (for foreign students)
- Project Management
- International Marketing
- English for Business and Engineering
- Product Design

Thanks to European Project Semester students are well prepared and obtain well-rounded education of working in a team and even managing the project. After this semester students are creative, imaginative and are able to cope with any task. Students are well prepared to begin work after graduation, even abroad.

2.2. Presentation of the Members

We are an international team. We come from different countries but we understand perfectly one another. We cooperate with two supervisors who help us with the project. They are Dr Magdalena Grębosz and Dr Jarosław Błaszczak.

Dr Magdalena Grębosz helps us with marketing strategy and with economic and juridical issues. She helps us with writing the final report and controls our work.

Dr Jarosław Błaszczak helps us with measurements in his famous anechoic room.

During the realisation of our project we work together during our team's meetings, meetings with the supervisors, work in the laboratory, at the IFE and at home. We also use internet, Google or Skype groups, and phone contact to communicate within the group and share information.

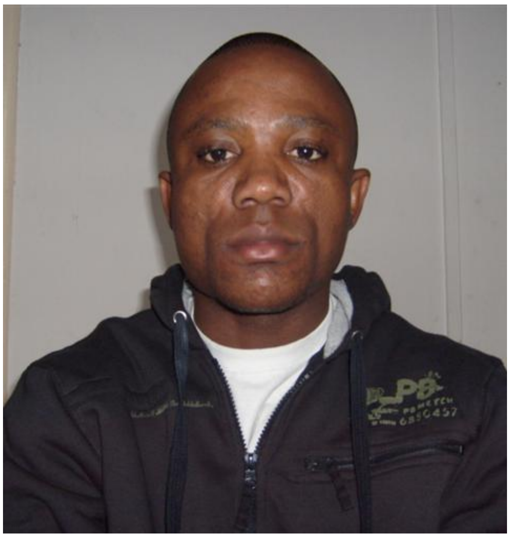
Next, you have a brief description of the students participating in this project.

2.2.1. Aneta Kurzawa

Aneta Kurzawa comes from Poland and lives in Lodz. She is 22 years old. She studies Biomedical Engineering at Technical University of Lodz at IFE.

She is punctual and a loyal friend. She always does her best. Her attribute is that she is an organised person and she is hard-working.

2.2.2. Joseph Apasa



Joseph, 29 years old, is a citizen of Democratic Republic of the Congo. He studies Gestion et Technologie (Business and Technology) at International Faculty of Engineering (IFE) at Technical University of Lodz. He describes himself as very democratic (every opinion should be considered), critical (but no opinion should be accepted blindly, without doubt), and analytical (open to every explanation, not afraid to discuss any topic).

His interests are Finance, Philosophy and Technology. He enjoys swimming, reading and appreciating artistic talents (music, cinema, martial arts). He speaks Swahili, Bembe, French, English, Lingala, Esperanto and some Polish.

"To get more or less than your right is injustice". This way of thinking initiated by Aristotle is the favourite quote of Joseph Apasa.

2.2.3. Alexandre Bretton

His name is Alexandre Bretton. He is 21 years old. He comes from Sevelinges, which is a small village near Lyon in France. After passing his Higher National Diploma with a major in mechanics and production engineering he joined the famous engineering school in France called Ecole Nationnale Supérieure des Arts et Métiers Paristech (ENSAM).

Alexandre did his first years in the centre of Cluny and decided to go for one semester abroad. He chose Poland because it is an eastern booming country, where he will be able to work later. After this semester, Alexandre will do an internship of 6 months in the energy field in New Caledonia. Then, for his last years, he will specialize in the nuclear engineering in order to work in this domain.

Alexandre has been playing basketball in a team for 14 years and 4 years in high level. He also practices mechanical sports like riding a motorbike or quad. During the winter, he went skiing in the mountain close to home. When he is at home he tinkers a lot with his father or alone.

He has recently renovated a truck into a camping car in order to travel around Europe. Now his main hobby is travelling. He has already visited the Balkan countries, Morocco, United States of America, Scotland and several Eastern countries.

2.2.4. Sergio García

Sergio Garcia Rojo is 23 years old. He is from Valladolid, a city located in the middle north of Spain. He studies Industrial Engineering and Business in Madrid, in the European University of Madrid, but this year he is doing Erasmus in Lodz, Poland. He decided to come to Poland because he was here two years ago and he really liked it. Next year he is going to complete his degree in Germany.

He loves playing sports. Since he was young he has been competing in football, tennis and paddling. His other passion is travelling, he likes to discover new places, meet new people and enjoy all of the good things that life has to offer.

2.2.5. Gerard Villadelprat

Gerard Villadelprat is 25 years old and he is Spanish. His hometown is Santa Coloma de Cervelló, very close to Barcelona.

Concerning his academic formation, he went to a German school where, apart from German, he took English and French lessons. He comes from the Escola Politècnica Superior d'Enginyeria de Vilanova i la Geltrú (EPSEVG) of the Universitat Politècnica de Catalunya (UPC), where he has been studying Mechanical Engineering. Now he is taking part in the European Project Semester in the framework of the ERASMUS mobility programme at the International Faculty of Engineering (IFE) of Technical University of Lódz (TUL). He is supposed to complete here his degree by presenting this work as the Final Project's Degree.

During the University period he has been combining his course with a part time job in a sport store and taking part in an internship in a factory linked with the automotive sector.

The most important reason why he decided to come to Poland was because of the European Project Semester programme (only available in few countries), which also gives an important opportunity to improve language skills and simultaneously get an insight into the Polish people and culture.

2.3. Presentation of the Project

For all the members of the group this project represents the first real contact with acoustics, acoustical pollution, noise and noise related effects and the ways to reduce or avoid some of them. Some other new topics, such as technical and economical aspects surrounding this topic have been introduced to us.

2.3.1. Description

Concerning the structure of the project, it can be said that it is definitely a multidisciplinary work, not only because of the different nationalities and different degree specialities, but also because of the three main subjects that are implied.

First of all, there is the most theoretical part, the Juridical, concerning the laws and European legislation and the noise Directives.

Then, we have the technical aspect of the project, which consists of several measurements in the laboratory in order to analyze the different factors that influence the screens' performance.

There is also a marketing part, focused mainly on the promotion strategy, from a screens' producer point of view and finally you will find an economical analysis with cost estimations related with screens producing costs and social costs reduction.

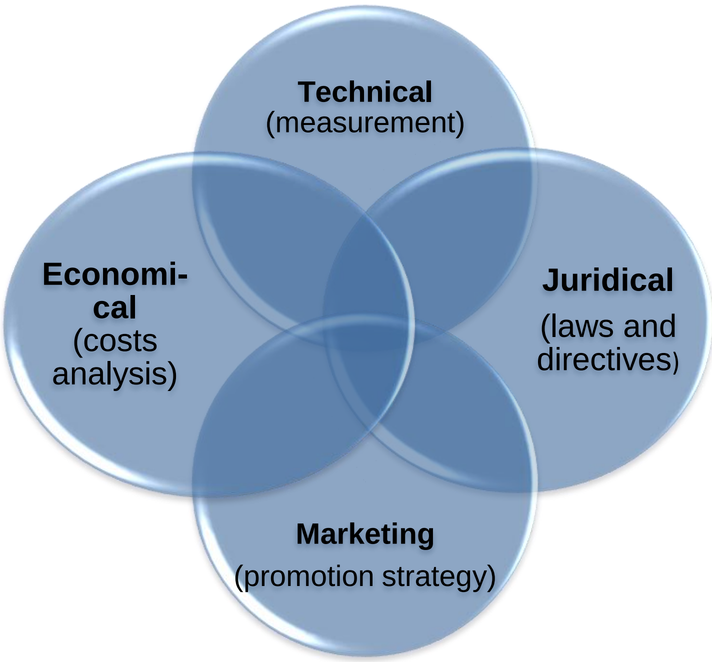


Fig. 2.1: Structure of the Project[1]

[1] Own elaboration

2.3.2. Objectives

Because of this multidisciplinary character of the project, it does not have one unique goal, but several, which could get into groups according to the three different aspects of the work.

The first objective has been to understand the concept of acoustical pollution: noise, noise environment, noise classification and traffic noise aspects, as well as the economic and social effects of them.

Concerning the technical part, we should identify different methods and tools to reduce traffic noise, and learn and know how to apply experimental researches in the anechoic room in order to analyze properly the effectiveness of acoustic screens from technical and scientific point of view.

Finally, we have had to be able to make an appropriate economical analysis to prepare a suitable promotion strategy for road screens producers, using different tools and taking into consideration different public.

2.3.3. Methodology

In this project it was important to plan where we would put our effort depending on our limitations, options and possibilities. So we have had to decide how to research, which information could be researched to get familiar with the topic, and which one should be created by ourselves.

In this case it is important to remark the differences between both research sources and the ways to get information.

We have been introduced to the new topic: noise pollution and all the concerning information. It was a process of acknowledgement through already existing documentation, i.e. a secondary research.

Secondary research is referred to the data that has already been collected by another researcher sometimes for another purpose. Secondary research is often referred to as desk research. It can be a useful starting point for a research exercise. If somebody else has collected data or published a report in a closely related area, it is often much cheaper to buy that report rather than start to collect data afresh.

In the secondary research we can distinguish two types:

- The internal sources: old researches and archives.
- The external sources: Trade, technical and professional media, books and articles or reports from other researchers; professional organizations and associations; specialist research reports; government departments and official publications.

On the other hand, for the technical analysis we had the chance to work with our own data generated it in the laboratory, in concrete in the anechoic room. We managed to record different kinds of measurements with a very wide frequency range, tested different positions of screens, materials and distances. That is primary research, often called field research, concerned with generating new information personally. This kind of research is much more expensive than secondary research, but the results are invariably more up-to-date and specific to research objectives. Our work, especially in the laboratory, should be understood as such research.

During the preparation of economic analysis and promotion strategy we based on the secondary and primary research.

2.3.4. Planning

The table 2.2 shows the time organisation of the project.

The first three topics are related with the introduction and juridical part which were the first we became familiar to.

The next weeks concern the technical study, including an introduction to acoustics from a technical point of view, the preparation of the tests and measurements and the data treatment.

The last part, economical analysis and promotion strategy is dealt at the end once the rest is finished. In parallel with the technical and economical part, the final report has being written.

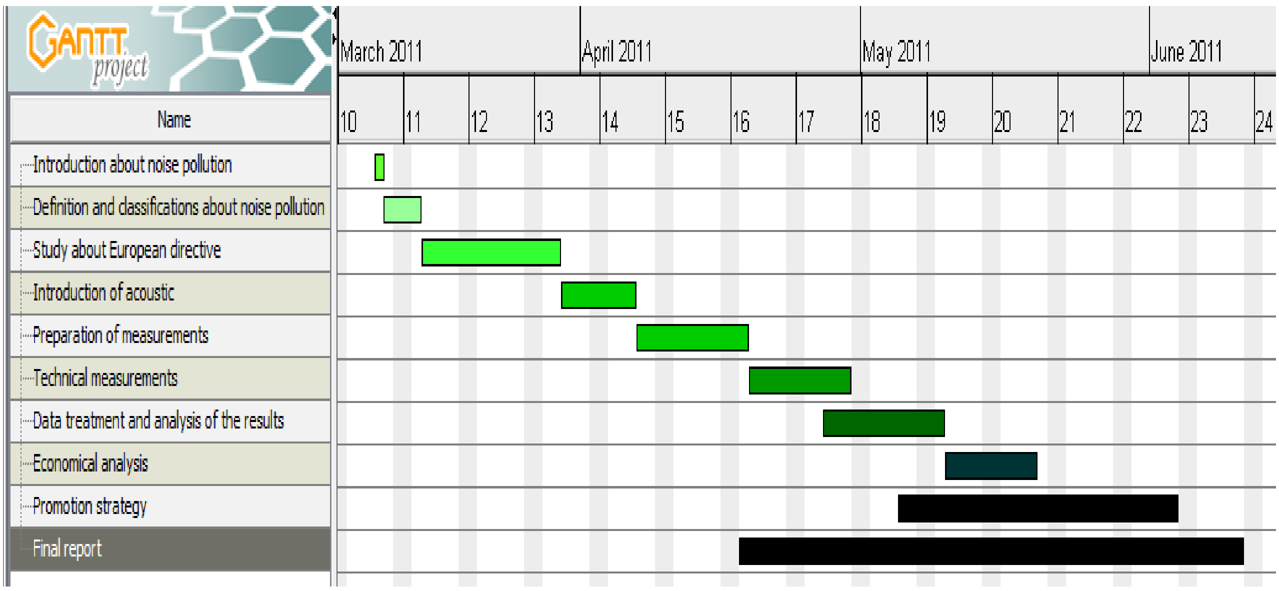


Table 2.1: Planning of the Project

2.3.5. Problems

Very famous word "Research" that we hear very often at our universities simply means: finding out, by use of systematic effort, information or answers to something we want to know. Research is done by asking questions and by searching for answers to those questions, which are satisfactory, methodologically valid, and balanced. We cannot research if we do not want to know anything. That means that we must have something we would like to know more about before we can decide to do any research. In other words, if we have question, we will find answer or we will not know when we have found one. That is why asking oneself good questions is necessary for conducting any research.

The research question is what one wants exactly to know about a given research topic. This is the question that one tries to answer while doing research on the topic.

Our topic being road acoustic screens, throughout the realisation of this project we have been answering the following questions:

- Why is it necessary to use road acoustic screens?
- What does efficiency of road acoustic screens depend on?
- How can a producing road acoustic screens company promote its products and succeed in its business?

We have encountered some problems during our work. These were related to:

- Time: Every member of our team had to attend some particular classes, which made scheduling meetings often not easy;
- Software: We took many measurements for the first time in laboratory but we had to repeat all as it turned out that the software that we used for recording the data was not working properly;
- Material: We have been limited because of the availability of materials, kinds of screens, space in the anechoic room (all the measurements have been modelled in scale 1:5) and staff to work.

2.4. Summary

The realisation of project “RAS” shows us that:

1. European Project Semester is a specific mobility programme in the framework of ERASMUS programmes.

2. We have to cooperate in a completely international and multicultural group and with English as the driving language.

3. We realised a multidisciplinary project which consists of:
    - Juridical part
    - Technical analysis
    - Economical analysis
    - Promotion strategy

4. A big challenge for the students with a lot of objectives to be reached:
    - To understand the problem of noise and noise environment, as well the noise classification.
    - To analyse the economic and social effects of noise.
    - To comprehend the traffic noise aspects.
    - To identify different methods and tools of traffic noise reduction.
    - To know and apply the experimental researches in anechoic room.
    - To analyse effectiveness of acoustic screens.
    - To make economic analysis of chosen acoustic screens application.
    - To prepare promotion strategy for acoustic screens producers.

5. A good methodology and a well defined planning is the most important starting point.

6. There are always problems.

3. NOISE POLLUTION

3.1. Definition of Noise and Noise Environment

In this part some definitions about sound, noise, sound pressure and some illustrations about them will be presented.

3.1.1. Sound[2]

Sound is a mechanical wave that is an oscillation of pressure transmitted through a solid, liquid, or gas, composed of frequencies within the range of hearing and of a level sufficiently strong to be heard, or the sensation stimulated in organs of hearing by such vibrations. A sound can be characterized by the following three quantities:

- Pitch.
- Quality.
- Loudness.

3.1.2. Noise[3]

Noise is often defined as any unwanted sound. In both analogue and digital electronics, noise is an unwanted perturbation to a wanted signal. It is called noise as a generalisation of the audible noise heard when listening to a weak radio transmission. One person's maximum-volume music listening pleasure might be another's unbearable noise. Normally sound over 65dB is considered unacceptable. Signal noise is heard as acoustic noise if played through a loudspeaker. Noise can block, distort, change or interfere with the meaning of a message in human, animal and electronic communication. In audible communication is called noise to any non-desired sound which interferes in the communication between persons or in their activities. The expression noise is sometimes used as synonymous of acoustic pollution. Then it is referring to a noise (sound) with a high intensity (or an addition of intensities) that can even result damaging for human health.

[2] This subchapter is based on the information of website: www.wikipedia.com, www.dictionary.cambridge.org

[3] This subchapter is based on the information of website: www.wikipedia.com, www.businessdictionary.com

3.1.3. Sound Pressure[4]

Sound pressure or acoustic pressure is the local pressure deviation from the ambient (average, or equilibrium) atmospheric pressure caused by a sound wave. Sound pressure can be measured using a microphone in air and a hydrophone in water. In a sound wave there are extremely small periodic variations in atmospheric pressure to which our ears respond in a rather complex manner. The minimum pressure fluctuation to which the ear can respond is less than one-billionth (10-9) of atmospheric pressure. Because of the wide range of pressure stimuli, it is convenient to measure sound pressures on a logarithmic scale, called the decibel (dB) scale. Although a decibel scale is actually a means for comparing two sounds, we can define a decibel scale of sound level by comparing sounds to a reference sound with a pressure amplitude Po=2*10-5 (N/m2) assigned a sound pressure level of 0 dB. Thus, we define sound pressure level (SPL or LP) as:

$$L_p = 10 \log_{10} \frac{P_{rms}^2}{P_o^2} = 20 \log_{10} \frac{P_{rms}}{P_o}$$

Equation 3.1: Sound Pressure

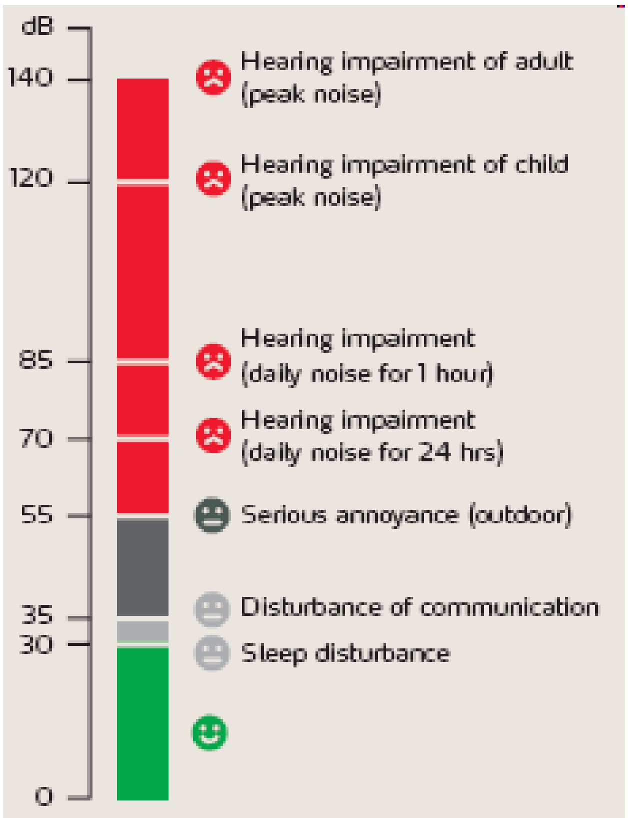


Fig. 3.1: Annoyance level according to dB level[5]

[4] Elaboration on base of www.engineeringtoolbox.com, www.science-dictionary.com

3.1.4. Harmful Noise

- 70 dB causes adverse changes in the vegetative body.
- Above 75 dB can cause hypertension, gastrointestinal disorders, increased secretion of adrenaline, stomach ulcers, accelerate to aging process.
- 90 dB can cause weakness and loss of hearing.
- 120 dB can cause mechanical disorders of hearing.
- Over 130 dB pain is threshold.

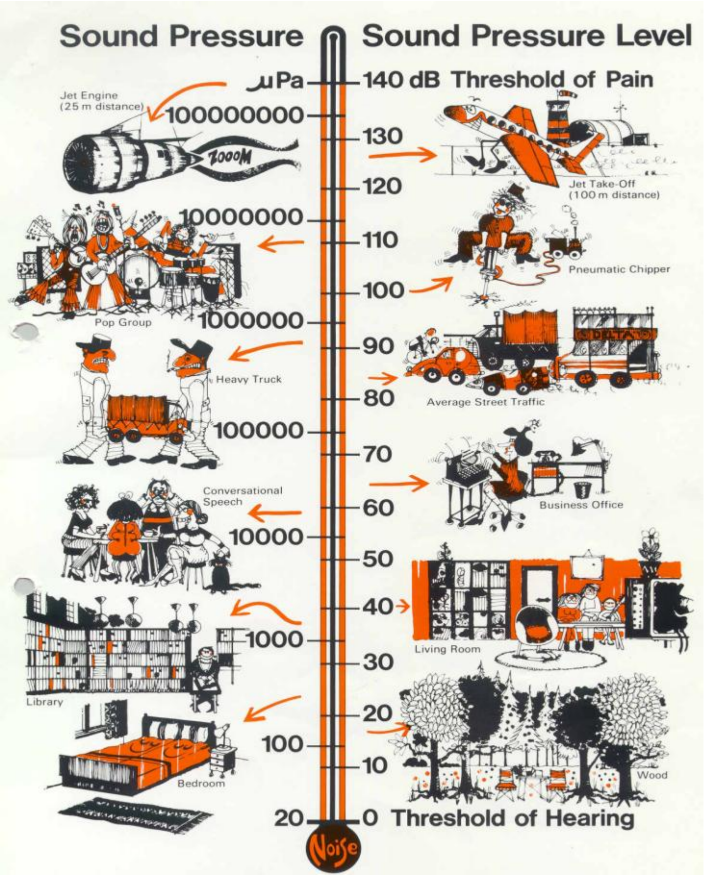


Fig. 3.2: Sound Pressure Level[6]

Noise can be harmful for a human body because too high levels can damage hearing. In the picture 3.3 we can see a special thermometer which shows different levels of sounds. It is truth that day in day out we associate with this noise and we cannot delete it. We can also see that every machine emits noise.

[5] Figure from Website: www.google.com

[6] Figure from Website: www.google.com

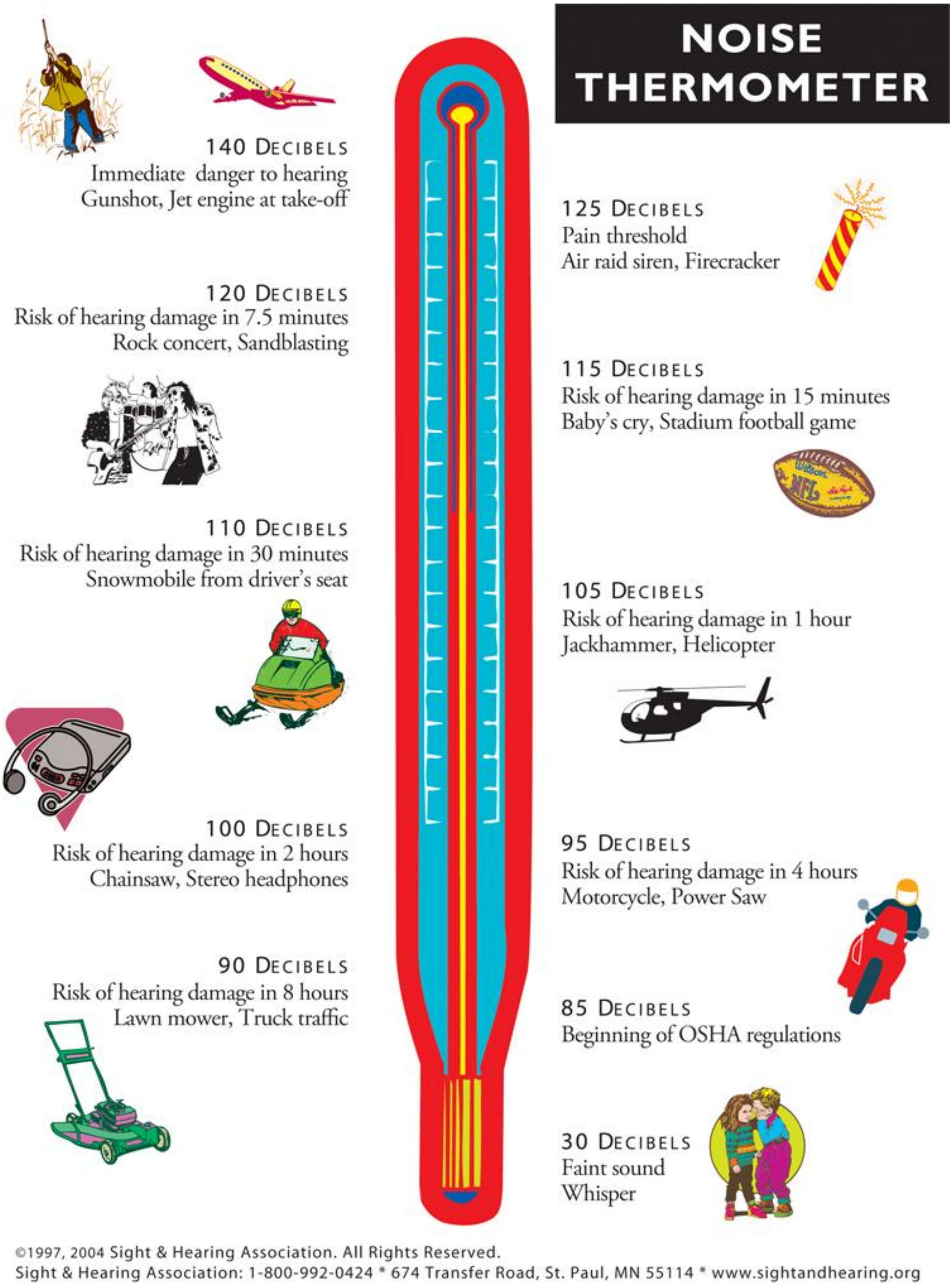


Fig. 3.3: Noise level examples[7]

[7] Figure from Website: www.betterhearing.org

3.2. Classification of Noise

In our everyday lives we hear many different sounds. Many times we hear noises that are harmful to our hearing. In various books we can find a lot of divisions of noise. We decided to divide noise to continuous noise, impulsive noise and intermittent noise. We also use the division into internal and external noise. We would like to discuss about every of them.

3.2.1. Division of noise

Noise can be divided in two groups, the external noise, also called environmental noise and the internal noise, noise in enclosed areas.
Because of the kind of utilisation of the acoustic screens, all the further times referring to noise, will be about external noise.

3.2.1.1. External noise

The noise appearing in environment, open space, called environmental noise or external noise, because it connected with the environment outside the workplace, outside the buildings. This noise affects all citizens, a threat occurring across all elements of the environment.

3.2.1.2. Noise in enclosed areas, called internal noise.

For enclosed spaces include, inter alia, the halls and rooms, industrial, residential and public buildings, and interior communications (trams, airplanes). The internal noise contains so many sources that it is difficult to give them a unified, coherent classification.

3.2.2. Types of Noise[8]

According to kind of noise, its generating source and its flow, we can distinguish between:

- Continuous Noise
- Impulsive Noise
- Intermittent Noise

[8] The typologies of noise and their representations has been found in Internet on 31/03/2011: www.wikipedia.com, www.ccohs.ca

3.2.2.1. Continuous noise

Continuous noise is produced by machinery that operates the same way without interruption, for example, fans, pumps and process equipment. To determine the level of noise is enough to measure for a few minutes with a computer manual. If you hear tones or low frequencies, can also be measured frequency spectrum for further analysis and documentation.

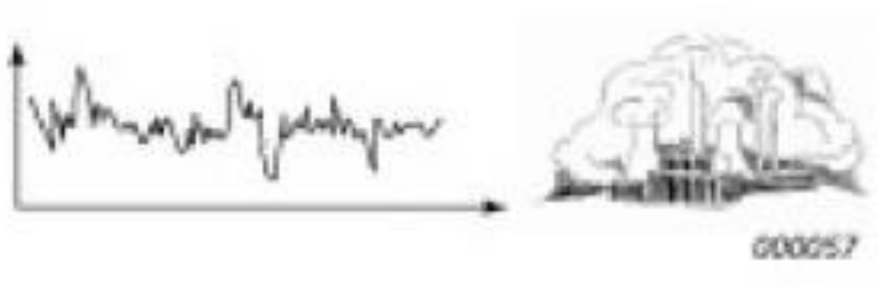


Fig. 3.4: Continuous Noise[9]

3.2.2.2. Impulsive noise

When machinery operates in cycles, or when they single vehicles or aircraft, the noise level increases and decreases rapidly. For each cycle of a machinery noise source, the noise level can be measured just as for continuous noise. But you should also note the duration of the cycle. Single passing vehicle or aircraft is called event. To measure the noise of an event is measured Sound Exposure Level, which combines in a single descriptor both the level and duration. The maximum sound pressure level can also be used. It can be measured by a similar number of events to establish a reliable average.

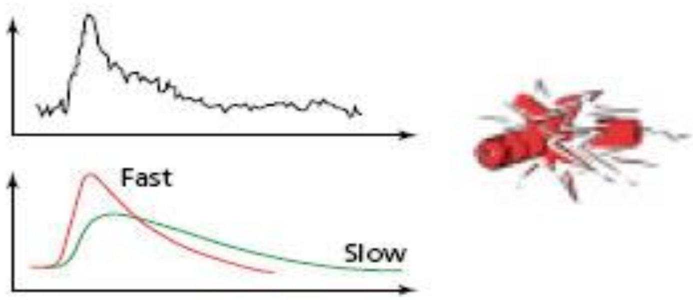


Fig. 3.5: Impulsive Noise[10]

[9] Figure from Website: www.google.com

[10] Figure from Website: www.google.com

3.2.2.3. Intermittent noise

Its startling effect causes more trouble than expected from a simple measurement of sound pressure level. To quantify the noise pulse, you can use the difference between a parameter with fast response and a slow response.

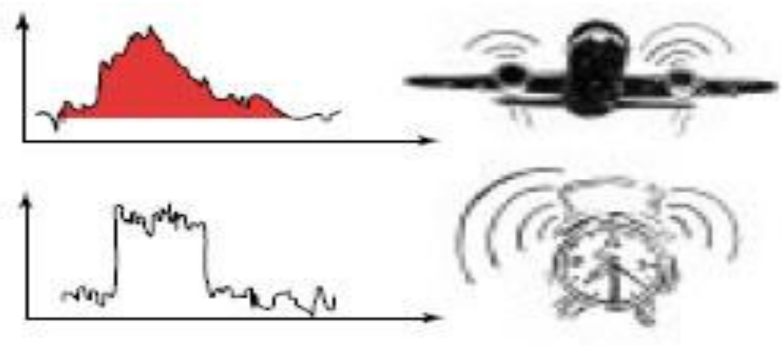


Fig. 3.6: Intermittent Noise[11]

[11] Figure from Website: www.google.com

3.3. Effects of Noise

The World Health Organization (WHO) defines health as "A state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity." This broad definition of health embraces the concept of well-being, and thereby renders noise impacts "health" issues. We separate noise effects into physiological, psychological, social effects and economic effects.

3.3.1. Physiological Effects[12]

The best-known physiological effect due to high noise levels is deafness.

Exposure to loud noise levels for a significant period of time causes hearing loss, that can become irreversible. In turn, exposure to noise levels of medium intensity, but with a further prolongation in time, has a similar impact, resulting in displacement situations both temporary and permanent hearing threshold. Evaluation methods are through audiometric testing and/or ortoscopic.

The temporary threshold shift of hearing, TTS, is a threshold evaluation produced by the presence of noise, existing full recovery after a period of time, provided they do not repeat the exposure. Usually occurs during the first hour of exposure to noise.

Permanent shift of hearing threshold, PTS, is a consequence aggravated by the passage of time and exposure to noise. When an individual has been subjected to numerous TTS and for long periods of time (several years), the recovery of the threshold will become increasingly slow and partial, to the point of becoming irreversible. Such a situation is called PTS.

This prolonged exposure to noise emission levels can produce considerable number of important changes in the body, including:

- Impaired circulatory functions and heart function (tachycardia).
- Alteration of respiratory function, for example, increased oxygen consumption.
- Alterations of endocrine function.
- Alterations in blood pressure.
- Alterations in the digestive system: vomiting, nausea, diarrheal, slow digestion.
- Decreased visual acuity and colour vision.
- Alterations in the cycle of sound.

[12] General Information about physiological effects on Internet research: www.monografias.com/trabajos17/riesgos-fisicos/riesgos-fisicos.shtml on 26/04/2011

3.3.1.1. Hearing[13]

The mechanism of hearing loss arises from trauma to stereo cilia of the cochlea, the principal fluid filled structure of the inner ear. The pinna combined with the middle ear amplifies sound pressure levels by a factor of twenty, so that extremely high sound pressure levels arrive in the cochlea, even from moderate atmospheric sound stimuli. Underlying pathology to the cochlea are reactive oxygen species, which play a significant role in noise-induced necrosis and apoptosis of the stereo cilia. Exposure to high levels of noise have differing effects within a given population, and the involvement of reactive oxygen species suggests possible avenues to treat or prevent damage to hearing and related cellular structures. The elevated sound levels cause trauma to the cochlear structure in the inner ear, which gives rise to irreversible hearing loss. A very loud sound in a particular frequency range can damage the cochlea's hair cells that respond to that range thereby reducing the ear's ability to hear those frequencies in the future. However, loud noise in *any* frequency range has deleterious effects across the entire range of human hearing. The outer ear (visible portion of the human ear) combined with the middle ear amplifies sound levels by a factor of 20 when sound reaches the inner ear.

3.3.1.2. Cardiovascular effect[14]

Noise has been associated with important cardiovascular health problems. In 1999, the World Health Organization concluded that the available evidence showed suggested a weak association between long-term noise exposure above 67-70 dB (A) and hypertension. More recent studies have suggested that noise levels of 50 dB (A) at night may also increase the risk of myocardial infarction by chronically elevating cortisol production. Fairly typical roadway noise levels are sufficient to constrict arterial blood flow and lead to elevated blood pressure. In this case, it appears that a certain fraction of the population is more susceptible to vasoconstriction. This may result because annoyance from the sound causes elevated adrenaline levels trigger a narrowing of the blood vessels (vasoconstriction), or independently through medical stress reactions. Other effects of high noise levels are increased frequency of headaches, fatigue, stomach ulcers and vertigo.

[13] Information based on internet research: www.betterhearing.org/ on 26/04/2011

[14] Information based on internet research: http://rendiles.tripod.com/RUIDO1.html on 26/04/2011

3.3.2. Psychological Effects[15]

The main consequence of the psychological effects of noise is the feeling of disgust, discomfort and loss of concentration. In addition, high levels of noise in mission disorders can cause mental health. In short, effects associated with environmental stress. In general, a highly predictive variable psychology effects associated with stressful situations is the attitude that the person or group has to its source of noise. If the attitude is negative, if the source generates negative feelings, the more likely that the situation is experienced as intrusive or stressful.

Other variables that contribute to increase the psychological effects of noise are intermittent and unpredictable. Glass and Singer (1972) studied how intermittent noises are often experienced as more aggressive than continuous.

On the other hand, the disturbing noise is usually much longer if the flash is a periodic, whether it is more difficult to predict that if the flasher is not regular. Precisely the unpredictability factor is the determinant of the side effects, and this because:

- Stress increases to be assessed the situation as threatening.
- Increased attention to the noise by subtracting powers of concentration for other activities.
- It is more difficult to adapt or accommodate to noise.

So if noise becomes predictable without reducing the intensity, many effects diminish or disappear. The main psychological effects are:

- Effects on sleep
- Behavioural effects
- Effects on memory and attention
- Effects on pregnancy

[15] The Information concerning this subchapter has been consulted in Internet on 26/04/2011 in: http://html.rincondelvago.com/contaminacion-acustica.html

3.3.2.1. Effects on sleep

Noise causes difficulties sleeping and wakes up those who are asleep. Sleep is an activity that occupies a third of our lives and allows us to relax, order and project our consciousness. The dream is composed of two types: classic deep sleep (not REM (deep sleep stage), which in turn is divided into four distinct phases), and on the other side is the paradoxical sleep. Sounds of about 60 dB have shown that reduce depth of sleep, increasing this reduction as the amplitude of the frequency band grows, which may awaken the individual, depending on the stage of sleep that is and the nature of the noise. It is important to note that surprisingly weak stimuli may also disrupt sleep.

3.3.2.2. Behavioural effects

Noise causes momentary changes in behaviour, which leads to a greater degree of indifference or irritability in the individual. These alterations, which are usually transient, occur as a result of noise that causes concern, insecurity and fear in some cases.

Because some stressful effects depend on qualities of the sound other than its absolute decibel value, the annoyance associated with sound may need to be considered in regard to health effects. For example, noise from airports is typically perceived as more bothersome than noise from traffic of equal volume. Annoyance effects of noise are minimally affected by demographics, but fear of the noise source and sensitivity to noise both strongly affect the 'annoyance' of a noise. Even sound levels as low as 40 dB (A) (about as loud as a refrigerator or library) can generate noise complaints and the lower threshold for noise producing sleep disturbance is 45 dB (A) or lower. Other factors that affect the 'annoyance level' of sound include beliefs about noise prevention and the importance of the noise source, and annoyance at the cause (i.e. non-noise related factors) of the noise. For instance, in an office setting, audible telephone conversations and discussions between co-workers were considered to be irritating, depending upon the contents of the conversations. Many of the interpretations of the level of annoyance and the relationship between noise levels and resulting health symptoms could be influenced by the quality of interpersonal relationships at the workplace, as well as the stress level generated by the work itself. Evidence regarding the impact of long-term noise versus recent changes in ongoing noise is equivocal on its impact on annoyance.

3.3.2.3. Effects on Memory and Attention

In those tasks where memory is used, it has been demonstrated improved performance in those individuals who are not subject to noise, because this growth occurs in the activation of the subject and this relation to performance in certain work, occurs on activation translated into a decrease in performance. The noise makes the joint review task more slowly, especially when dealing with unfamiliar words. In noisy conditions, the individual wears psychologically to maintain their level of performance.

The noise spreads the attention being not located in a specific activity, causing lack of attention in others. It also causes losing the concentration of activity.

3.3.2.4. Effects on Pregnancy

It has been observed that pregnant mothers who have been since the beginning of her pregnancy in noisy areas have children who are left untouched, but if exposure occurs after 5 months of gestation, after birth the children cannot stand the noise, cry when they feel it, and at birth are smaller than normal.

Besides these two major problems caused by noise, there are other factors that can influence human action because of the noise.

3.3.3. Social and Economical Effects

The combination of all the factors described above, also have repercussions in the social and economic problems. Exposure to noise can damage strong levels of communication and patterns of coexistence in people. As an unwanted outsider in most cases cannot control, often causes changes in mood such as: irritability, anger, anxiety, nervousness, depression, discomfort and impotence. This type of situation and behaviour can lead to economics problems, mainly due to lack of performance, what becomes ineffective to work, which can lead to economic losses for the company, and worse, can get him off his work. Also the noise pollution can influence in the price of lots, homes, rentals, etc, because nobody likes to be surrounded by noise, which would also produce lower prices and losses in these areas.

3.4. Noise Directive[16]

The aim of this Directive 2002/49/EC of the European Parliament and the Council of 25 June 2002 relating to the assessment and management of environmental noise shall be to define a common approach intended to avoid, prevent or reduce on a prioritized basis the harmful effects of the noise pollution by following those actions:

- The determination of exposure to environmental noise, through noise mapping, by methods of assessment common to the Member States;
- Ensuring that information on environmental noise and its effects is made available to the public.

The directive has also as aim to provide a basis for developing and completing the existing set of Community measures concerning noise emitted by the major sources, in particular road and rail vehicles and infrastructure, aircraft, outdoor and industrial equipment and mobile machinery, and for developing additional measures, in the short, medium and long term.

That's why it's necessary to establish common assessment methods for 'environmental noise' and a definition for 'limit values', in terms of harmonized indicators for the determination of noise levels.

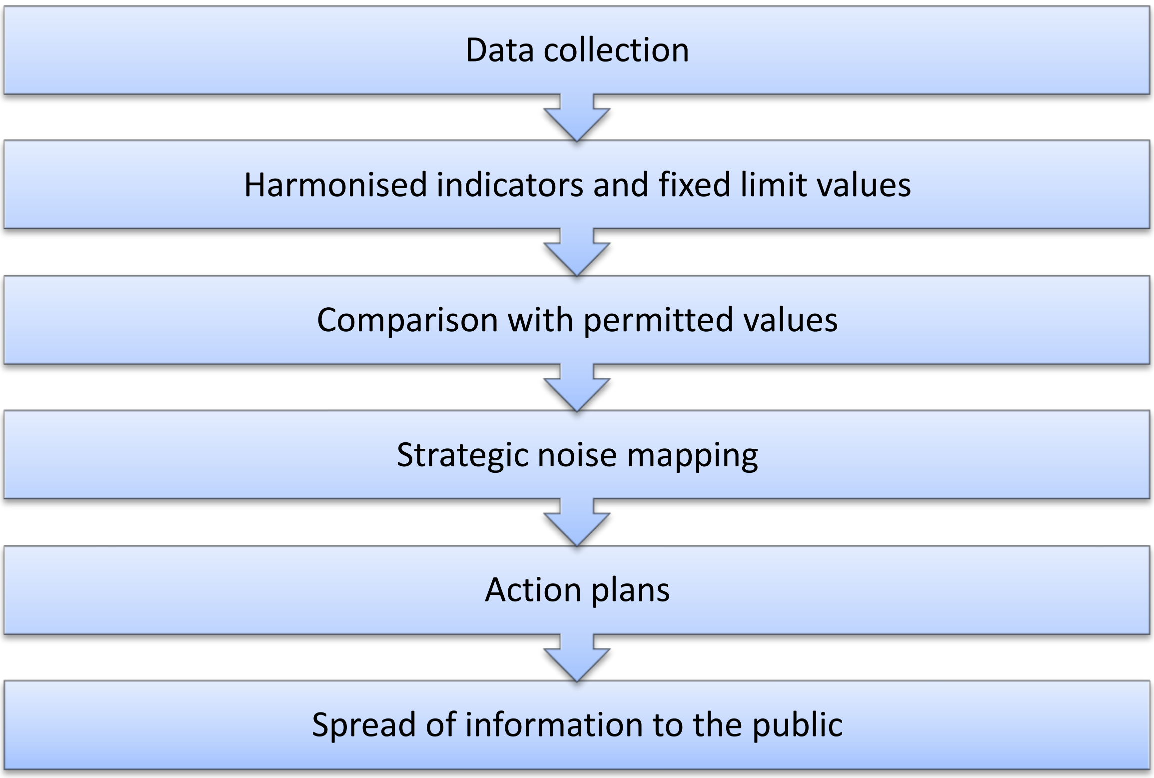


Fig. 3.7: Common Assessments Methods for "Environmental Noise"[17]

[16] This subchapter is a summary of the Official Journal of the European Communities

[17] Own elaboration.

The actions suggested by EU to protect the population against the noise are the following:

- Data collection: measurement of the level of noise
- Harmonized indicators and fixed limit values: the selected common noise indicators are L_{den} (Day, Evening, Night), to assess annoyance, and L_{night}, to assess sleep disturbance. Indeed, during the night the permitted value is lower than during the day because people need to sleep in good conditions.

$$L_{den} = 10 \lg \frac{1}{24}\left(12 * 10^{\frac{L_{day}}{10}} + 4 * 10^{\frac{L_{evening}+5}{10}} + 8 * 10^{\frac{L_{night}+10}{10}}\right)$$

Equation 3.2: Noise Indicators

- Comparison with permitted values: comparison between the collected measurement and the limit values.
- Strategic noise mapping: creation of a map, where we can see the different level of noise and the most affected areas.
- Action plans: plans should address priorities in specific areas like schools, hospitals and others noise sensitive buildings.
- Spread of information to the public: publication to the public by using the most appropriate information channels.

This directive must be respected in all countries of the European Union. However, it is possible that in some countries, the permitted values are more restrictive than the values of this directive.

4. TECHNICAL ANALISYS

This chapter deals with the technical aspect of the project concerning the theoretical basis of the sound, the proposals, description of laboratory, materials etc, the experimentations themselves, their results and a final analysis.

4.1. Theoretical Basis

In the previous lines, we have shown that the main physical element that we are dealing with in this project is noise. The adjective "acoustic" found in the title of our project is susceptible to define the precise sense of what the concept noise is. However the relevant qualifier can turn into having more than one significant. In our case "acoustic" simply means: relating to sound or hearing. Noise is therefore defined in connection with sound.

The scientific discipline that studies sound is Acoustics. The study of sound comprises its production, transmission and effects. This justify the width of the research fields of Acoustics which investigate, to mention a few: the spread of sound waves, sound processing (stopping, reducing, increasing, transforming, etc), effects at personal and environmental levels, etc. In some cases, researches in Acoustics can associate other disciplines, making them interdisciplinary.

A sound can be pleasant to the person hearing it. It is thus a kind of music. Music is the art of producing sounds by combination in order to make them please the ear. Music is also the product of that art, the result of the sound combination, the "artificial" sounds that we like. It is obvious that the main mission of every real musician is to produce music that means the sounds pleasing the public. In that context, music is only the audio component of the music industry, all others being supportive (dances, fashion, etc).

However not every music (product of musician) can please everybody. A same music can be extremely pleasant to a first person, neither good nor bad to a second (indifferent), and extremely annoying to a third one. The music that, instead of pleasing, annoys simply becomes a noise. This reasoning applies to other kinds of sounds. For example, bird songs, laughter and cries of children, snoring during sleep, security alarms etc, can cause either good or bad reactions of people who hear them depending on the level of acceptability or annoyance.

The personal difference of opinions when it comes to determine which sound is and which one is not noisy implies relativity. People are free and able to say which sound (music or other) is delightful or not, how and why. In the case of formal music, the parameters influencing opinions can be: the way the song or melody is played, the rhythms, the instruments used, etc.

As we said before, music as art combine sounds to realize its products. Given that there is infinite possibilities of how sounds can be combined in making any music, it follows that there is also infinity possibilities of making people like (or dislike) one's music. Musical talent is thus the ability to guess what most of people will like to hear and successfully perform it.

Even the most agreeable music can become a noise when played:

- at very high (loud) or unstable sound volume
- with too fast, too slow or disorderly irregular rhythm
- at inconvenient scales (instruments, voices)

From the conditions above, getting satisfaction when listening to any music depends, among others, on the choices made by the artist concerning the rhythms, the scales etc, but also depends on the conditions in which the music is heard (intensity of volume, regularity of signals). Later we will show that those factors refer to theoretical characteristics of sound (e.g.: the musical scale refers to the frequency of the sounds). We understand that one can act on sounds by manipulating its components. One can act on music, also on noise because both have the same nature of sound.

The fact that everybody can have a different opinion when asked either a sound is or is not noisy, considering the factors already quoted, implies relativity of the concept noise at personal levels. At wider levels, the noise produced by some persons affects others. Noise becomes a community problem. This is why official directives are put in place by national and international institutions (e.g.: European Union). The factor taken into account by the directives is the sound intensity of the noise. It is admitted to have negative effects on human health from a certain level the sound.

Some noises have qualified to be called environmental. These are mainly noises created by some human activities. Although the noises so emitted are harmful to people living in the surrounding areas, it is in most of cases impossible to stop the activity generating the noises. Examples include airports, railways and roads. The only possibility for the inhabitants to protect themselves from those environmental noises is to damp or reduce the strength of the noises' effects. In this sake acoustic screens are used.

Technically, in order to envisage efficient acoustic screens and in the framework of our project, it is therefore necessary to understand how a sound is formed, spreads and behaves with obstacles.

The physical nature of sound is the wave (in Physics sounds are waves). So in the next sub-chapters we will analyse sound waves: their properties and types; how they spread, interact with other waves and refraction. Subsequently we will analyse how road acoustic screens work.

4.1.1. SOUND WAVES

4.1.1.1. Wave, the nature of Sound[18]

“Webster's dictionary defines a wave as a disturbance or variation that transfers energy progressively from point to point in a medium and that may take the form of an elastic deformation or of a variation of pressure, electric or magnetic intensity, electric potential, or temperature. The most important part of this definition is that a wave is a disturbance or variation which travels through a medium. The medium through which the wave travels may experience some local oscillations as the wave passes, but the particles in the medium to not travel with the wave. The disturbance may take any number of shapes, from a finite width pulse to an infinitely long sine wave.”

An example of wave is when you throw a stone on a calm swimming pool creating motions on water. These motions are waves. They are passing through the water by moving it without taking it away and after every wave the water regain its initial level.

4.1.1.2. Wave medium

A medium is a substance or material through which the wave travel or that carries the disturbance. For example, we all know the news media. The name News Media designate the main means of mass communication (especially television, radio, and newspapers) regarded collectively. These are institutions that carry the news from one person to another in our city, town, country etc. The news only gets around through the media. The news is not created by the media and the news is not the media; they are different in nature.

In the same way, a wave medium is the substance or material that carries the wave from one place to another. The wave medium is not the wave and it doesn't create the wave; the medium just transports the wave from its source to another place.

In the example of wave given above, the medium is water. The disturbance moves every drop of water for a while and soon the drop regain its initial position. That can be well demonstrated by pouting anything floating on the water. Let us take an empty beer can for illustration. When a wave passes in the water, the can will change its location for a short time and will return to its initial position.

It is worth mentioning that a wave transports just energy and not matter. Thus the waves play an important role in our lives because the energy that they carry is also information for us. With our eyes and ears, we are able to capture what the light or the sound transmits for us without any displacement of matter. Both light and sound are waves.

---

[18] Quotation from the website: http://paws.kettering.edu/~drussell/Demos/waves-intro/waves-intro.html *on 25-April-2011*.

4.1.1.3. Types of waves

There are different types of waves. These can be classified with regard to some of their properties. Regarding their ability to transmit energy through vacuum, waves can belong to three categories:

- Mechanical waves: these are waves which are not capable of transmitting their energy through a vacuum. Mechanical waves require a medium in order to transport their energy from one location to another. An example of mechanical waves is the sound since sound waves are not capable of travelling through a vacuum.
- Electromagnetic waves: These are waves which are capable of transmitting their energy through a vacuum. Electromagnetic waves are produced by the vibration of charged particles. Examples of electromagnetic waves are light waves.
- Matter waves are produced by electrons and particles.

Regarding the motion of particles of medium during the disturbance, also three categories are distinguished:

- Transverse waves: are waves in which particles of the medium move in a direction perpendicular to the direction that the wave moves. Examples are waves introduced in a string piece.

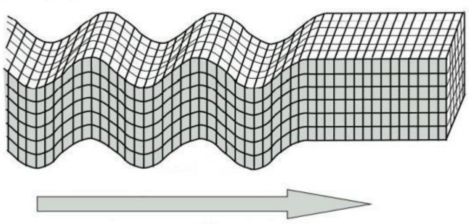


Fig. 4.1: Transverse Wave[19]

- Longitudinal waves: these are waves in which particles of the medium move in a direction parallel to the direction that the wave moves (particle motion are parallel to wave motion).

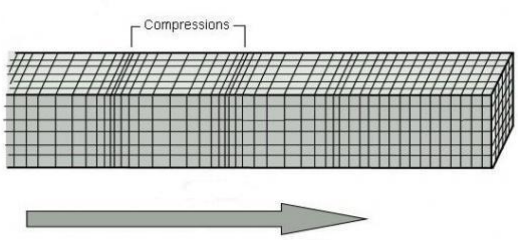


Fig. 4.2: Longitudinal Wave[20]

[19] Image source: http://www.geowiki.fr/index.php?title=Composition_interne_de_la_Terre

[20] Image source: http://www.geowiki.fr/index.php?title=Composition_interne_de_la_Terre

A good example of a longitudinal wave is a sound wave travelling through the air. During its displacement from the lips of a speaker to the ear of a listener, particles of air vibrate back and forth in the same direction and the opposite direction of energy transport. Each individual particle pushes on its neighbouring particle so as to push it forward. The collision of the first particle with its neighbour serves to make a second particle regain its original position and displaces it in a forward direction. This back and forth motion of particles in the direction of energy transport creates regions within the medium where the particles are pressed together and other regions where the particles are spread apart. This process continues along the *chain* of particles until the ear of the listener is reached by the sound wave.

Due to the longitudinal motion of the air particles, two different kinds of regions can be identified. In some regions called compressions, the air particles are compressed together. In other regions called rarefactions, the air particles are spread apart. The compressions are regions of high air pressure while the rarefactions are regions of low air pressure. Sound is also said to be a pressure wave because of this fact.

Waves that travel within the depths of the ocean are longitudinal waves, but the waves that travel along the surface of the oceans are surface waves. In longitudinal and transverse waves, all the particles in the entire bulk of the medium move in a parallel and a perpendicular direction (respectively) relative to the direction of energy transport. In a surface wave, it is only the particles at the surface of the medium that undergo the circular motion. The motion of particles tends to decrease as one proceeds further from the surface.

At this stage we can summarize that sound is a wave, mechanical, longitudinal and pressure one. Let us analyse the properties of sound in the next sub-chapter.

4.1.2. PROPERTIES OF SOUND WAVES

How fast does the wave move through the medium? How long is it? How often do its particles vibrate about their fixed position? How much time does it take for the particles to complete a vibration cycle? How far the particles vibrate away from their resting position?

To answer adequately the questions above suppose understanding the general characteristics of waves which are respectively Wavelength, Speed, Period, Frequency and Amplitude. Some of these characteristics might be known in everyday life with different names.

Generally, waves can be graphically represented as follows:

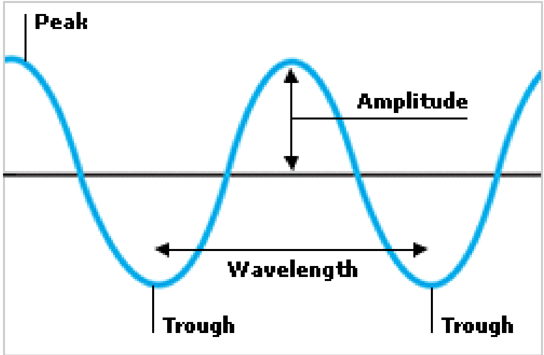


Fig. 4.3: Graphically representation of waves

4.1.2.1. The Wavelength

Wavelength is the distance from one peak (called the Crest) to another of a wave. The wavelength is the distance between maximum compressions, given that sound is a compression wave.

Literally Wavelength is the length of the wave, which means the distance between any point on a certain cycle of the wave and the equivalent point on the next cycle.

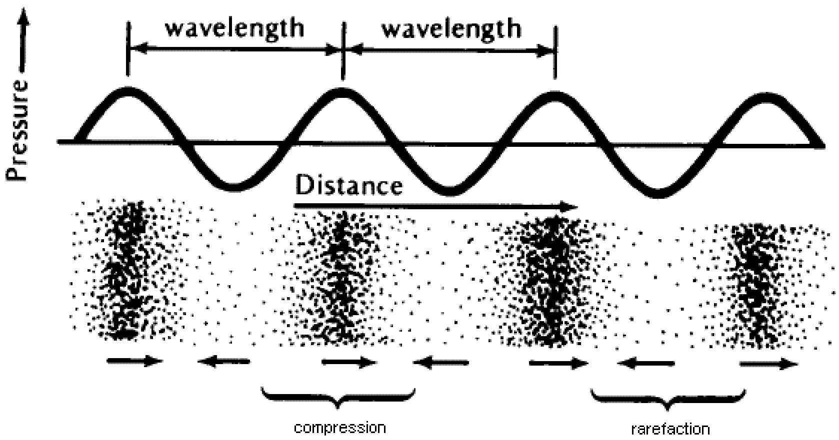


Fig. 4.4: Wavelength

4.1.2.2. The Speed

The speed of a sound refers to how fast the disturbance is passed from particle to particle, or the distance that the disturbance travels per unit of time.

The speed of sound is dependent on two things: the type of medium in which the sound waves propagate and the temperature of the said medium.

The speed of sound in air actually depends on the temperature of the air. For example, the speed of sound in air at a temperature of 20 ºC is about 344 m/s. This value changes to 332 m/s if the air temperature is 0 ºC. On the other hand, if we compare the speed of sound in Hydrogen and in Carbon dioxide when both are at 0 ºC, Carbon dioxide allows a slower speed at 258 m/s, compared to Hydrogen's 1,270 m/s. Generally speaking, the speed of sound is constant for a given altitude. That means that you can have one speed in one altitude and another in a higher altitude.

The temperature of the air varies with altitude, giving the following variations in the speed of sound using the standard atmosphere (conditions can vary in rare cases).

Temperature [ºC]	Speed of sound [m/s]	Temperature [ºC]	Speed of sound [m/s]
+30	349.08	0	331.30
+25	346.18	-5	328.24
+20	343.26	-10	325.16
+15	340.31	-15	322.04
+10	337.33	-20	318.89
+5	334.33	-25	315.72

Table 4.1: Wave speed according to temperature[21]

[21] Table source: www.wikipedia.org

Given normal atmospheric conditions, the temperature, and thus speed of sound, varies with altitude as follows:

Altitude	Temperature	m/s	km/h
Sea level	15 °C	340	1225
11000 m - 20000 m (cruising altitude of commercial jets)	-57°C	295	1062
29000 m (the hypersonic X-43A)	-48 °C	301	1083

Table 4.2: Wave speed at certain altitudes ranges[22]

At normal atmospheric pressure, the speed of sound can be calculated in dry air using the following formula:

$$V = 331.4 + 0.6T_c$$

Equation 4.1: Speed of Sound in dry air

Where:
V = velocity (m/s),
T_c = temperature in Celsius.

4.1.2.3. The Period

Generally a Period is the time it takes to complete one cycle. The period of a sound wave is the time for a particle on a medium to make one complete vibration cycle.
When an event occurs repeatedly, it is said to be periodic and that refers to the time for the event to repeat itself as the period. Period, being a time, is measured in units of time such as seconds, hours, days or years. The international (SI) unit of the period is Second (s).

[22] Table source: www.wikipedia.org

4.1.2.4. The Frequency

4.1.2.4.1. GENERALITIES

Frequency is the number of times the wavelength occurs in one second. It refers to how often the particles of the medium vibrate when a wave passes through the medium. It is measured in hertz (Hz). 1Hz equals one cycle per second.

The frequency of sound is the rate at which the waves pass a given point. So in terms of musical instruments, it is the rate at which a guitar string or a loudspeaker vibrates.

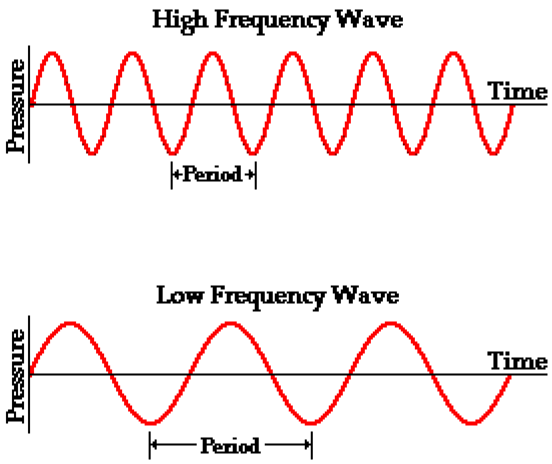


Fig. 4.5: High and Low Frequency Waves

Frequency is the property of sound that mainly determines Pitch. Pitch is the human ear's perception of frequency of a sound vibration (This is the word used by musicians for sound frequency). The perceived pitch of a sound is just the ear's response to frequency. That means that for practical purposes the pitch is just the frequency.

Frequency and pitch describe the same thing, but from different points of view. While frequency measures the cycle rate of the physical waveform, pitch is how high or low it sounds when people hear it. Pitch is therefore directly related to frequency: the higher the frequency of a waveform, the higher the pitch of the sound that we hear.

A good illustrating example is the sound of a motorcycle's engine accelerating. As the engine turns faster, that means at a higher frequency, the engine makes a higher-pitched sound.

Frequency, Wavelength and wave Speed are related as follows:

$$f = v / \lambda$$

Equation 4.2: Relation between Frequency and Wavelength

Where:

f is the frequency,

v is the constant speed (also called phase speed or phase velocity) and

λ [lambda] is the wavelength of the sinusoidal waveform.

It follows that the shorter the wavelength, the higher the frequency, and thus the higher the pitch of the sound. Short waves sound high and long waves sound low.

The table 4.3 of pitch frequencies in equal temperament, based on A4 = 440 Hz to the nearest Hertz (middle C = C4).

0	1	2	3	4	5	6	7	8
C 16	C 33	C 65	C 131	C 262	C 523	C 1047	C 2093	C 4186
C# 17	C# 35	C# 69	C# 139	C# 278	C# 554	C# 1109	C# 2218	C# 4435
D 18	D 37	D 73	D 147	D 294	D 587	D 1175	D 2349	D 4699
D# 20	D# 39	D# 78	D# 156	D# 311	D# 622	D# 1245	D# 2489	D# 4978
E 21	E 41	E 82	E 165	E 330	E 659	E 1319	E 2637	E 5274
F 22	F 44	F 87	F 175	F 349	F 699	F 1397	F 2794	F 5588
F# 23	F# 46	F# 93	F# 185	F# 370	F# 740	F# 1475	F# 2960	F# 5920
G 25	G 49	G 98	G 196	G 392	G 784	G 1568	G 3136	G 6272
G# 26	G# 52	G# 104	G# 208	G# 415	G# 831	G# 1661	G# 3322	G# 6645
A 28	A 55	A 110	A 220	A 440	A 880	A 1760	A 3520	A 7040
A# 29	A# 58	A# 117	A# 233	A# 466	A# 932	A# 1865	A# 3729	A# 7459
B 31	B 62	B 124	B 247	B 494	B 988	B 1976	B 3951	B 7902

Table 4.3: Pitch Frequencies in equal Temperament

4.1.2.4.2. THE OCTAVE

Humans are able to perceive sound waves with frequencies in the range from 20Hz to 20000Hz=20kHz (depending on age, exposure to loud signals and other factors, there should be a few exceptions). Waves below 20 Hz are called Infra-sounds and those beyond 20 kHz are Ultrasounds.

The whole scale of audible frequencies can be divided into steps or ranges called octaves. The higher the frequency is the wider the range. The unit that describes the concept of these frequency steps is called Octave.

An octave is the interval between two sounds one of which has twice the frequency of the other. In other words, an octave is the interval between two frequencies having a ratio of 2:1. When a greater frequency resolution is needed for some studies, a unit with less value such as 1/3 octave can be used.

The image 4.6 is a graphics user interface (GUI) from audio-processing computer software and it shows an octave band equaliser. We have graphic equalizers on some apparatus that we use, such as radio, television set and even computers. The equalizers enable us to set the kind of sound that we want to hear from a combination of frequency levels. In the image below, there are 10 octave bands in the audio range, represented by the 10 sliders. Below the sliders are seen the octave interval nominal frequencies. Each slider controls the gain for a one-octave-wide band of frequencies. The gain, in decibels (dB), is shown in the small window above each slider.

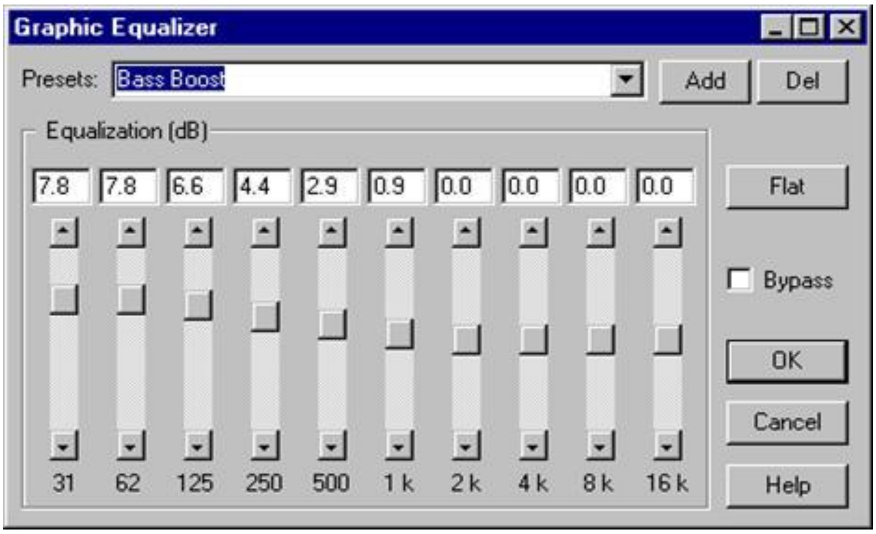


Fig. 4.6: Audio Graphic Equalizer[23]

The standard octave intervals in acoustics are worked out starting from the *Reference Frequency* of 1 kHz. The full sequence of frequencies is:

Hz	16	31.5	63	125	250	500	**1k**	2k	4k	8k	16k

Table 4.4: Whole Octave Scale

As we said earlier, music is a combination of sounds. Certain sound waves when played simultaneously produce a particularly pleasant sensation when heard. For example, any two sounds separated by an octave result in a particularly pleasing sensation when heard. That means that some rules apply so that two sound waves can sound good when played together. Sound waves having the frequency ratio of 5:4 also sound good when played together.

[23] Image source: http://eesfrequencyresponseofamplifiers.blogspot.com/2010/03/octave-and-other-frequency-intervals_20.html

In the table 4.5 there are examples of sound wave intervals with relevant frequency ratios.

Interval	Frequency Ratio	Examples
Octave	2:1	512 Hz and 256 Hz
Third	5:4	320 Hz and 256 Hz
Fourth	4:3	342 Hz and 256 Hz
Fifth	3:2	384 Hz and 256 Hz

Table 4.5: Wave Intervals with relevant frequency ratios

The illustration 4.7 features position of some familiar sounds located on the frequency range.

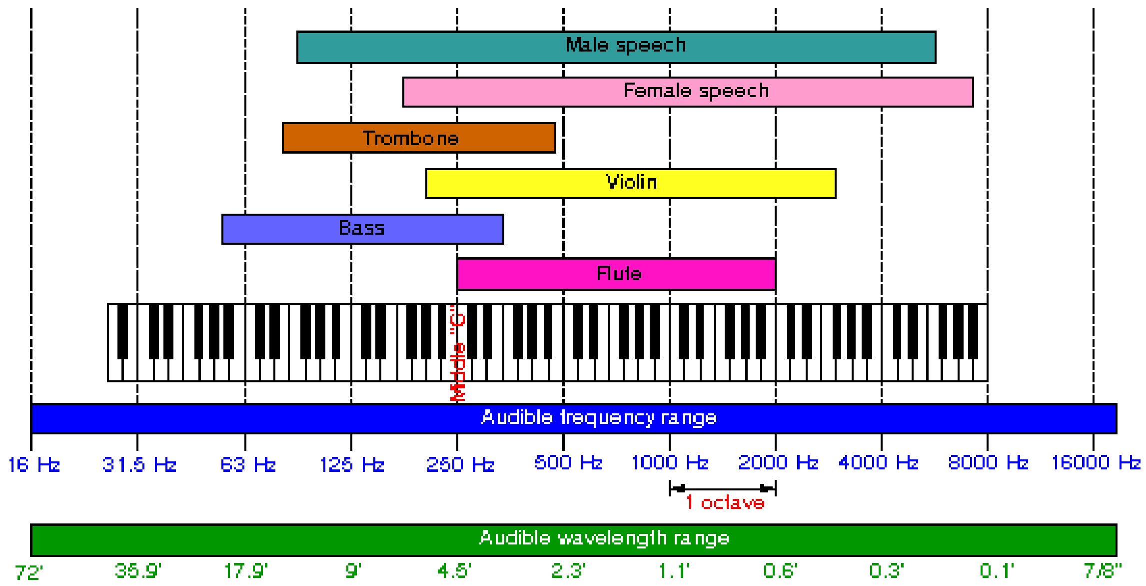


Fig. 4.7: Position of familiar sound on frequency ranges[24]

[24] Image source: http://www.simonisystems.com/acoustics.htm

4.1.2.5. The Amplitude

The definition suggested by WordReference.com for Amplitude is: “the maximum extent or magnitude of a vibration or other oscillating phenomenon, measured from the equilibrium position or average value”. With regard to the sinusoidal form of waves, amplitude is the measure from the resting position to either the crest (high point of the wave) or the trough (low point of the wave).

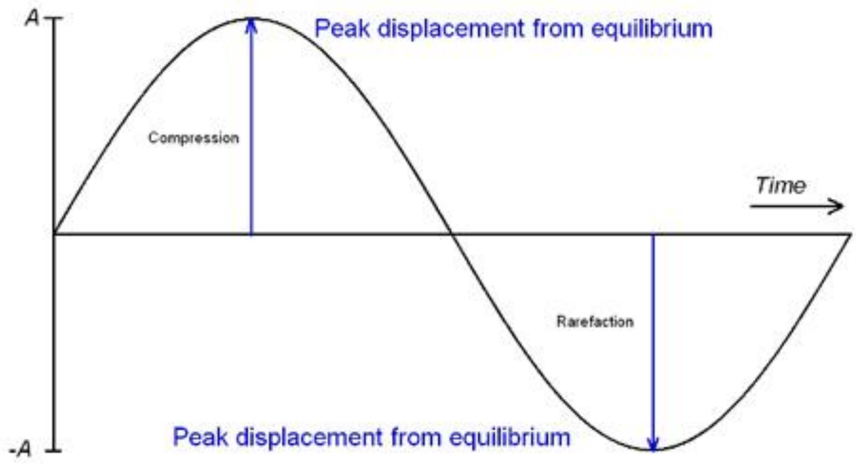


Fig. 4.8: Amplitude[25]

In terms of sound waves, amplitude means a measure of the amount of energy in a wave. The drawing above shows that amplitude can be either positive or negative. The positive amplitude indicates Compression and the negative one indicates Rarefaction. The resting position is the level where the value of energy is zero.

While frequency determines the pitch of a sound, amplitude relates to its loudness. Loudness is simply the quantity of energy contained in the sound. It is also called Volume. Besides, we have the word (or a button) “volume” on almost every electronic device that we use and on which it is necessary to regulate sound loudness.

Sound is a wave like a wave of water that we can see on the sea. The higher it looks, the more powerful it is and for sure it has much more energy than a smaller wave. Similarly, a loud sound carries more energy and thus seriously shakes our eardrums and all the mechanisms of our hearing system. So if the sound is too loud, it means that it carries too much energy.

[25] Image source: http://www.jiscdigitalmedia.ac.uk/audio/advice/the-physical-principles-of-sound

Consequently, the very loud sound can break our auditory system and make us deaf. It is therefore necessary for people to know the levels of loudness of sounds in order to be able to master them. This is one of the main reasons why people measure loudness of sounds.

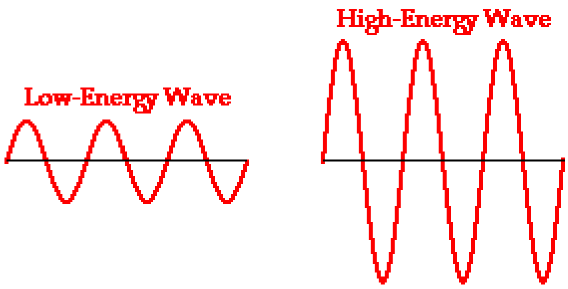


Fig. 4.9: High and Low-Energy Waves[26]

When it comes to measuring the strength of the sound, we talk about amplitude of the wave. When a wave is drawn on a graph, amplitude is the height of the wave. So, amplitude seems to be a more theoretical concept. But an interesting question can be what does the height of a sound wave mean in our real life?

This question is about associating theories (of sound waves) to practical sound-related real situations. In the frame of its answer, let us analyse how amplitude can be measured, first objectively and then subjectively in order to comply with the human subjective nature. This approach requests us to understand the concepts: intensity, pressure and loudness of sound.

[26] Image source: http://www.physicsclassroom.com/class/waves/u10l2c.cfm

4.1.3. Characteristics of Sound

4.1.3.1. Sound Intensity

Also called Acoustic Intensity, this is the amount of energy flowing per unit time through a unit area that is perpendicular to the direction in which the sound waves are travelling. Unlike loudness, sound intensity is objective and can be measured by auditory equipment independent of an observer's hearing.

Sound intensity can be measured in units of energy or work [joules per second per square centimetre] or in units of power [watts per square metre].

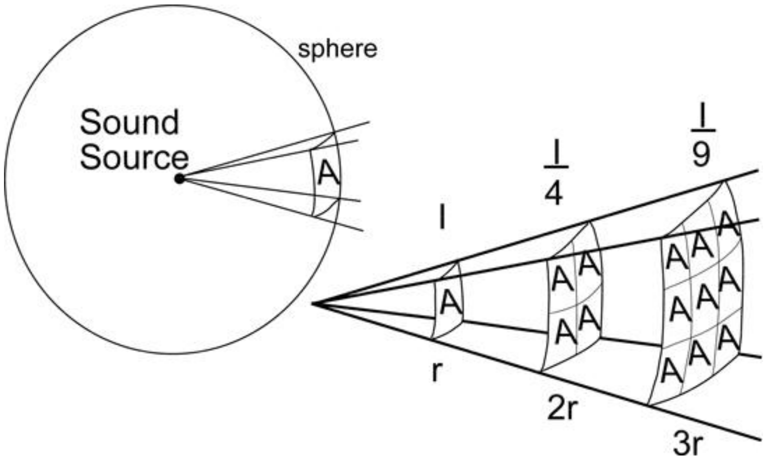


Fig. 4.10: Sound Spreading[27]

The sound intensity (I) decreases with the distance to source given that for a point source, energy spread out in all directions. Since energy is conserved and the area through which this energy is transported is increasing, the power (being a quantity that is measured on a *per-area* basis) must decrease. The mathematical relationship between intensity and distance is sometimes referred to as an inverse square law.

The intensity varies inversely with the square of the distance from the source. So if the distance from the source is doubled (increased by a factor of 2) then the intensity is quartered (decreased by a factor of 4). Similarly if the distance is multiplied by 10, the sound is 100 times less intense. Intensity and distance can be expressed as in equation 4.3.

[27] Image source: http://www.jiscdigitalmedia.ac.uk/audio/advice/the-physical-principles-of-sound

$$I = P / (4 \pi r^2)$$

Equation 4.3: Intensity of Sound

Where:

P = sound power [W];

π = 3.14;

r = radius or distance from source [m]).

In simple words, Intensity = Power / Area. Thus sound intensity is expressed in [Watt / metre square]. [4 π r^2] is the area of a sphere.

4.1.3.2. Sound Pressure

Sound Intensity and Sound Pressure are related as follows:

$$I = P^2 / \rho c$$

Equation 4.4: Relation between Sound Intensity and Sound Pressure

Where

p = sound pressure [Pa];

ρ = density of air (1.2 kg/m3 at 20°C);

c = speed of sound (331 m/s).

The Sound Pressure is the force of sound on a surface area perpendicular to the direction of the sound. It is also, at a given point, the pressure difference caused by a sound wave, compared to the average atmospheric pressure. Sound is usually measured with microphones responding proportionally to the sound pressure.

4.1.3.3. Loudness[28]

Loudness, referred to as Sound Intensity Level and Sound Pressure Level, is a subjective term describing the strength of the ear's perception of a sound. It must not be confused with Sound Intensity and Sound Pressure which designate objective quantities.

As known, the human perception of physical quantities is never absolute : for example, the difference in weight between a 2 kg object and a 1 kg object is perceived as greater than the difference between two objects of, for example, 51 and 50 kg, although we are dealing with a 1 Kilo difference. In the first case, the ratio between the 2 objects is 2/1 = 2, while in the second it is 51/50 = 1.02, which is far lower.

As we showed earlier, musicians call Pitch what in Physics is the frequency of sounds. Similarly, musicians use the Italian words Forte and Piano to indicate the differences of sounds' loudness, which relates to the amplitude of the sound wave. Both, Forte and Piano are called Dynamics. In music, dynamics means how loud or quiet the music is, or simply its level of loudness. In table 4.6 there are some dynamics:

Abbreviation	Italian word	English meaning
• pp	pianissimo	very quiet
• p	piano	quiet
• mp	mezzo piano	medium quiet
• mf	mezzo forte	medium loud
• f	forte	loud
• ff	fortissimo	very loud

Table 4.6: Dynamics Levels[29]

What we see in this table are variants of Piano and Forte. We can notice that they are purely subjective levels of sound since none quantitative nor measurable information can be obtained. However expert musicians know how to regulate the differences of dynamics when playing music. The reason is that the levels of the dynamics refer to how musical sounds are perceived by human ears. So, while Sound Intensity measures the quantity of energy carried by a sound, Sound Intensity Level describes how loud the sound is to the ear.

[28] The information of this subchapter is based on the Website: www.acousticalsurfaces.com/acoustic_IOI/101_12.htm

[29] Table source: http://simple.wikipedia.org/wiki/Dynamics_(music)

Humans have very sensitive ears capable of detecting sound waves of both very low and very high intensity. However, the human perception of sound with regard to different levels of intensity is nonlinear; the ear responds much more efficiently to sounds of very small amplitude than to sounds of very large amplitude. Because of the enormous non-linearity of the ear in sensing pressure waves, a nonlinear scale is convenient in describing the intensity of sound waves. For this reason the Decibel scale is used to indicate the sound loudness also referred to as Sound Intensity Level.

The decibel is defined as one tenth of a bell where one bell represents a difference in level between two intensities I, Io where one is ten times greater than the other. Thus, the sound intensity level is the comparison of intensity to another and can be expressed as follows:

$$\mathbf{L = 10 \log (I/I_0)}$$

Equation 4.5: Sound Intensity Level by Comparing Intensities

Where:

L is the sound intensity level in Decibels;

I is the intensity of an arbitrary sound wave measured in watts per square metre;

I_0 is the reference intensity corresponding to a level of 0 decibels, approximately the intensity of a wave of 1,000 hertz frequency at the threshold of hearing (about 10^12 watt per square metre).

The decibel scale is based on powers or multiples of 10. It is logarithmic. The result of this logarithmic basis for the scale is that increasing a sound intensity by a factor of 10 raises its level by 10 dB; increasing it by a factor of 100 raises its level by 20 dB; by 1,000, 30 dB and so on.

In other words, in the decibel scale:

The lowest sound that humans can hear (threshold of hearing) is assigned a sound level of 0 decibels (abbreviated 0 dB); this sound corresponds to an intensity of 1*10-12 W/m2.

- A sound that is 10 times more intense (1*10-11 W/m2) is assigned a sound level of 10 dB.
- A sound that is 10*10 or 100 times more intense (1*10-10 W/m2) is assigned a sound level of 20 db.
- A sound that is 10*10*10 or 1000 times more intense (1*10-9 W/m2) is assigned a sound level of 30 db.
- A sound that is 10*10*10*10 or 10000 times more intense (1*10-8 W/m2) is assigned a sound level of 40 db, and so on.

In the table 4.7 some familiar sounds with an estimate of their intensity and decibel level are listed.

Source	Intensity	Intensity Level	Number of Times Greater Than TOH
Threshold of Hearing (TOH)	1*10^-12 W/m^2	0 dB	10^0
Rustling Leaves	1*10^-11 W/m^2	10 dB	10^1
Whisper	1*10^-10 W/m^2	20 dB	10^2
Normal Conversation	1*10^-6 W/m^2	60 dB	10^6
Busy Street Traffic	1*10^-5 W/m^2	70 dB	10^7
Vacuum Cleaner	1*10^-4 W/m^2	80 dB	10^8
Large Orchestra	6.3*10^-3 W/m^2	98 dB	10^9.8
Walkman at Maximum Level	1*10^-2 W/m^2	100 dB	10^10
Front Rows of Rock Concert	1*10^-1 W/m^2	110 dB	10^11
Threshold of Pain	1*10^1 W/m^2	130 dB	10^13
Military Jet Takeoff	1*10^2 W/m^2	140 dB	10^14
Instant Perforation of Eardrum	1*10^4 W/m^2	160 dB	10^16

Table 4.7: Intensity and dB Level Estimation of Some Sounds[30]

The sound pressure level is also the comparison of one pressure to another. It is expressed as follows:

$$L = 20 \log (P / P_0)$$

Equation 4.6: Sound Intensity Level by Comparing Pressures

Where:
L is the sound intensity level in Decibels;
P is the pressure of a given sound wave measured in Pascal;
P_0 = 2*(10^-5) is the reference pressure corresponding to a level of 0 decibels, the lowest sound that we can hear.

[30] Table source: http://www.physicsclassroom.com/class/sound/u11l2b.cfm

Decibels cannot be added to obtain the level of loudness of a combination of sounds. Rather, the loudness level of a resultant sound can be done as follows:

When Two Decibel Levels Differ By:	Add the Following Number to the Higher Value:
0 -1 dB	3 dB
2 -3 dB	2 dB
4 - 9 dB	1 dB
10 dB or More	0 dB

Table 4.8: Resulting dB level by Combining Sounds[31]

<u>Examples:</u>

88 dB + 90 dB = 92 dB

75 dB = 81 dB = 82 dB

70 dB = 80 dB = 80 dB

[31] Table source: http://www.acousticalsurfaces.com/acoustic_IOI/101_12.htm

4.1.3.4. The Root Mean Square

Sound waves are periodic phenomena, what justifies their relative sinusoidal form. If we calculate the average value of a sine wave, it will unfortunately equal zero, since it rises and falls symmetrically above and below the zero reference. This will not tell us nothing about its amplitude, since low-amplitude and high-amplitude sine waves will appear equivalent. For this reason the quantity called Root Mean Square (RMS) is used to measure meaningfully the average amplitude of a wave over time.

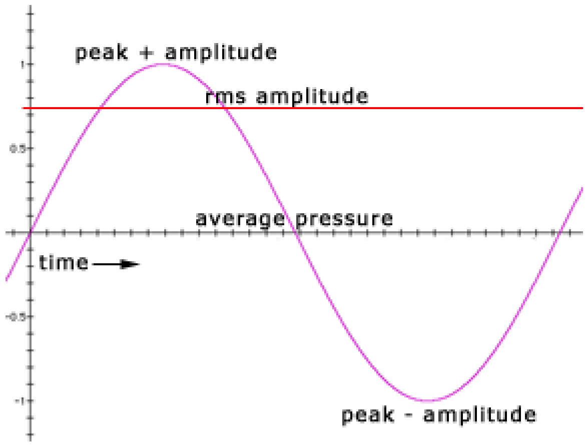


Fig. 4.11: Graphical Root Mean Square[32]

The Root Mean Square (RMS) is the square root of the arithmetic mean of the squares of a set of values, used as a measure of the typical magnitude of a set of numbers, regardless of their sign.
In the case of a set of *n* values

$$\{x_1, x_2, \ldots, x_n\} x_{\mathrm{rms}} = \sqrt{\frac{{x_1}^2 + {x_2}^2 + \cdots + {x_n}^2}{n}}.$$

Equation 4.7: Analytical Root Mean Square

Scientists often use the term Root Mean Square as a synonym for Standard Deviation and Quadratic Mean when they refer to the Square Root of the mean squared deviation of a signal from a given baseline or fit.

[32] Image source: http://www.indiana.edu/~emusic/acoustics/amplitude.htm

4.1.4. BEHAVIOUR OF SOUND WAVES

Sound waves travel from one point to another through the medium. During propagation, waves can be reflected, refracted, or diffracted by the medium or obstacles.

Reflection: a sound wave which hits a barrier is reflected when the sound is thrown back by the obstacle without absorbing it.

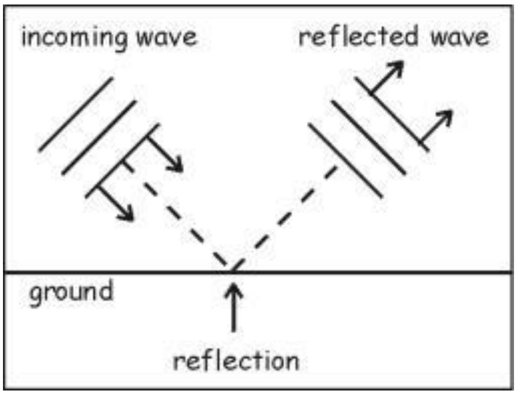


Fig. 4.12: Wave Reflection

Refraction: a sound wave is refracted when its direction changes in passing obliquely from one medium into another in which its wave velocity is different.

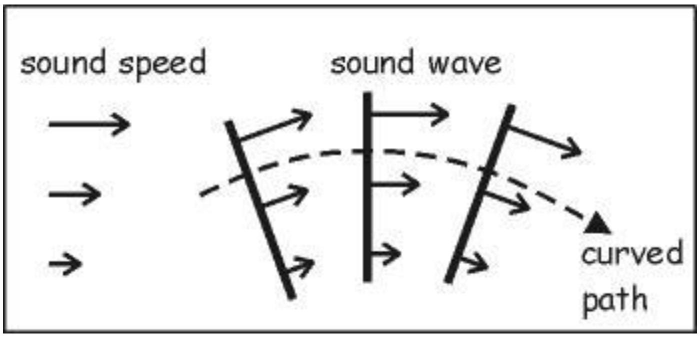


Fig. 4.13: Wave Refraction[33]

[33] Images source: http://home.kpn.nl/msalomons/sound.html

Diffraction: a sound wave is diffracted when a wave travels through a small hole in a barrier and bends around the edges.

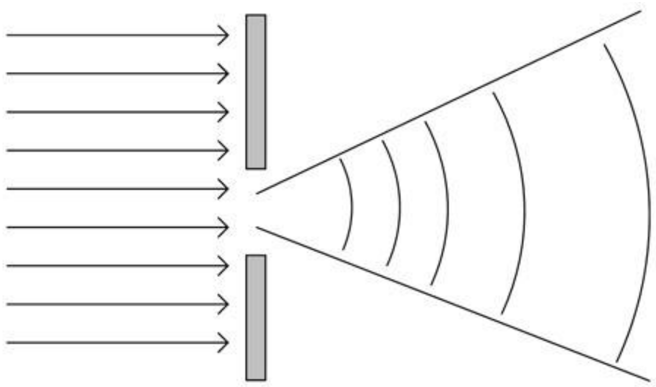


Fig. 4.14: Wave Diffraction[34]

Depending on the need of analysis, more behaviour of sound waves can be observed (e.g.: Sound Interference, the Doppler Effect, etc). In the frame of this project, we will focus on the sound diffraction as it illustrates how noises manage to go across road acoustic screens to reach protected people. This will be analysed in the next sub-chapter.

[34] Image source: http://gely.info/diffraction-des-ondes-a-la-surfacehtml/

4.1.5. ROAD ACOUSTIC SCREENS

Throughout the previous sub-chapters we have analysed the nature of noise which is the sound. In this one, we analyse how road acoustic screens work technically.

4.1.5.1. Definition[35]

A road acoustic screen is a structure built along a road to reduce significantly the level of noise resulting from traffic, in order to protect the health of people living in the surroundings.
Road acoustic screens are also referred to as Highway Noise Barriers.
"Noise barriers are solid obstructions built between the highway and the homes along a highway. They do not *completely* block all noise; they only reduce overall noise levels. Effective noise barriers typically reduce noise levels by 5 to 10 decibels (dB), cutting the loudness of traffic noise by as much as one half. For example, a barrier which achieves a 10-dB reduction can reduce the sound level of a typical tractor trailer pass-by to that of an automobile"

4.1.5.2. Constitution

The acoustic screens that can be seen besides roads comprise at least a frame and the body. The frame is the structure that is built to support the body or let us say, the acoustic screen itself. The frame is mainly made from concrete, iron or relevant alloys. It can be best seen on transparent acoustic screens.
The body of an acoustic screen can be fabricated from various types of materials (metal and metal alloys, polymers, ceramics and glasses, composite materials). The material used for the screen's body is very important though more factors count for the efficiency of the noise barrier. Materials are selected depending on their properties:

- Acoustic: how the noise is absorbed by the screen;
- Mechanical: how strong it stands or can resist to different actions;
- Economical: how much it costs;
- Aesthetic: how pretty it looks.

Picture 4.1: Road Acoustic Acrylic Glass Screen

[35] Quotation in this subchapter from Website: www.fhwa.dot.gov/environment/keepdown.htm on 13/05/2011

4.1.5.3. How road acoustic screens work[36]

Road acoustic screens reduce the sound which enters a community from a busy road by absorbing it, transmitting, reflecting it back across the road or forcing it to take a longer path. This longer path is called the diffracted path.

To understand how acoustic screens work, let us review how sound propagates.

If there is none obstacle between the source of the sound and the person who hear it (the receiver), sound or noise travels in straight line.

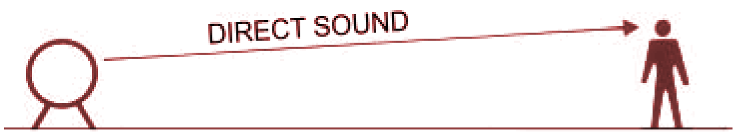


Fig. 4.15: Sound Travel Without Obstacles

If the noise meets an obstacle or barrier in its way, the case of acoustic screens, it manages to reach the listener through Diffraction. We have explained about diffraction earlier. Depending on the material, the screen can absorb part of the noise or eventually let another part go through it. We talk about Transmission when the noise goes across the barrier by piercing it. By reflection, another part of the noise is sent back by the acoustic screen.

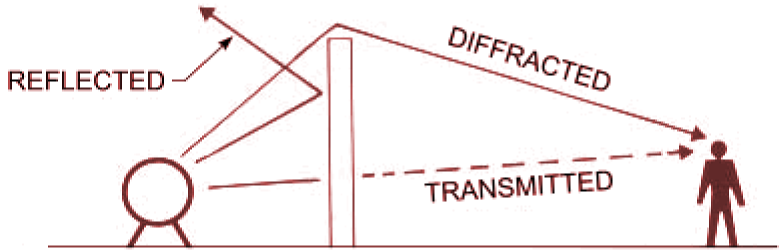


Fig. 4.16: Sound Travel With a Screen as Obstacle

The noise that is transmitted and reaching the receiver is significantly reduced by the barrier. So most noise reaching the receiver do so by bending over the top of the barrier and around the ends of the barrier, therefore by diffraction. The noise diffracted over the top of a barrier will be attenuated by increasing barrier height. Noise diffracted around barrier edges is attenuated by increasing barrier length or by turning the ends of the barrier towards the source.

[36] Source of Information of this Subchapter from: http://www.industrialacoustics.com/

The acoustic screen located between the source and the receiver creates a Shadow Zone. The straight path from the source over the top of the barrier forms the boundary of this zone. All receivers located in the shadow zone will experience some sound attenuation depending on the diffraction angle *θ*.

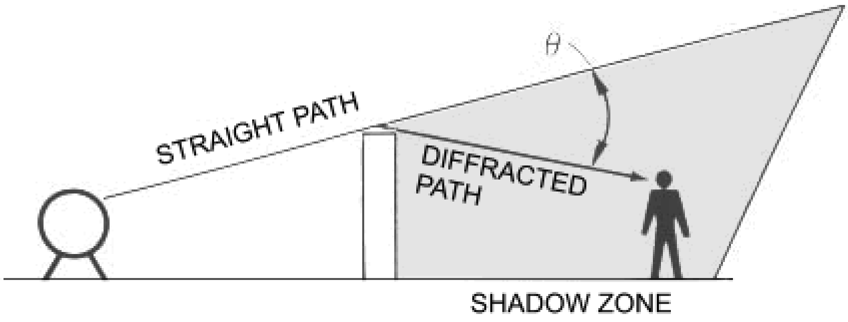


Fig. 4.17: Shadow Zone[37]

When the angle *θ* increases, attenuation due to the barrier also increases. *Θ* will increase if barrier height increases or if source or receiver is placed closer to the barrier. Mathematically, the geometric relationship between source, barrier and receiver can be related to barrier attenuation and frequency by means of Fresnel Number N.

$$N = 2\delta / \lambda$$

Equation 4.8: Fresnel Number

Where:

λ = Wavelength of sound

δ = A + B –d

[37] Images source: http://www.industrialacoustics.com/uk/reference/bluebook/c_-_partial_barriers.htm

4.1.5.4. Illustrations[38]

This drawing shows how noise attenuation increases with the acoustic screen's height.

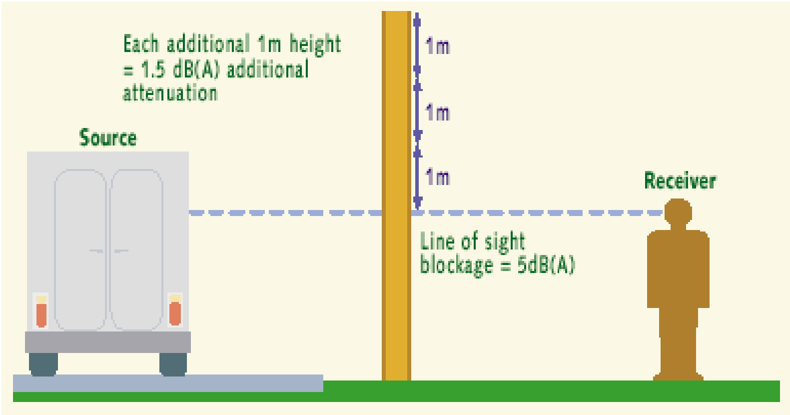


Fig. 4.18: Noise Attenuation with Screen's Height

This drawing features how acoustic screens work.

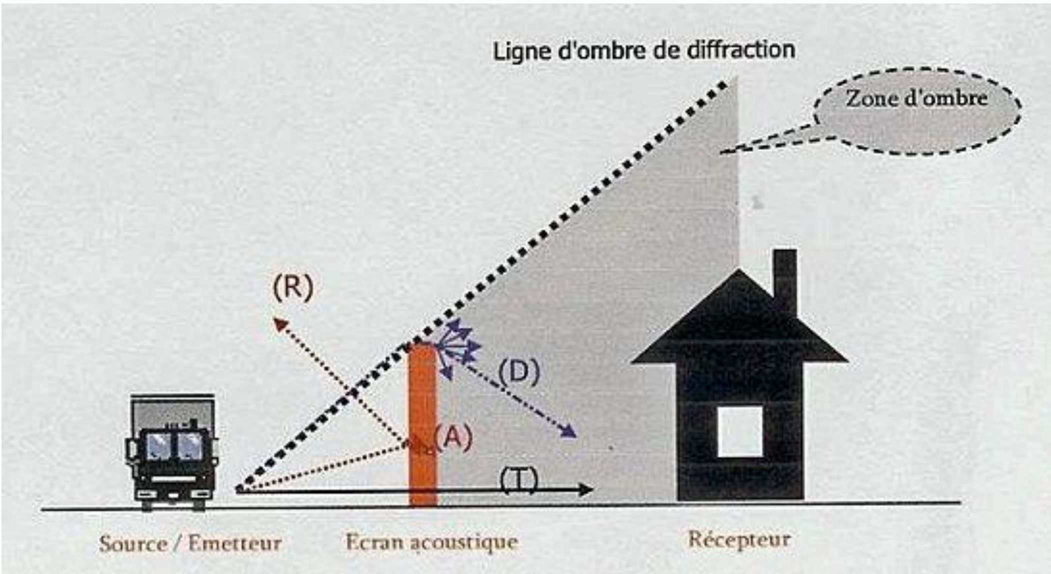


Fig. 4.19: Acoustic Screens Work

There is a source of noise (the truck), a road acoustic screen and the receiver of the noise (the home); where:

(T): part of the noise is transmitted through the screen;

(A): part of the noise is absorbed by the screen;

(R): part of the noise is reflected by the screen;

(D): part of the noise is spread throughout the shadow zone by diffraction.

---

[38] Images sources of this subchapter: http://www.artusaindustries.us/Noise_Barriers.html

4.2. Proposals

After the understanding the important theoretical aspects of sound, the next step was to determine how the experiments will be done, it means, how we shall simulate the system “sound source + acoustic screen + receiver”.

At this step, every member of the group had to provide ideas. Outcomes were presented in the form of suggestions to the supervisor then discussed during a meeting. The factor taken into account was mainly feasibility. This is the reason why some suggestions could not be considered.

Below there is the summary of the main suggestion.

As a starting point and because of the main topic of this project, the road acoustic screens where the core of developed suggestions. According to our previous knowledge they were one of the most effective and cheapest passive options to reduce the level of noise in traffic areas, so the first ideas started from this solution.

The most common suggestion was around the possible materials we could test in order to compare them and to analyze their acoustic properties and may be, able to absorb some traffic pollution. Following some commented materials for the panels are listed:

- Aluminium
- Plastic
- Styrofoam
- Leather
- Cork
- Acrylic Glass
- Plexa
- Polyethylene

Of course also the frame and the whole structure of the screens were taken into account, which should be cheap, easy to install wherever and especially with easy maintenance as well as resistant enough to stand the bad weather conditions, like wind, hard rain or snow.

Another common aspect was to integrate as much as possible these screens in the nature, especially in the speedways. As a last resort, to create a natural screen wherever it could be possible with trees, like fir trees or some kind of capable bushes to stand the bad weather conditions which could have even a better ecological impact on the environment.

In city centre or areas with no enough space the screens could be at least recovered with vegetation (ivy) with the capacity to absorb some noise and traffic pollution.

Obviously the design of the installation of the screens structures should take care about the local flora and fauna, having small spaces in the bottom for animals preventing them to go directly into the road.

On another hand, road acoustic screens could even have an advertising or artistic function, if it doesn't affect their acoustic properties. The classic screens could be covered with advertisements or traffic informative reminders. Also they can be dedicated for urban artists to expose their work, for example, for graffiti painters, so they could have their own space instead of painting throughout the urban centre indiscriminately.

Finally some other ideas, which weren't related directly with the road screens, are also reported such as the possibility to recover the frontage of some buildings in the most possible discrete way to reduce the direct penetration of noise in the houses, or to build a kind of tunnel by recovering both sides of the road in order to keep better the noise. This option shouldn't be completely closed in order to let the exhaust smoke of vehicles go to the atmosphere.

Concerning to completely new infrastructures constructions, the roads could be built directly in a deeper level in the ground, if the underground conditions allow it, so that the road would be some meters lower than the pavement (but not covered). In this case it would be necessary to set up handrail in the pavement and some bridges for pedestrians to connect both sides of the street or road.

Finally it was thought about the road itself which could be a good complementary allied in order to reduce the level of noise. In the renovations of the road pavement specific asphalt called "noise reducing pavements"[39] could be used.

Apart of this, the law should be stricter in controlling the cars' level of noise.

[39] Information about Noise Reducing Pavements on website:
http://www.innovatieprogrammageluid.nl/data/files/algemeen/Noise%20reducing%20pavements%20in%20Japan.pdf f

4.3. Description

In this subchapter a brief description of the laboratory and the anechoic room, as well as the used instrumentation and screens will be found.

4.3.1. Laboratory

Picture 4.2: The Institute of Turbo-Machinery

The experiments have taken place in the laboratory with the aim to determine the factors on which efficiency of an acoustic screen depends. In this third part of our technical analysis we connect the theories above to practical situations through experiments.

The work was to be done in laboratory because only there are necessary installations to conduct experiments. Our work of measurements was done in the anechoic room which is in the laboratory of Acoustics, located in the Institute of Turbo-machinery (Instytut Maszyn Przepływowych), 219/223 Wolczanska Street, 90-924 Lodz; in the Technical University of Lodz.

Picture 4.3: Anechoic Room

The anechoic room is a noise isolated room, in where all the walls, roof and ground are covered with an absorbing noise material that makes from this room the perfect one to test sound devices, microphones, to record music or to make any kind of sound-related experimentations thanks to a very complete recording as well as noise generator equipment and all the necessary software to compute it. Also the humidity and temperature are regulated.

4.3.2. Instrumentation

In this chapter the electronic devices and protection stuff to perform our measurements are listed below. The technical specifications of some recording hardware are described in the annexes.

4.3.2.1. Ears protectors

Picture 4.4: Ears Protectors

They are essential in this kind of measurements. As far as we know that noise is damaging for human healthy, is important to keep protected from frequencies we have been exposed in the laboratory during the recordings.

4.3.2.2. Medium-Range Speaker (especially good for 500Hz up to 8kHz)

Picture 4.5: Medium-Range Speaker

It is our source of noise simulating traffic noise. It has been always in the same distance from the screen, in the same way that roads and road acoustic screens remain parallel in the same distance along the road stretch.

4.3.2.3. Microphone 1/2" Bruel & Kjaer

Picture 4.6: Microphone 1/2" Bruel & Kjaer type 4191

The microphone has been behind the screen simulating the receiver of noise in a real situation (buildings, pedestrians, etc.). It has been installed at different heights and at different distances from the screen to analyze better these factors.

4.3.2.4. WaveBook

Picture 4.7: WaveBook

WaveBook/516E 16-bit 1MHz Data Acquisition System with Ethernet Interface

4.3.2.5. Sound Generator

Picture 4.8: Sound Generator

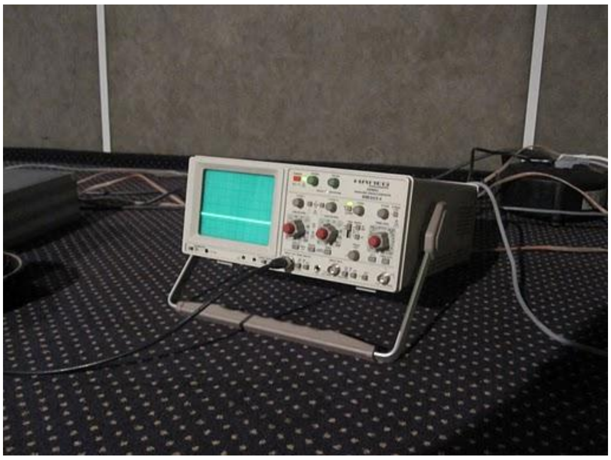
Agilent 33220A 20MHz function/arbitrary waveform generator

4.3.2.6. Amplifier

Picture 4.9: Pre-amplifier Bruel&Kjer 2669C

CAMBRIDGE AUDIO azur 640A integrated amplifier

4.3.2.7. Oscilloscope



Picture 4.10: Oscilloscope

HAMEG INSTRUMENTS 35MHz analogue oscilloscope HM303-6

4.3.2.8. Nexus connected via WaveBook

Picture 4.11: Nexus

Bruel&Kjer nexus conditioning amplifier

4.3.3. Screens

After discussing the issue, we have decided to perform experiments with the panels that we have been able to find. The panels are made from different materials, what is important for our simulations. These are materials to be used as acoustic screens during experiments in laboratory. The screens are the following:

Picture 4.12: Red Screen

Rectangular screen dimensions: 1.5 m x 1 m, with plates PD2 (sound isolation) with a thickness of 20 mm. The inclination of the panel is adjustable.

Picture 4.13: Foam Screen

Screen constituted by 4 foam panels with a thickness of 200mm.

Picture 4.14: Plastic Screen

Rectangular screen dimensions: 1.5 m x 1 m, with the acoustic felt of a thickness 17 mm, Screen had two deflected wing dimensions 0.5mx 1 m.

Picture 4.15: Leather Screen

Screen shaped open from one side of the rectangular dimensions: height of 1 m and a width of 1.5 m, with the acoustic felt of a thickness 17 mm and rubber thickness 2mm

4.4. Experiments

Our laboratory installations comprised three main systems: setting, simulation and computing. Altogether we had ten (10) frequency settings to run for each of ten (14) simulations, making the hundred (100) measurements that we have done. A single measurement was therefore a combination of a frequency and a simulation.

4.4.1. Demo Recordings

Picture 4.16: Calibrating Equipment

Before starting the real measurements, some time was spent in the anechoic room recording some "demo" tests in order to become familiar with the different devices, to calibrate the software, to learn how to manage it and to acquire practice enough to develop later the real measurements without surprises.

4.4.2. Setting

Every simulation was measured on each of the 10 steps of the sound which are frequencies. As we showed earlier, frequency relates to the pitch of a sound. We have taken into account octaves to determine the frequencies of measurements. The frequencies are the following in Hertz:

Nr.	Frequency [Hz]	Nr.	Frequency [Hz]
1	31.5	**6**	1000
2	63	**7**	2000
3	125	**8**	4000
4	250	**9**	8000
5	500	**10**	16000

Table 4.9: Chosen Octave Scale

4.4.3. Simulation

Simulation can be defined as the act of imitating the behaviour of some situation or some process by means of something suitably analogous, especially for the purpose of study or personnel training.

We had to simulate the system "noise source + acoustic screen + noise receiver" in order to make it possible to study in laboratory where relevant installations are found.

Every simulation comprised:

- a source of noise: the loudspeaker;
- an acoustic screen;
- A noise receiver: the microphone.

The purpose of our work in laboratory was to find out the factors on which efficiency of acoustic screens depends. So we have taken into account the following different factors:

- distance between the acoustic screen and the microphone;
- height of the microphone;
- angle of inclination of the acoustic screen;
- material of acoustic screens

4.4.4. Configurations

We have performed (9) simulations based on the factors quoted above, including one simulation without acoustic screen (in free air). The simulation in free air is necessary for comparing the level of loudness (see later). Altogether that makes ten (10) simulations as follows:

f	screen	distance	height	angle	Parameters, which change
1	x	1	0,5	90	Reference
2	red	1	0,5	90	Distance between the panel and the microphone
3	red	0,5	0,5	90	
4	red	1,5	0,5	90	
5	red	1	0,5	105	Angle of the panel
6	red	1	0,5	75	
7	red	1	0,5	90	Height of the microphone
8	red	1	0,2	90	
9	plastic	1	0,5	90	Material of the panel
10	foam	1	0,5	90	

Table 4.10: Tested configurations

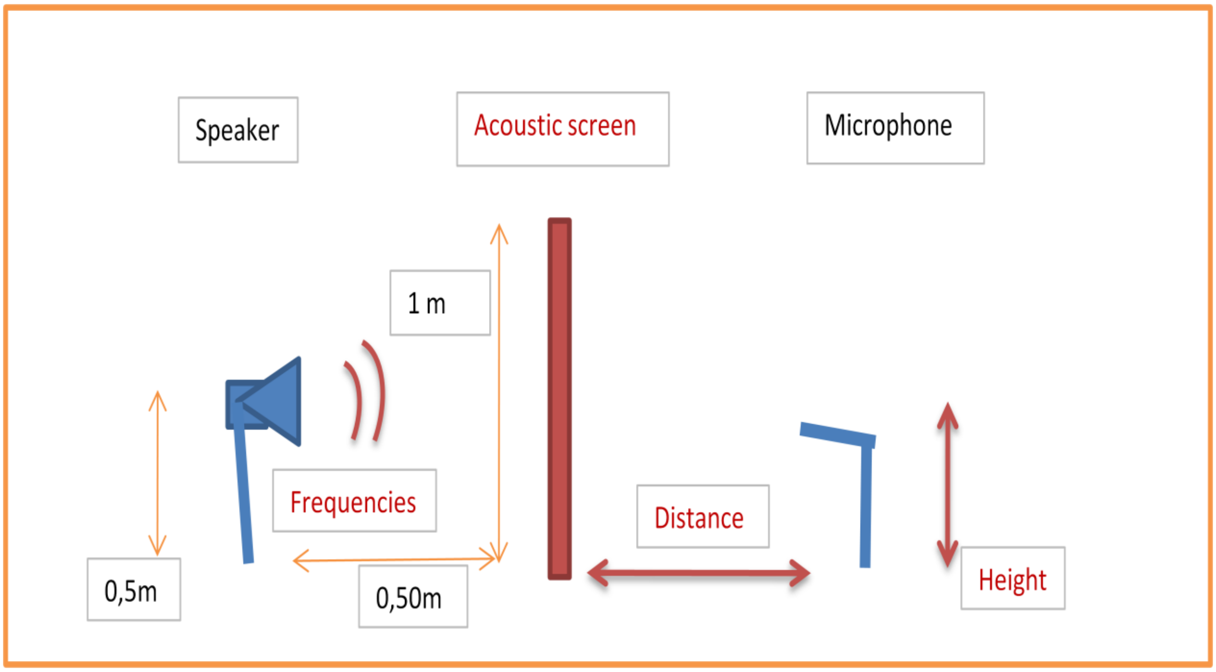


Fig. 4.20: Disposition of the instruments

4.4.5. Data Processing

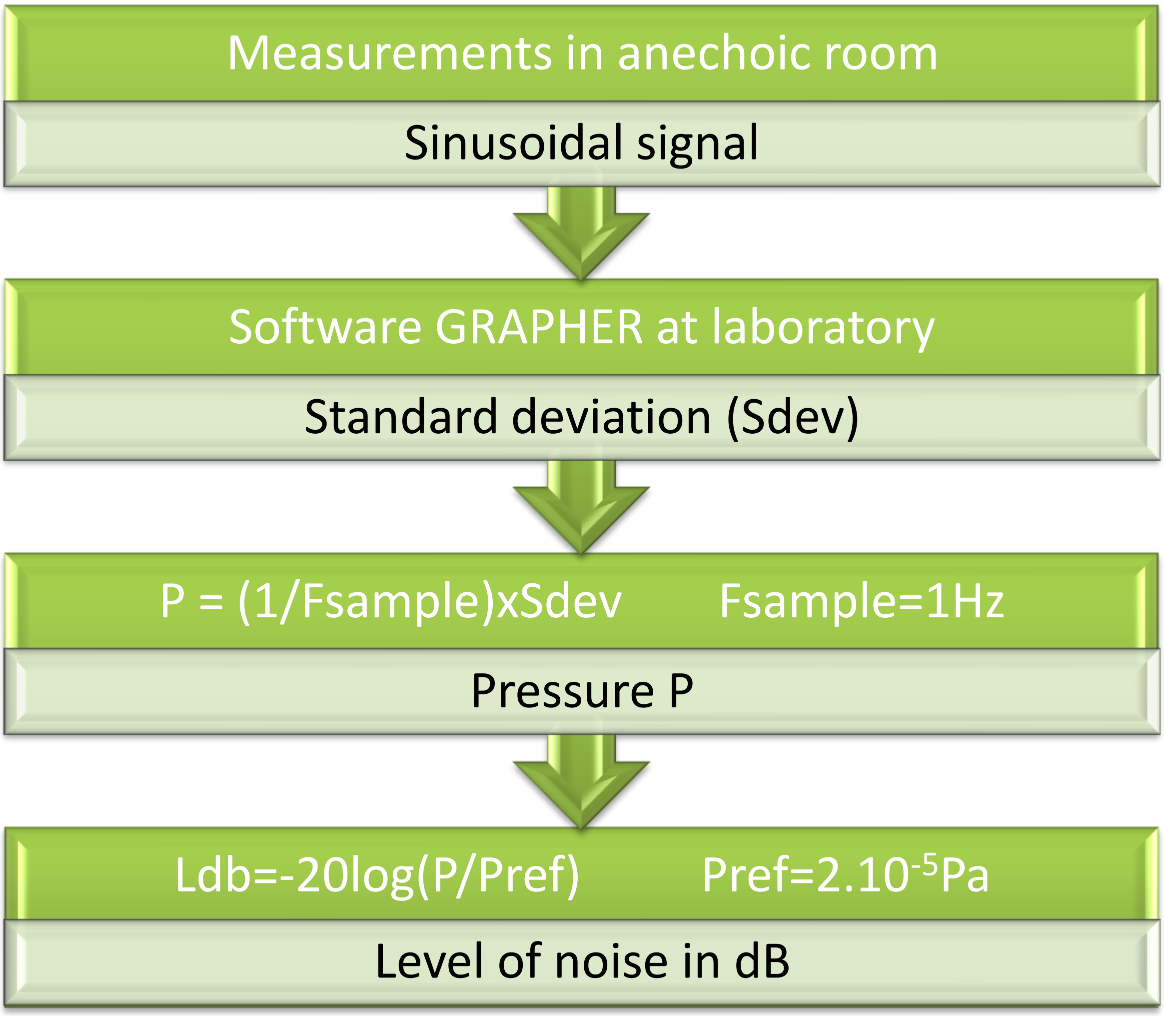


Fig. 4.21: Process Scheme

As result of our measurement, we obtain a file with thousands of points.

These points represent a sinusoidal signal for each frequency tested.

With the help of the software called GRAPHER, we obtain the Standard Deviation for each signal.

Then, with a mathematic formula using the sample frequency (F_{sample} = 1Hz), we transform the standard deviation into a pressure.

Finally, with another mathematic formula using the reference pressure ($P_{ref}=2.10^{-5}$Pa), we transform the pressure into a decibel data.

4.4.6. Results

4.4.6.1. Root Mean Square values

f \ n°	1	2	3	4	5	6	7	8	9	10
31,5	0,0779	0,0354	0,0455	0,0492	0,0680	0,0311	0,1090	0,0554	0,0459	0,0262
63,0	0,0885	0,0383	0,0400	0,0519	0,0578	0,0387	0,0891	0,0583	0,0433	0,0257
125,0	0,0693	0,0303	0,0454	0,0456	0,0487	0,0377	0,0622	0,0303	0,0414	0,0267
250,0	0,0704	0,0344	0,0415	0,0447	0,0475	0,0366	0,0620	0,0244	0,0494	0,0243
500,0	0,0804	0,0348	0,0401	0,0458	0,0587	0,0397	0,0660	0,0348	0,0442	0,0239
1000,0	0,0622	0,0332	0,0420	0,0467	0,0640	0,0262	0,0715	0,0232	0,0437	0,0255
2000,0	0,0556	0,0398	0,0461	0,0482	0,0530	0,0327	0,0890	0,0298	0,0470	0,0293
4000,0	0,0576	0,0400	0,0419	0,0476	0,0443	0,0357	0,0716	0,0400	0,0413	0,0271
8000,0	0,0525	0,0389	0,0420	0,0430	0,0533	0,0394	0,0603	0,0289	0,0461	0,0274
16000,0	0,0516	0,0316	0,0479	0,0456	0,0439	0,0294	0,0538	0,0216	0,0450	0,0239

Table 4.11: Root Mean Square Values

4.4.6.2. Final values in decibel dB

f\n°	1	2	3	4	5	6	7	8	9	10
31.5	71,81	64,96	67,14	62,82	70,63	63,82	74,73	68,85	67,22	62,35
63	72,92	65,63	66,03	63,29	69,21	65,74	72,98	69,29	66,70	62,18
125	70,79	63,60	67,12	62,17	67,72	65,52	69,85	63,60	66,32	62,50
250	70,94	64,70	66,34	61,99	67,52	65,25	69,82	61,71	67,86	61,68
500	72,08	64,80	66,03	62,19	69,35	65,95	70,37	64,80	66,88	61,54
1000	69,86	64,40	66,45	62,36	70,11	62,34	71,07	61,28	66,80	62,11
2000	68,88	65,98	67,25	62,64	68,47	64,28	72,97	63,47	67,43	63,31
4000	69,18	66,01	66,42	62,53	66,90	65,03	71,08	66,01	66,30	62,65
8000	68,38	65,79	66,44	61,65	68,51	65,88	69,58	63,21	67,25	62,73
16000	68,24	63,96	67,59	62,17	66,83	63,36	68,60	60,65	67,04	61,54

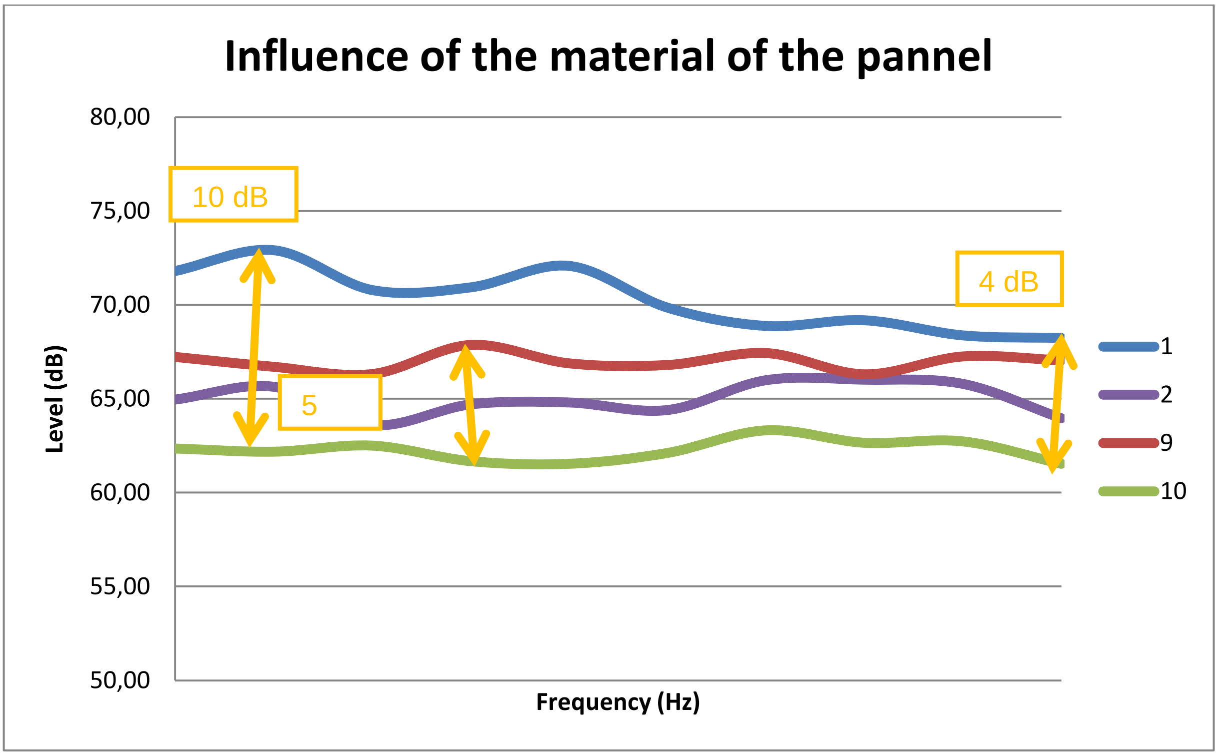
Table 4.12: Volume Level in dB[40]

[40] Tables source: Own elaboration

4.5. Analysis

4.5.1. Influence of the material

We choose to test three types of materials; you can see the result on the plot.



Plot 4.1: Influence of the material

1: without screen

2: the red screen

9: the black screen

10: the foam screen

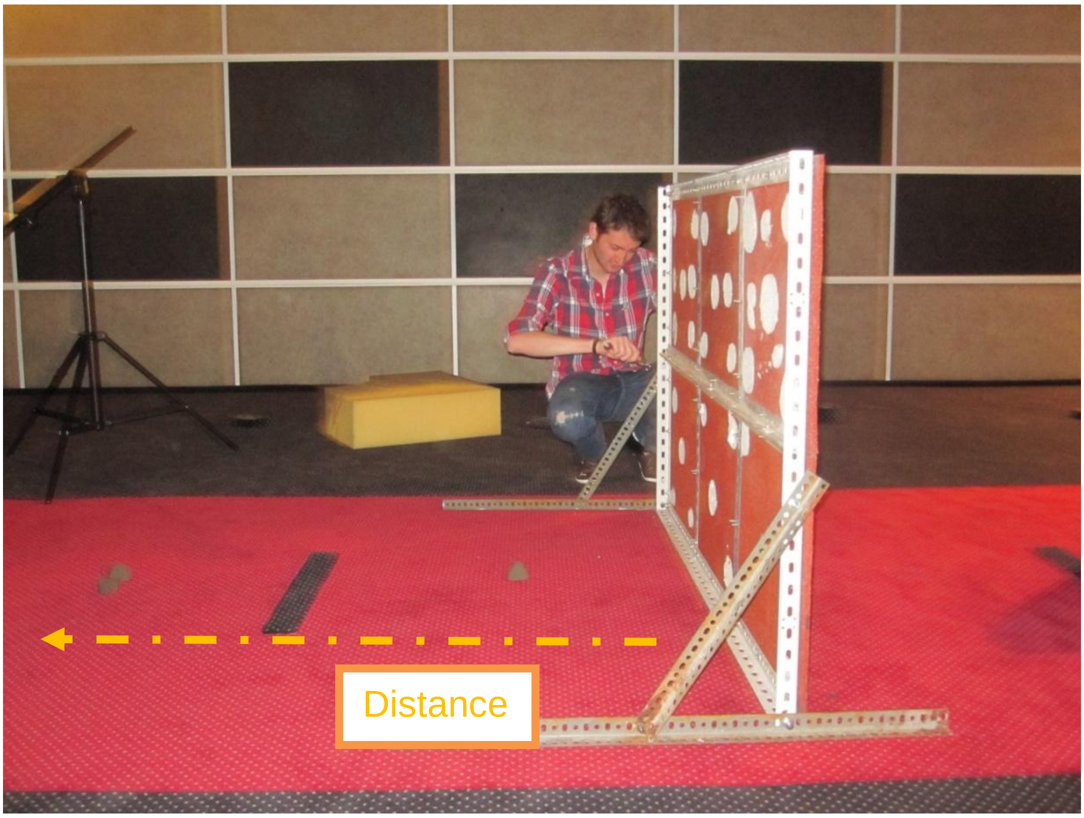
There is a maximum of five decibels between the best and the worst acoustic panel.

The plot shows that the worst one is the plastic screen and the best is the foam panel because plastic don't absorb noise contrary to foam.

Using the foam screen, we reduce the level of noise by ten decibels for the low frequencies but only four decibels for high frequencies.

So, we can say that the efficiency of the panel depends of the type of frequencies.

4.5.2. Influence of the distance between the panel and the microphone



Picture 4.17: Variation of the distance between panels and microphone

When we change the distance, there is an attenuation of the level depending the distance.

Indeed, in free space, when the microphone moves away from the source, the noise level is attenuated. We can use this formula to calculate this attenuation:

$$PB = PA - 20 \log \frac{DB}{DA}$$

Equation 4.9: Noise attenuation

Where:

PA: acoustic pressure in A

PB: acoustic pressure in B

DA: distance from A to the source

DB: distance from B to the source

This law is reflected in the chart 4.22, taking as reference the noise level measured at 1 meter from the source.

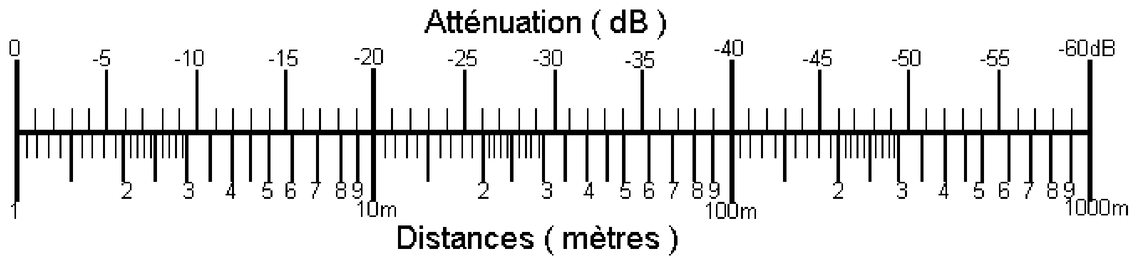
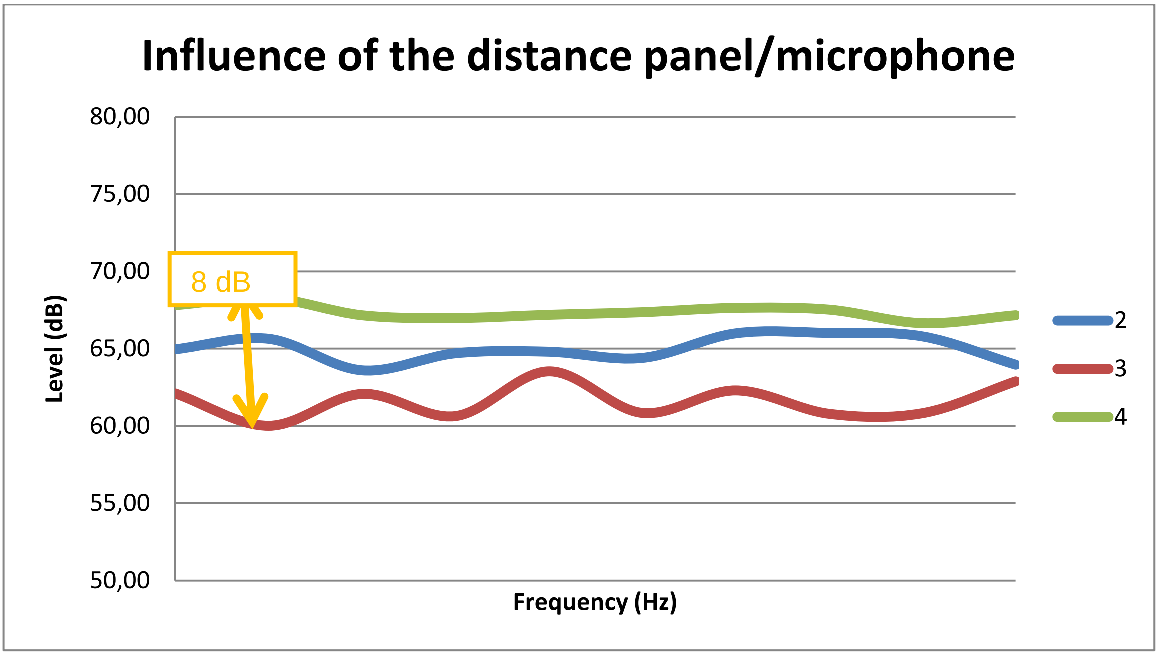


Fig. 4.22: dB attenuation according to distance[41]



Plot 4.2: Influence of the distance between panel and microphone

2: distance of 0,5m

3: distance of 1m

4: distance of 1,5m

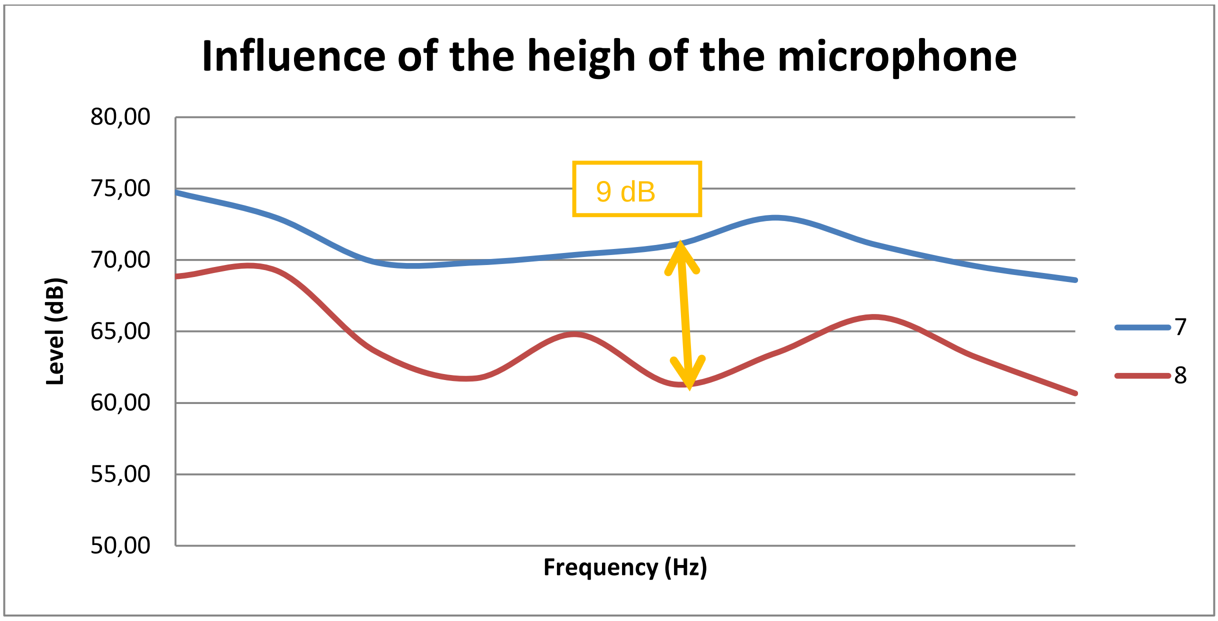
The plot shows that the more the microphone is near the screen, the less the level of noise is high. The higher difference between these three measurements is height decibel and the level of noise does not depend on the frequencies because the curves are almost constants.

[41] Image source: http://francismerck.free.fr/technique01.html#ancre55849

4.5.3. Influence of the height of the microphone

Picture 4.18: Microphone

We tested two different heights: 20cm and 50cm



Plot 4.3: Influence of the height of the microphone

7: height of 50 cm

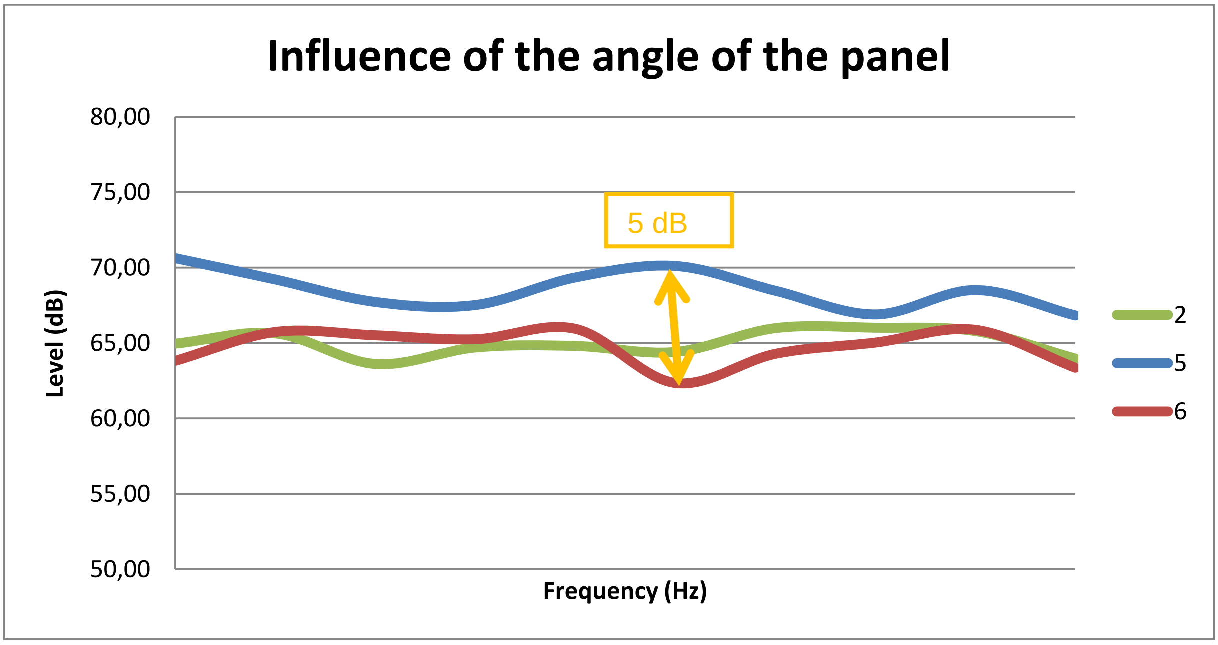
8: height of 20 cm

There is a mean different of seven and a maximum of nine decibels between these two measurements. The height of the microphone is an important parameter so before installing acoustic panels people have to find the good high of the screen. It can be in function of the height of building to protect.

4.5.4. Influence of the angle of the panel

Picture 4.19: Testing inclination of the screens

The classic acoustic panels, which is already install on the roads, are all vertical.
We found it is interesting to test several inclinations of the panel and see its influence
We tested three angles: 75°, 90° and 105°



Plot 4.4: Influence of inclination of the panel

2: 90°
5: 75°
6: 105°

As you can see on the plot, the more efficient angle is 75°.

The main difference between the best and the worst values is only five decibels so the angle of the panel has a small consequence. That's why, constructors of acoustic panels use vertical screens (it may be easiest to install so cheaper to install)

5. PROMOTION STRATEGY[42]

5.1. Promotion and Communication

For a potential customer or client (individual, company, organization, government) to acquire or purchase a product that he needs or desires, no matter if it is a good, service, idea, place, person or any combination of them, he requires to: 1) know its existence, 2) feel convinced to buy that product and 3) remember that it exists. Therefore, to achieve that potential customers buy our product (which obviously has to be of good quality, satisfying needs and desires, has a price that customers are willing to pay and be available in the right place and time), is essential to conduct a series of activities adequately communicated to those potential clients the existence of this product and persuaded to buy it. And to achieve these goals, we use one of marketing tools: Promotion strategy.

Therefore we can define promotion as: the key of marketing which the company seeks to convey the qualities of their product to their customers so that they will be encouraged to buy, therefore, is the way of transmitting information.

[42] The theoretical part of this chapter is own elaboration based on additional lectures of Marketing given by M. Grębosz, Jobber D., Fahy J.: *Foundations of Marketing*. McGraw-Hill Education. Berkshire 2003, Kotler Ph., Amstrong G.: *Principles of Marketing*. Prentice-Hall International Editions. New York 1994, Palmer A.: *Principles of Marketing*. Oxford University Press. New York 2000.

5.2. Tools of Promotion

The promotion has specific objectives such as: inform, persuade and remind the client the existence of our product and services.

The promotion includes a set of tools such as advertising, sales promotion, public relations, direct marketing, personal selling and experiences to achieve our objectives.

Then we will see the items available to each of these tools:

- Advertising
- Public Relation
- Events and Experiences
- Personal Sales
- Direct Marketing
- Sponsoring

5.2.1. Advertising

Print ads, radio and TV, packaging, cartoons, pamphlets, posters and leaflets, directories, billboards, audiovisual materials.

5.2.2. Public relation

Press releases, speeches, seminars, annual reports, grants, publications, community relations and company magazine.

5.2.3. Events and experiences

Sporting events, entertainment, art exhibitions, causes, factory visits, activities on the street.

5.2.4. Personal Sales

They are such as sales representative, sales meetings, incentive programs, exhibitions, fairs and trade shows.

5.2.5. Direct Marketing

Catalogues, mail messages, telemarketing, copra internet, TV sale, fax messages, email and voice mail are different ways of direct marketing.

5.3. Promotion planning

The promotional process it´s divided in the next steps:

5.3.1.1. Definition of promotional items

Decision on the ultimate goal of promotion and on organizational performance wanted.

5.3.1.2. Definition of types of promotion

Much depends on the position in the chain supplies. It can be informative promotion or sales promotion.

5.3.1.3. Definition of the tools of promotion

A. Choice of tools according the budget
B. Choice of tools according the type of final customer
C. Choice of tools according the role of distributors
D. Choice of tools according the objectives of promotion

5.3.1.4. Definition of the Promotional Stimulus

Achieving expected results, taking into account the relationship between the incentive and the product. We must also take the stimulus size and cost.

5.3.1.5. Definition of the Promotional Process

The most important point is the conditions of participation, taking into account the incentive distribution and duration of the promotion.

5.3.1.6. Physical Organization of the Promotion

It seeks to improve the capacity and speed of attention, which in turn will improve the distribution. It can be taken as a prates of the promotion and giving special treatment to advertising.

5.3.1.7. Implementation of the Promotion

Problems occur due to delays in the preparation that may affect the launch delays.

5.3.1.8. Control Promotion

Analysis was performed on the promotion process and the results of the promotion.

5.4. Members of Decision Making Process in our case

Our products, acoustic screens, is not a product that can be sold to any consumer. It requires a need creation, i.e., consumers and buyers understand that they need such product, either for their own consumption or not. Therefore we had performed a study reflected in the table 5.1, where we can see who can be our consumers and buyers. We have differentiated five groups according their importance in the process of purchasing our product.

	Neighbors	Drivers	People who build the road	Administrations (government, minister...)	Technical expert	Ecological organization
Initiator	x	x		x	x	x
Influencer	x				x	x
Decider			x	x		
Buyer			x	x		
Consummer	x					

Table 5.1: Decision Members

5.4.1.1. Initiator

First of all we have to decide who can initiate the demand for our product, those who want our product. With them begins the possibility of selling our product. Groups that can make game here are the neighbours, drivers, administrations, technical experts and environmental organizations. They all have the power to sue and demand the use of our products for safety, health or control but in our opinion the strongest are neighbours and government. With neighbours we refer to the power of society to demand a service when they consider it necessary for the development of life. And the administration that will look down or force to request our product due to the social demand that has the support of the other groups. The government has also to respect the European Union Directives, so the administration can force the introduction of acoustic screens.

5.4.1.2. Influencer

Once initiated and created the need for our product, the next step is the power of the groups that have the ability to influence the purchase decision. The most influential groups are neighbours and environmental organizations. Both can force to purchase the product with protests, demonstrations and complaints about the need for the use of acoustic screens. These actions can come strengthened by the support of experts who advise their use.

5.4.1.3. Decider and Buyer

In this part we find those who take the decision to purchase our product. Both, government and private companies sue our product due to the influence and the need created by the others groups. Because they are buyers, they have the power to decide to buy or not our product.

5.4.1.4. Consumer

As we can see the buyer not always enjoys the product. In this case, the neighbours will be consumers mainly those that requested it.

5.5. Promotion Strategy for Acoustic Screens Producers

To develop a good strategy for promoting, the most important thing we´ve done is identify the needs of each group in order to create the ideal way to convince them to purchase our product.

5.5.1. Target Market Needs

5.5.1.1. Neighbours

They want the less noise as possible. They want to be listened, to be understood, to see an acoustic panel adapted with theirs environments, to care their health, to feel protected.

5.5.1.2. Administration

They want to apply the laws and European directive, to satisfy the citizens, to spend less money as possible, to install the panels as quickly as possible and to have the minimum possible maintenance. The panels have to be safe for the drivers.

5.5.1.3. Private construction companies

The objectives are the same like for the administrations; they want the best product with good price.

5.5.1.4. Ecological organization

They want to preserve the environment and introduce the acoustic screens because they have a minimum visual and ecological impact.

5.5.1.5. Experts

They want a new product with the best material to keep noise.

5.5.2. Tools of promotion for different groups

Once identified the needs, we must think about how we convince them, that our product is necessary. We decided that the most interesting groups for us are neighbours, private construction companies and public administration. So we have created the following tools of conviction.

5.5.3. Tools

5.5.3.1. Public administrations

We offer a fair budget offering a good product. We have the best project in the selection process, our panels are conform to European standards, show that neighbours, ecological organizations are happy after using our panels we can collect theirs feedbacks, our panels are the cheapest on the market, the installation is very easy and quick, it's not necessary to be an expert to install our panels (so the municipal employees can do it). The maintenance is very easy and quick.

To promote our products we prepare the commercials support materials and we organize the conference for the employees of public administration concerning the noise problem and connected with presentation of our products.

5.5.3.2. Private companies

To promote our products we use the same tools that in the case of the public administration. We prepare the commercials support materials and we organize the conference for the employees of public administration concerning the noise problem and connected with presentation of our products. We participle also in the fair and we use also the support of the sales representatives.

The plan of conference is the following:

NATIONAL CONFERENCE OF NOISE AND ROAD ACOUSTIC SCREENS

Introduction

The National Conference of Noise and Road Acoustic Screens held in Lodz (Poland) from 5 to 13 of June 2011. Delegations from 10 cities are participating in the awareness for the reduction of noise pollution through the use of acoustic screens.

Part 1: Preamble

The Preamble presents an overview of the main issues discussed at the National Conference of Noise and Road Acoustic Screens.

Part 2: Principles

During this session, we establish a careful balance between the real problem that is noise pollution and the need to use acoustic screens.

Part 3: The noise problem

The presentation of the:

- Means of control of the main sources of noise
- need to reduce noise pollution
- diseases caused by noise.

Part 4: Relationship among population, noise and road screens

The presentation of the problems of:

- Health of citizens.
- Quality of life.

Part 5: Road acoustic screens

The presentation:

- How does it work.
- The need for an acoustic screen.
- The benefits of using an acoustic screen.

- Technical properties of the screens.

Part 6: Products

- Different types of screens.
- Installation and maintenance.

5.5.3.3. Neighbours

To promote the acoustic screens between the neighbours which are the influencers and initiators of decision making process, we propose different billboards with a same message: Noise is harmful. Road acoustic screens are useful.

Fig. 5.1: Billboard 1.A

Fig. 5.2: Billboard 1.B

Fig. 5.3: Billboard 2

Fig. 5.4: Billboard 3

Fig. 5.5: Handout

6. ECONOMICAL ANALYSIS

Literally, a product is anything that is produced. However this definition does not suit for the realities of business. Let us consider for example a ventilator. The draught is produced from the mechanical effort, but the air produced cannot be called "product" though it is the result of a process. More factors must therefore be taken into account beyond the activity of production for a result of any process to qualify as a product in business.

In economics, a product is anything that is done (obtained from human activity, even indirectly), having a price (can be exchanged) and able to satisfy a need. A product can be a good or a service. Most of cases of products in business are mixed: products include a main component (generally a good) which is accompanied by a secondary component (e.g.: sale services); or vice versa.

Road acoustic screens are products since they result from human processes (production), are sold (have exchange value), and used by people who need them (consumption). The screens are therefore an object of business. Companies such as Sound Barrier Solutions Ltd (UK), Foshan Yingzhe Building Material Co., Ltd (China) and Acoustical Surfaces Inc (USA), are specialized in this kind business[43].

Like every business, a company producing road acoustic screens needs to make profits, otherwise its activities will have none essential purpose. Profit is what the company gets from a sale after deducting all the costs. This is what we will analyze in this chapter. But in case of acoustic screens we should also take into consideration the costs and profits for the public administration. In this chapter we also analyze this aspect.

[43] Sources for this part of the chapter: http://soundbarriersolutions.com/; http://www.frat-yingzhe.com/index.asp; http://www.acousticalsurfaces.com/

6.1. COSTING

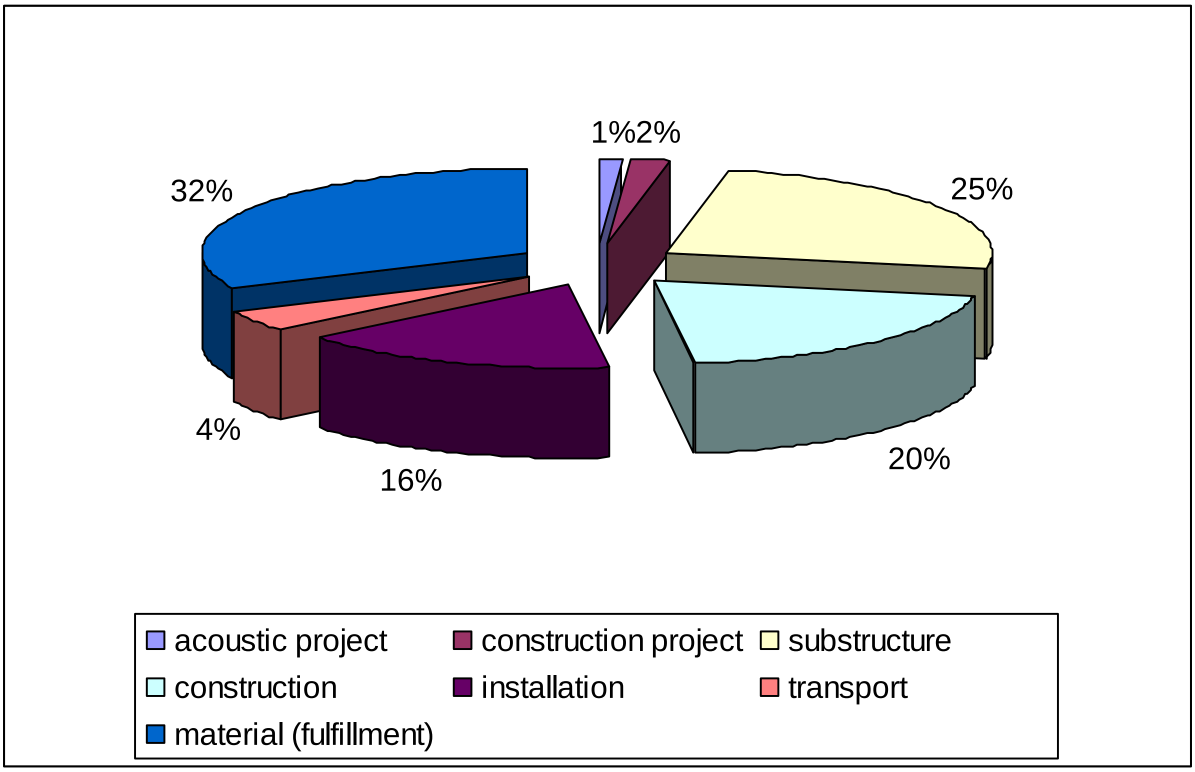
In this chapter an overview on the costs will be done.

6.1.1. Project

The cost of road acoustic screens varies depending on many factors which are mainly:

- The type of material to be used and its characteristics (acoustic, mechanical, esthetical, economical, etc.)
- Dimensions or geometry of the screen (length, height, width, layout): the larger a screen is, the more it will cost
- The business environment (laws about wages, competition, etc)
- Soil conditions
- The complexity of installation.

Generally the costs that a company producing road acoustic screens are constituted as shown in the figure 6.1.



Plot 6.1: Structure of the costs for road acoustic screens project[44]

[44] Information of this subchapter is based on the website: http://www.akustyczne.pl/index_projektowanie.php, on 06.06.2011

Frequently the largest percentage of construction costs is the cost of screens materials (fulfilment). Properly selected material has the effect of reduction of other costs, connected with the type of structure, the weight of construction or the cost of work during the installation.
To minimize the costs, the producer of road acoustic screens should:

- assure the right choice of materials,
- prepare the good substructure,
- simplify the installation,
- decrease the transport costs.

Depending on the technology, the price of $1m^2$ of screen may vary by up to 200%. During the construction of the road acoustic screens, the producer should also take into consideration the following parameters:

- maximum efficiency (absorption, insulation, proper geometry),
- maximum long warranty,
- maximum long life of screen,
- aesthetics, including the possibility of maintenance such as removing of graffiti.

The average costs of road acoustic screen in Poland are as follows:

- classic panel – 500 pln/m2
- panel with reinforced concrete planters or wire baskets – 200 pln/m2
- panel of transparent acrylic glass – 1000 pln/m2.

During the choice of acoustic screens producer, the administration analyses the general costs, but also the social noise annoyance and the costs of noise reduction.

Social Noise Annoyance (SNA) is determined as follows:

$$SNA = n * L_{Aeq}.$$

Equation 6.1: Social Noise Annoyance

Where:
n is the number of residents in chosen area
L_{Aeq} is the level of noise recorded in the area.

The public administration wants to reduce a value of SNA.

The cost of reduction of noise (1 dB/1 resident) is determined basing on the SNA as follows:

$$CR = \text{cost of screen}/SNA$$

Equation 6.2: Cost of Reduction

From the ratio above, we can remark that if CR is minimal, we obtain maximal reduction of SNA with minimal costs.

6.1.2. Cost of the acoustic screens

During the calculation of costs of screens, the administration should analyze the following parameters of the proposed screens:

- estimated surface
- estimated cost of the screen realization (taking into account the materials)
- CR ratio of the proposed solution.

6.2. Simulation

This simulation is based on the data from one of the Polish city. The following dates were delivered by our supervisor: the total length of the screen, the average height of the screen, the share of transparent surfaces, the number of residents, the measured level of noise. On the based on these data we made the calculations.

L.p.	Street	The total length of the screen	The average height of the screen	The share of transparent surfaces
-	-	[m]	[m]	[%]
1	A	3200	3	10
2	B	600	4	10
3	C	1800	5	10
4	D	2600	5	15
5	E	4000	2	5
6	F	600	2	10
7	G	800	3	10
8	H	2800	3	10
9	I	1000	6	10
10	J	2300	3	10
11	K	4000	5	10
12	L	1600	2	10
13	M	1600	2	10

.

Table 6.1: Streets Specifications

6.2.1. Estimation of screens' costs

With the previous data we can calculate the total cost of the screens by steps shown in the table 6.

Standard surface	Total surface	Surface: standard	Surface: transparent	Unit cost: standard	Unit cost: transparent	cost: standard	cost: transparent	Cost of realization
[%]	m2	m2	m2	[pln]	[pln]	[pln]	[pln]	[pln]
90	9600	8640	960	500	1000	4320000	960000	5280000
90	2400	2160	240	500	1000	1080000	240000	1320000
90	9000	8100	900	500	1000	4050000	900000	4950000
85	13000	11050	1950	500	1000	5525000	1950000	7475000
95	8000	7600	400	500	1000	3800000	400000	4200000
90	1200	1080	120	500	1000	540000	120000	660000
90	2400	2160	240	500	1000	1080000	240000	1320000
90	8400	7560	840	500	1000	3780000	840000	4620000
90	6000	5400	600	500	1000	2700000	600000	3300000
90	6900	6210	690	500	1000	3105000	690000	3795000
90	20000	18000	2000	500	1000	9000000	2000000	11000000
90	3200	2880	320	500	1000	1440000	320000	1760000
90	3200	2880	320	500	1000	1440000	320000	1760000
TOTAL COST OF SCREENS								**51'440'000**

Table 6.2: Screens Cost

6.2.2. Estimation of social costs

The following table features an example of calculation of "social" costs. It shows the social noise annoyance of days with regard to night conditions, then the costs of noise reduction in terms of money. In other words, how much does it cost to reduce 1dB of noise per person.

L.p.	Street	Standards	Noise level - day	Noise level Night	Difference	Number of residents	SNA	Cost of screen	CR
-	**-**	**[dB]**	**[dB]**	**[dB]**	**[dB]**	**[person]**	**[person * dB]**	**[pln]**	**[pln/ person*dB]**
1	A	60/50	63,9	58,1	**5,8**	920	**5336**	**5280000**	**989,51**
2	B	60/50	62	56,2	**5,8**	593	**3439,4**	**1320000**	**383,79**
3	C	60/50	66,2	60,4	**5,8**	1402	**8131,6**	**4950000**	**608,74**
4	D	60/50	65,1	59,3	**5,8**	2115	**12267**	**7475000**	**609,36**
5	E	60/50	66,4	60,6	**5,8**	2238	**12980,4**	**4200000**	**323,56**
6	F	60/50	63,1	59,1	**9,1**	528	**4804,8**	**660000**	**137,36**
7	G	60/50	59,6	53,8	**5,8**	1250	**7250**	**1320000**	**182,07**
8	H	60/50	67,2	63,2	**4**	1083	**4332**	**4620000**	**1066,48**
9	I	60/50	61,1	57,1	**4**	449	**1796**	**3300000**	**1837,42**
10	J	60/50	65,1	61,1	**4**	2933	**11732**	**3795000**	**323,47**
11	K	60/50	65,4	59,6	**5,8**	2859	**16582,2**	**11000000**	**663,36**
12	L	60/50	65	59,2	**5,8**	1042	**6043,6**	**1760000**	**291,22**
13	M	60/50	63,1	57,3	**5,8**	525	**3045**	**1760000**	**578,00**

Table 6.3: Social costs calculations

7. GENERAL CONCLUSIONS

Realizing this project has been for all members of our group a superb experience and a wonderful way of learning. The project has been to us a big challenge given that:

- Members of the team had different native languages and for some, this was the first formal work done in English;
- Schedules were different: everyone had other subjects or academic activities to attend, what requested efficient time management;
- Members were different persons with different personal characteristics. So the group needed some time for members to build confidence among them;
- The work was to be done by complying with deadlines;
- The project was multidisciplinary (it covered different aspects: theoretical, technical, economical, etc) and based on topics that team members were not yet familiar with.
- Technical experiments were to be done in laboratory where students were not yet familiar with work installation.

With regard to the challenges quoted above, we are happy to be able to notice our achievements in connection with team work:

- We have been able to build a good and efficient team;
- We have acquired the necessary knowledge to conduct successfully our work;
- We have managed well the time: The project has been completed in the agreed time and schedules of meeting were set to comply with those of members (and supervisors).

We are happy to have been able to provide systematic answers to our research questions by achieving our project objectives. The outcomes and description of our research work have been presented in this report throughout the chapters.

We have analysed noise as a source of pollution, its classification and effects. Sources of air pollution can be divided based on the origin of two groups:

- Natural origin
- Pollution caused by human activity

There is cleat awareness of the negative effect on people that has a noisy environment. The discomfort that results can be very diverse, ranging from conditions at the time of sleep and inability to concentrate or injuries themselves, depending on the intensity and duration of noise. The pollution it produces has become, in large urban centres and production centres, a serious problem.

The term noise pollution covers a myriad of problems that we suffer one way or another every day, traffic of cars, trains and planes, the high noise level of some appliances are three everyday examples. Each of these problems requires a thorough analysis to arbitrate, since technically and economically appropriate remedial measures. There is another element to take into account, which increases the complexity of the analysis. It is the subjectivity of the individual in regard to the perception and assessment of noise from the point of view of acoustic comfort.

We cannot forget about dangerous noise exposure. High level of sound is very dangerous for human's life. Effects of sound can be illustrated in two ways: direct pathway and indirect pathway. Direct pathway can contribute to hearing loss and indirect pathway can cause annoyance and even disturbance of activities.

We have also to mention about risk factors such as: increasing of blood pressure or blood clotting factors not to mention about blood lipids and blood glucose. Other very important things are cardiovascular diseases such as: hypertension, arteriosclerosis or other heart diseases which we can get after being in a place where the level of sound is very high.

When trying to reduce the harmful effects of noise on a receiver, one can address the problem by studying the source, its mode of transmission and the receiver. Reducing the emission of the source is usually the most effective corrective measure, but it is sometimes insufficient and in most of cases, simply impossible. So it is not enough to limit action at the source, but also and very necessary to consider propagation paths.

We have also analyzed noise with regard to its physical nature. Noise is sound and in Physics sound is wave. The sound is a wave which is: Mechanical (it requires a medium in order to transport its energy and cannot travel through a vacuum); Longitudinal (particle motions are parallel to wave motion). Like other kinds of waves, sound has the following properties: Wavelength, Speed, Period, Frequency and Amplitude. These characteristics are known in our everyday life with different names. In this context, wave's amplitude relates to loudness and frequency to sound pitch.

The experiments that we have performed in laboratory in order to analyze how road acoustic screens work and how can their efficiency be improved has allowed us to confirm that:

- The efficiency of acoustic screens much depends on their width and the frequencies. Wider screens have the advantage of absorbing the noise. That has been the case of the foam. However, to use the foam as material one must take into account the fact that it can be wet when it rains. A specific solution is therefore necessary.
- Although noise levels of lower frequencies have been slightly higher than those of higher frequencies in most cases, it is obvious that frequency has very low effect in terms of noise annoyance.
- The loudness decreases when the distance of the receiver increases. In fact, our plots have shown that the more the microphone is near the screen, the less the level of noise is high. The height of the microphone was a very important parameter. When installing acoustic panels people have to find the good height of the screen, in function of the height of building to protect.
- The classic acoustic panels, which is already install on the roads, are all vertical. We found it is interesting to test several inclinations of the panel and see its influence. We tested three angles: 75°, 90° and 105°. The main difference between the best and the worst was only five decibel so the angle of the panel has a small consequence.

Concerning promotion we have to say that companies producing road acoustic screens can promote their products by different methods and tools of marketing, especially those applying for products of which the customers are organizations. In fact, the market of road acoustic screens is B2B (Business to Business) one. Therefore, methods applying for screens marketing are those suitable for customers who are public institutions, private companies and indirectly to the neighbours who are supposed to be the final consumers.

Most of companies producing road acoustic screens make also different other products relating to acoustics. However road acoustic screens remain at the centre of their activities. The reason is that traffic noise barriers generate turnovers by far higher in volume than any other product. This is due to the hundreds or thousands of meters stretching along highways and on which the screens are generally installed. The length multiplied by the height of the screens gives the surface which is the basis for cost calculations. Once the total surface of screens known, the result of its multiplication by the unit cost (per square meter) gives the total cost of the screens. Other costs are added to the screens' total cost to make the operating cost price.

Cost price is the sum of all costs borne by the company and that enabled the later to make the product available to the market. For road acoustic screens, the cost price comprises costs relating to:

- Administration: this category includes all the costs borne for preliminary researches, licenses; value added taxes, and other set expenses relating to the everyday life of the company.
- Materials: these are raw materials, consumables such as electricity and other energies, water, work uniforms, etc.; and components used to make or install the screens.
- Labour costs: this category comprises all types of wages paid to people who work.
- Maintenance: these are after sale services which are necessary to insure satisfaction of consumers and good reputation of the company.

Knowing the cost price, the company can then estimate the profit it wishes to achieve by applying a reasonable percentage either on the cost or the sale price.

Bibliography

Books

Jobber D., Fahy J.: *Foundations of Marketing*. McGraw-Hill Education. Berkshire 2003.

Kotler Ph., Amstrong G.: *Principles of Marketing*. Prentice-Hall International Ed. New York 1994.

Luxon L., Prasher D.: *Noise and Its Effects*, 2007.

Palmer A.: *Principles of Marketing*. Oxford University Press. New York 2000

Articles

Presentation “The effects of noise” made by Dr. Magdalena Grębosz

Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002

Magda Grębosz: Marketing Support for Lectures at IFE, Lodz, 2011

Magda Grębosz: Economical Analysis Support for Lectures at IFE, Lodz, 2011

Internet

www.wikipedia.com

www.google.com

www.betterhearing.org

http://rendiles.tripod.com/RUIDO1.html

http://www.monografias.com/trabajos17/riesgos-fisicos/riesgos-fisicos.shtml

http://html.rincondelvago.com/contaminacion-por-ruido.html

http://html.rincondelvago.com/contaminacion-acustica.html

http://paws.kettering.edu/~drussell/Demos/waves-intro/waves-intro.html

http://www.acousticalsurfaces.com/acoustic_IOI/101_12.htm

http://www.fhwa.dot.gov/environment/keepdown.htm

http://www.industrialacoustics.com/

http://www.akustyczne.pl/index_projektowanie.php

http://soundbarriersolutions.com/

http://www.frat-yingzhe.com/index.asp

http://www.acousticalsurfaces.com/

www.science-dictionary.com

www.personal.cityu.edu.hk

www.ccohs.ca

www.businessdictionary.com

www.dictionary.cambridge.org

www.engineeringtoolbox.com

http://www.geowiki.fr/index.php?title=Composition_interne_de_la_Terre

http://www.factmonster.com/dk/science/encyclopedia/energy-waves.html

http://www.corpora-sonorus.com/courses/index.php?option=com_content&view=section&layout=blog&id=7&Itemid=55

http://www.physicsclassroom.com/class/sound/u11l2a.cfm

http://eesfrequencyresponseofamplifiers.blogspot.com/2010/03/octave-and-other-frequency-intervals_20.html

http://www.simonisystems.com/acoustics.htm

http://www.jiscdigitalmedia.ac.uk/audio/advice/the-physical-principles-of-sound

http://www.physicsclassroom.com/class/waves/u10l2c.cfm

http://www.jiscdigitalmedia.ac.uk/audio/advice/the-physical-principles-of-sound

http://www.indiana.edu/~emusic/acoustics/amplitude.htm

http://home.kpn.nl/msalomons/sound.html

http://gely.info/diffraction-des-ondes-a-la-surfacehtml/

http://www.kfs.oeaw.ac.at/content/view/381/485/lang,8859-1/

http://www.industrialacoustics.com/uk/reference/bluebook/c_-_partial_barriers.html

http://www.artusaindustries.us/Noise_Barriers.html

http://moins2decibels.over-blog.com/article-21070732.html

http://peabody.sapp.org/class/st2/lab/notehz/

http://www.physicsclassroom.com/class/sound/u11l2a.cfm

http://simple.wikipedia.org/wiki/Dynamics_(music)

http://www.physicsclassroom.com/class/sound/u11l2b.cfm

http://www.acousticalsurfaces.com/acoustic_IOI/101_12.htm

http://francismerck.free.fr/technique01.html#ancre55849

List of Equations

List of Figures

List of Tables

List of Pictures

List of Plots

Annexes

Recording hardware specifications:

- WaveBook/516E 16-bit 1MHz Data Acquisition System with Ethernet Interface
    - 1 MHz, 16-bit A/D
    - 1 µs/channel scanning of any combination of channels
    - Single and multichannel analogue triggering with programmable level and slope
    - Digital TTL-level and pattern triggering
    - Pulse trigger and external clock
    - Programmable pre- and post-trigger sampling rates
    - Sixteen digital inputs can be scanned synchronously with analogue signals
    - Operable from AC line, a 10 to 30 VDC source, such as a car battery
    - Expandable up to 288 high-speed channels
    - SYNC connection allows multiple units to sample synchronously
    - Add up to 854 lower-speed thermocouple channels
    - DSP-based design provides real-time digital calibration on all channels

- Microphone 1/2'' Bruel & Kjaer type 4191
    - Sensitivity: 12.5 mV/Pa
    - Frequency: 3.15 Hz – 40 kHz
    - Dynamic Range: 20 – 162 dB
    - Temperature: – 30 to + 300°C (– 22to + 572°F)
    - Polarization: 200 V
    - Precision measurements to 40 kHz
    - Equipment complying with IEC 61672 class 1

- Sound Generator
  - USB, GPIB and LAN interfaces included in the 33220A function generator
  - Graph mode for visual verification of signal settings
  - Option 001 provides multiple-unit link for synchronous channels
  - The Arbitrary Waveform Generator is LXI Class C Compliant
  - 20 MHz sine and square waveforms
  - Ramp, triangle, noise, pulse generation with variable edge, and DC waveforms
  - 14-bit, 50 MSa/s, 64 Kpoint arbitrary waveforms
  - AM, FM, PM, FSK, and PWM Modulation, Linear & logarithmic sweeps and burst all standard

- Amplifier CAMBRIDGE AUDIO azur 640A
  - 65 watts per channel (8 Ohms)
  - 100 watts per channel (4 Ohms)
  - CAP5™ protection system with no sound quality degrading active circuitry added into the signal path
  - Upgraded power supply
  - SNR 96dB ‘A’ weighted
  - Class ‘A’ follower driver stage
  - Polypropylene bypass capacitors
  - Second set of speaker outputs
  - Headphone output
  - Standby function
  - By-passable tone controls
  - Low resonance, acoustically damped chassis improves sonic performance
  - Stylish all-metal casework with a solid aluminium front panel
  - Slim-line Azur remote control with aluminium top panel

- HAMEG INSTRUMENTS 35MHz analogue oscilloscope HM303-6
    - Vertical: 2 Channels, DC - 35MHz, 1mV/div. - 20V/div.
    - Time Base: 0.2s to 10ns/div.; Variable Hold Off; Alternate Triggering
    - Triggering: DC-100MHz; Auto Peak to Peak; Active TV Sync. Separator
    - Additional Features: Component Tester, 1kHz/1MHz Calibrator

- Bruel&Kjer nexus conditioning amplifier
    - TNC input connectors
    - Input can be single- ended or floating
    - Four charge channels
    - Specially suitable for applications where shocks and impulses occur such as gas turbine testing and munitions testing
    - General signal conditioning amplifiers for use with charge accelerometers, hydrophones and force transducers
    - Reference and Test Generators
        - Output signal is sinusoidal: 159.2 Hz (±1%) level: 1 VRMS
    - Filters -1 dB (-10%)
        - Low- Pass Cut-Off Frequencies: 0.1, 2, 3, 10, 22.4, 30, 100 kHz
        - High- Pass Cut-Off Frequencies: 0.1, 1, 10, 20 Hz